THE PHYSICAL AND CHEMICAL EFFECTS OF MID-WINTER PUMPING OF TUNDRA LAKES ON THE NORTH SLOPE, ALASKA

A
THESIS

Presented to the Faculty
Of the University of Alaska Fairbanks
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

By

Derek Dan Miller, B.S.

Fairbanks, Alaska

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SIGNATURE PAGE

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ABSTRACT

Tundra lakes are a valuable freshwater resource on the Alaskan Arctic Coastal Plain and are of increasing relevance as the petroleum industry in Alaska continues to rely on the freshwater resource to support exploration and production activities. An investigation of the physical and chemical effects of mid-winter pumping activities was conducted at four tundra lakes on the Alaska Arctic Coastal Plain during the 2002-2003 and 2003-2004 winters. The purpose of the study was to determine the impact of removing water from tundra lakes for the construction of ice roads and pads. Measurements of water surface level, specific conductance, temperature and dissolved oxygen were recorded in near real-time, providing an opportunity to detect immediate and cumulative responses from pumping activities. Water quality variables and recharge processes were also examined to further determine the impacts of mid-winter pumping activity. In examining and characterizing the effects of the water withdrawal, changes in water surface level were detected but no chemical or thermal differences were detected due to pumping.

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INTRODUCTION

Ice roads, pads and airstrips are an essential part of the winter arctic transportation infrastructure on the North Slope of Alaska and other cold regions. Trucking freight by ice roads allows for the timely delivery of materials and supplies at a fraction of the cost of traditional airfreight. Mobilizing exploration activities from ice pads also allows for minimal commitment while investigating the resource potentials of various sites. Moreover, the ice infrastructure has a minimum impact on the environment as it simply melts away seasonally and minimizes any environmental footprint on the sensitive arctic terrain.

John Denison pioneered the construction of ice roads in the 1950s in response to the existing inefficient system for hauling mining equipment and supplies throughout the gold-rich western Canadian provinces (Iglauer, 1991). Using experimental construction methods, Denison was able to build a transportation route linking lake to lake by ice roads and thereby make faster, more efficient long haul trips by taking shorter and more open routes through the terrain. The crowning achievement of Denison’s methods was the completion of a 520 km ice road leading from a camp in Port Radium near Great Bear Lake to Yellowknife, NWT.

On the North Slope, where transportation requirements center on the oil industry, ice road construction begins once the tundra is frozen and an adequate amount of snow cover exists to allow low-impact tundra travel vehicles access to the terrain. The available snow is consolidated by the vehicles for a base layer and then successive sprayings of water taken from nearby permitted lakes builds an ice roadbed to a sufficient depth. Alternative techniques use ice chips which are spread over the roadbed and then sprayed with water. This results in both faster road construction and less ice road maintenance. Overall, the modern construction for oil activities of ice roads is well planned and executed. However, concerns about the potential effects of withdrawing large volumes of water from the tundra lakes have arisen.

The main concern is that pumping will negatively impact physical and chemical variables at the lakes, which will in turn negatively affect the environmental conditions in the lake. The hypothesis of this thesis is that pumping tundra lakes will cause discrete changes in physical and chemical variables that characterize the lakes’ chemical, hydrological, or thermal regimes. The null hypothesis is that such changes cannot be detected.

A good example of potential impact from pumping activity is that pumped lakes might incur a water balance deficit due to water withdrawal if not adequately recharged by spring meltwaters. The deficit might be observed immediately in the following spring after winter pumping or potentially as a cumulative, long-term impact from repeated winter pumping activity at the same lake over many years.

This thesis examines and characterizes lake recharge, water surface levels, specific conductance, temperature, dissolved oxygen and numerous other water quality variables in order to analyze the impact of pumping activity. Two pumped lakes are compared to two non-pumped control lakes to determine differences due to pumping.

Water surface levels were investigated in an attempt to observe pumping activity in near real-time at 15-minute intervals. Estimations based on idealized lake bathymetry projections were calculated and compared to detected changes in water surface levels. Detecting water surface level changes is a challenge because the expected change is minimal. The ability to accurately gauge water surface levels at the pumped lakes in near real-time would be a practical tool for pumping operators, planners and regulators where water surface levels could be networked into an accessible database providing a proxy to a limiting water surface level declines at the permitted water supply pumped lakes.

Specific conductance was measured in lakes as well. Specific conductance correlates well with other water quality variables and is generally a good indicator of the chemical regime of the lake. Specific conductance could therefore be used as a measurable proxy for other variables.

Temperature is also an important variable to quantify. Thermal disturbances due to pumping might occur that would affect the metabolism of lake biota. Any thermal differences between pumped and control lakes are important to characterize.

Dissolved oxygen is a critical variable for resident fish. To overwinter, resident fish maintain a slow metabolism in the low oxygen water so any unnatural increase in dissolved oxygen concentration would increase their metabolism, perhaps starving them and decreasing chances for overwinter survival. Determining any impact on dissolved oxygen resulting from pumping activity is important.

Water quality variables including pH, alkalinity, turbidity, nutrients and metals are specific indicators of lake health. Pumping might change metal concentrations or increase turbidity.   Measuring water quality variables at pumped and control lakes is an essential determination in observing the effect of pumping activity.

Meteorological data was also collected at a site near the study lakes to better interpret relationships between environmental factors such as precipitation as snow and the data being measured at the lakes. Environmental influences on the data are essential to characterize since the expected responses at the lakes are slight.

This thesis examines the physical and chemical effects of the current water withdrawal volumes while providing a look into the overall hydrology and chemistry of tundra lakes in the Alaskan Arctic. Determining the effects on tundra lakes of current pumping amounts is essential as the oil industry continues to strive to minimize any anthropogenic impact to the environment they used. Results and conclusions of this thesis should aid the regulatory framework and guide sustainable pumping activity. Scientific knowledge gained also adds valuable quantitative and qualitative data to arctic limnology.

Four lakes (two pumped, two control) on the North Slope of Alaska within the Kuparuk Oilfield Operating Unit were examined. The lakes were monitored and sampled throughout the 2002-2003 and 2003-2004 winters for numerous chemical and hydrological variables. Dynamics of water surface elevation, specific conductance and dissolved oxygen of the under-ice water and profiles of lake temperature were observed in near real-time. Numerous water quality variables using field, benchtop and laboratory techniques were also quantified. Investigation of lake recharge was also completed during the spring of 2003 and 2004.

SITE DESCRIPTION

The four primary study lakes (K113C, K203C, K209P and K214P) are in the Arctic Coastal Plain of Alaska, an area approximately 70,900 km^2 (Walker, 1973) bounded between the foothills of the Brooks Range to the south and the Arctic Ocean to the north. The study lakes are approximately 30-45 km south of the Arctic Ocean and located west of the lower Kuparuk River and east of the Colville River (Figures 1 and 2).

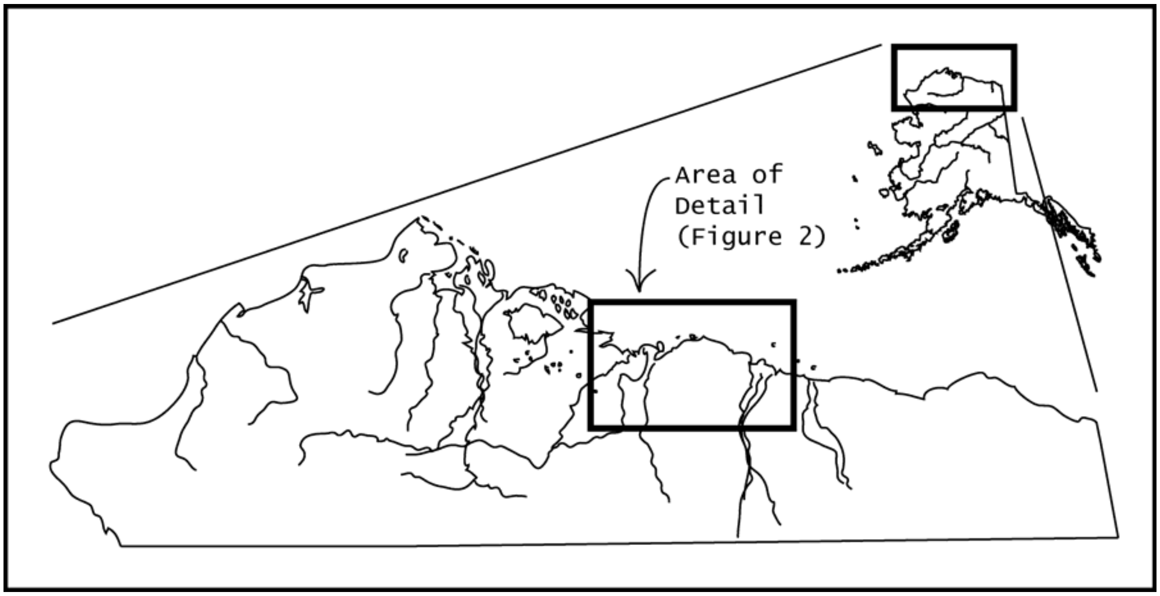

Figure 1: Map illustrating location of general study site within the Alaskan Arctic Coastal Plain.

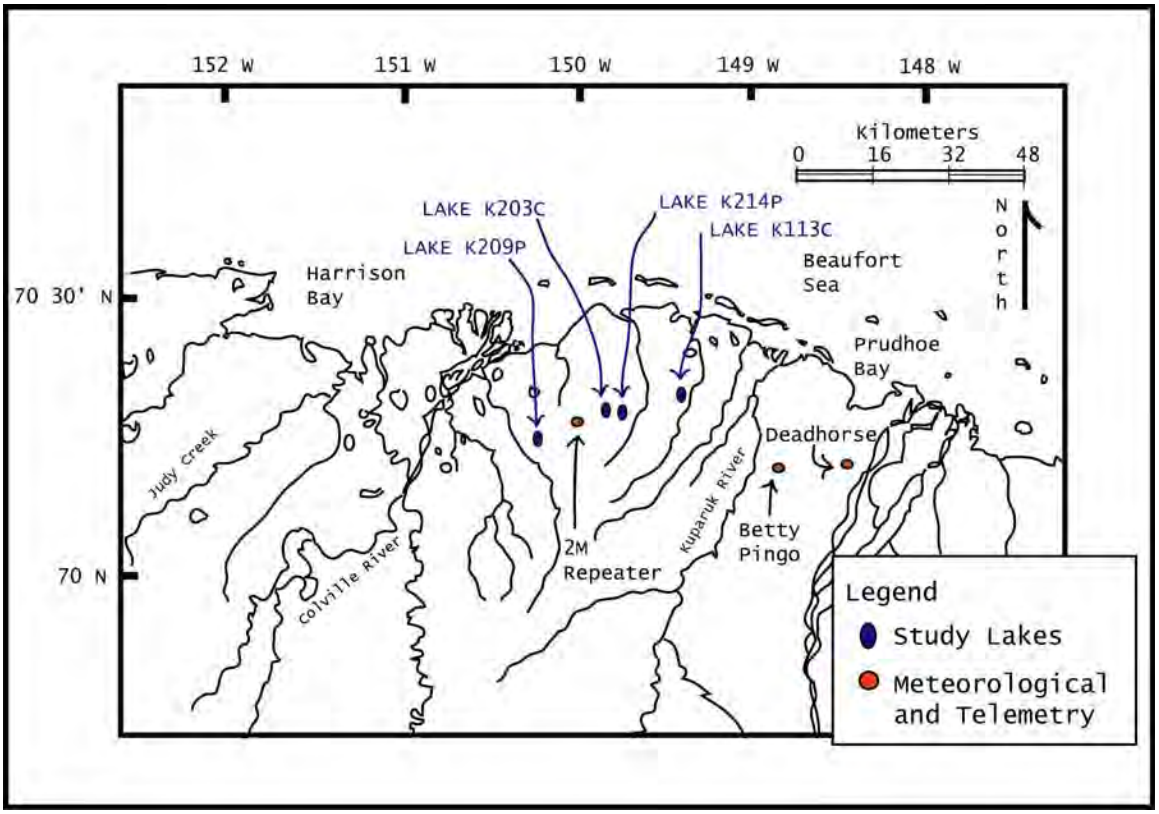

Figure 2: Map illustrating location of study lakes along with telemetry and meteorological sites.

Tables 1-3 summarize the geography, operations, hydrology, biology and research history of the lakes. All lakes were created by thaw or thermokarst processes and are generally uniform in morphology (Moulton, 1998). Although all of the study lakes were permitted for pumping, lakes K113C (i.e. lake K113 Control) and K203C were not pumped during the 2002-2003 and 2003-2004 winter and provide a basis for comparison to the lakes that were pumped - K209P (i.e. K209 Pumped) and K214P. K113C has the smallest surface area of all lakes (165,921 m^2) although it is also the deepest (2.29 m). Lake K214P, with the greatest surface area (2,104,365 m^2) also contains the most water of all lakes with 1,203,757 m^3.

The study lakes are likely representative of relatively deep (1.8 – 2.2 m) thaw lakes within the Arctic Coastal Plain that do not have significant interaction with the Arctic Ocean. This extrapolation is uncertain, however, as few formal investigations of similar tundra lakes have occurred in regions outside the Point Barrow area.

Table 1: Summary of lake characteristics – geography & operations.

Parameter	Lake K113C	Lake K203C	Lake K209P	Lake K214P	Citation
Latitude (NAD 27)	N 70 19' 11.6"	N 70 17' 07.2"	N 70 14' 08.6"	N 70 17' 32.1"	-
Longitude (NAD 27)	W 149 19' 08.0"	W 149 51' 34.7"	W 150 20' 54.1"	W 149 54' 52.8"	-
USGS Quadrangle Map	Beechey Point B-4: T11N R11E, Sect 10	Beechey Point B-5: T11N R9E, Sect 21	Harrison Bay A-1: T10N R7E, Sect 10, 15	Beechey Point B-5: T11N R9E, Sect 20	-
Operating Field	Kuparuk	Kuparuk	Kuparuk	Kuparuk	-
Nearest pad or facility	DS 1M	CPF 2	DS 2L	CPF 2	-
Permitted for winter pumping activity?	Yes	Yes	Yes	Yes	Lauruhn, 2001
Permit Volume (m^3)	73,815	215,768	308,510	143,088	Lauruhn, 2001
Purpose of pumping activity	Control – No Pumping	Control – No Pumping	Exploration	Exploration / Firewater	-
Pumped in 2002-03 winter?	No	No	Yes	Yes	CPAI, 2004
Pumped in 2003-04 winter?	No	No	Yes	Yes	CPAI, 2004
Other names	-	W27.1, M8104	L9128, AA18.1	W26.1, M8103	ACS, 2001

Table 2: Summary of lake characteristics – hydrology and biology.

Parameter	Lake K113C	Lake K203C	Lake K209P	Lake K214P	Citation
Surface area (km^2)	165,921	841,746	1,404,259	2,104,365	Morris, 2003; Moulton, 1998
Maximum water depth (m)	2.29	1.88	1.86	1.75	Moulton, 1998
Total volume (m^3)	121,019	532,606	998,589	1,203,757	-
Road dusting potential	high, lake adjacent to high traffic Spine Road	moderate, lake near to CPF2 facility	minimal, lake 0.5 km away from nearest pad	moderate, lake near to CPF2 facility	-
Subsurface connection to nearby streams	Unlikely	Unlikely	possible, bounded between Miluveah River and Kachemach River	Unlikely	-
Fish species present	Ninespine Stickleback	Ninespine Stickleback	Ninespine Stickleback	Ninespine Stickleback	Moulton, 1998

Table 3: Summary of lake characteristics – history of research and operations.

Parameter	Lake K113C	Lake K203C	Lake K209P	Lake K214P	Citation
Past hydrology data or studies	-	MBJ in 2002	-	MBJ in 2002	MBJ, 2002
Past chemistry data or studies	-	MBJ in 2002	Moulton in 1991 and 1997	MBJ in 2002	Moulton, 1998; MBJ, 2002
Past biological data or studies	-	Moulton 1981	Moulton in 1996	Moulton 1981 and 1982	Moulton, 1998
Years pumped in winter	-	-	2003, 2003-04	2002-03, 2003-04	CPAI, 2004
Permanent pumping installation	no	no	no	yes	-
Survey benchmark locations	TBMs on northern product line VSMs	TBMs on VSMs and monuments near NW corner of lake	VSMs on pipeline to north side near shore	VSMs and monuments along east and west sides of lake	(TBM = Temporary Benchmark, VSM = Vertical Support Member)

Dominant landforms within the Alaskan Arctic Coastal Plain include low and high centered polygons, strangmoor ridges and other nonpatterned ground (Everett and Parkinson, 1977). Common vegetation includes grasses, sedges, mosses and lichens. Wet areas surrounding the lake perimeter contain mostly Carex and Eriophorum sedges with understories of moss (Hobbie, 1980). Surrounding soils are typically highly organic, highly acidic fibrous peat and approximately 8,000-10,000 years old (Jorgenson, 2002). Nearer to the coast, eolian sands and marine alluvium soils dominate. The dominant surface geological unit throughout the arctic coastal plain is late Quaternary unconsolidated sands and gravels (Black, 1964). Soils can be ice-rich or ice-poor. The topographic relief of the coastal plain is flat with an average surface slope between 0.1-0.2% (Rovansek, 1996); consequently, drainage is poor. Steeper scarps do exist within the vicinity of the lakes and are useful in delineating watersheds.

The Alaskan Arctic Coastal Plain is rich in standing surface waters. Hussey and Michaelson (1966) estimate that 50–75% of the Alaskan Arctic Coastal Plain is covered either by lakes and ponds or old thaw lake basins. According to Hall et al. (1994) 83% of the coastal plain is wetlands. However, evaporation exceeds precipitation through the summer (Mendez et al., 1998) and the extent of wetlands gradually declines (Bowling et al., 2003). Active freshwater lakes and ponds may cover up to 40% of the surface (Hobbie, 1980) near the coast. However, most water bodies within the Alaskan Arctic Coastal Plain are shallow and have a maximum depth less than 2.0 m. The occurrence of lakes decreases inland with the near-coast zone having the most surface water. However, the occurrence of deeper lakes also increases inland (Figure 3).

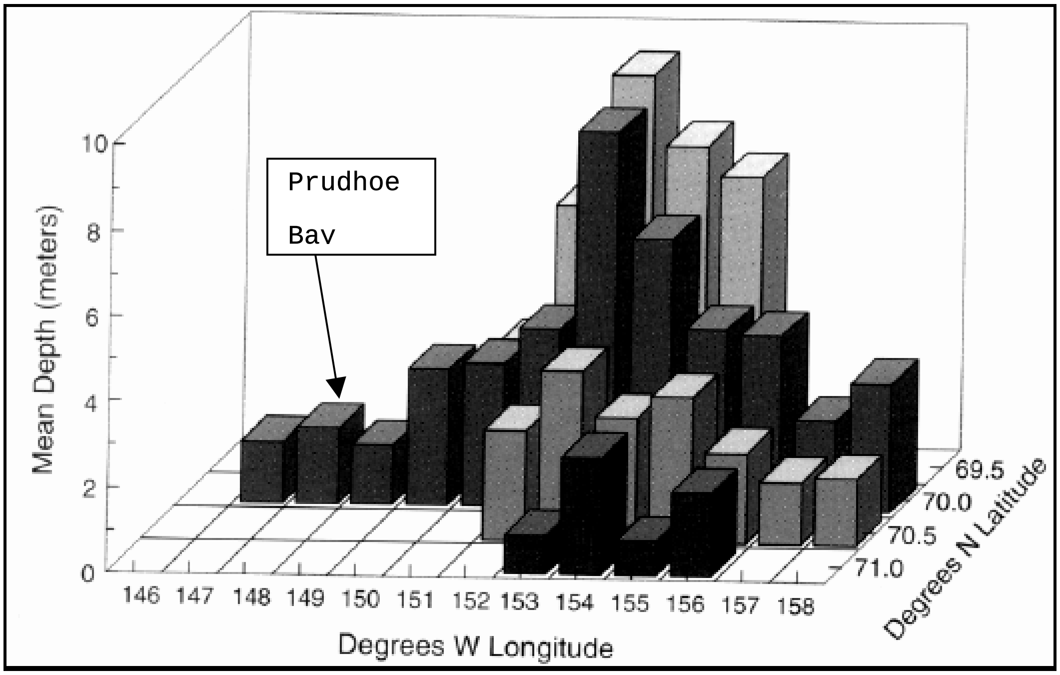

Figure 3: Distribution of mean maximum depths for Alaskan Arctic Coastal Plain lakes (Truett and Johnson, 2000).

Despite being abundant in surface water, the Alaskan Arctic Coastal Plain receives little annual precipitation. Precipitation is usually in the form of snow from mid-September to mid-May and in the form of rain during the summer months although snow can fall throughout the year. Precipitation as snow is about 40% of the total annual precipitation amount. (Kane et al., 2000).

Snow is the most important water source for the lakes as meltwater is the primary recharge mechanism and the dominant input to the lakes annually. Any precipitation received later in the summer months is only received from direct precipitation to the lakes surface as input by overland flow is rare. The lack of summer runoff is a result of high summer evaporation drying the watershed and the consequent lack of hydraulic connections within the lake drainage network (Bowling et. al., 2003). A 10-year data set at Betty Pingo site suggests the snow water equivalence (SWE) contributing to recharge ranges from 5.8 – 12.9

cm with an average of 8.9 cm (Kane and Hinzman, 2004). However, the grounded snow is subject to frequent redistribution by the persistent strong winds and is highly variable in depth with respect to the local topography. Compacted snow on lake ice has a lower snow water equivalent than that on the surrounding tundra and also less thermal resistance (Sturm and Liston, 2003).

Snowmelt generally occurs in late May or early June, lasts 7-10 days and is normally the only appreciable stream flow event. Runoff begins when the snowpack is mostly ablated and completely saturated with water. Maximum discharge usually occurs within 24 hours of saturation and in the next four days, 40-60% of the total runoff occurs (Hobbie, 1980). Because the active layer is saturated at this time, little infiltration occurs and most meltwater contributes to runoff with some loss to evaporation.

Lakes remain ice covered well past snowmelt until late June or early July when the ice cover candles, moats and gradually melts. After snowmelt the lake water balance is dominated by evaporation (Rovansek et al., 1996). Evapotranspiration is high due to continuous solar radiation input from late-April to mid-August. Evaporation most often exceeds precipitation resulting in a net water loss, which must be replenished by next year’s snowmelt runoff (Mendez et al., 1998; Bowling et. al., 2003).

Mean annual air temperatures at 1 m (30-year average = -11.56^{o}C (Western Regional Climate Center, 2004)) are well below freezing throughout the Alaskan Arctic Coastal Plain so continuous permafrost exists throughout the area. Permafrost is a primary control on most hydrological processes in the area. Osterkamp et al. (1985) reported an average permafrost depth of 680 m in the Prudhoe Bay region. The active layer (the layer of soil above the permafrost that thaws each summer and refreezes every winter), ranges from 25 to 100 cm. Factors influencing thaw depth are vegetation type, ice content, topography, insulation by plant litter and soil type (Hobbie, 1980). After spring snowmelt is complete, the contribution to the water balance from active layer flow is minimal (Rovansek et al., 1996).

Winds are persistent and strong throughout the year, with monthly mean wind speeds of 3.7 – 5.6 m/s and gusts reaching above 20 m/s. Summer winds are predominately from the northeast and southwest (Olsson et al., 2002).

LITERATURE REVIEW

Numerous classifications have been applied to coastal plain lakes since the Alaskan Arctic Coastal Plain gained further research relevance and accessibility with the discovery of oil in the Prudhoe Bay region in November 1968. Hablett (1979) discriminated lakes within the Natural Petroleum Reserve Alaska (NPRA) based on a lake’s fishery potential: a 1.8 m threshold depth, an outlet in spring and adequate spawning substrate for fish survival through the winter. Bendock and Burr (1985) categorized lakes of three types based on their natural history:

(1) Deflation Lakes – deepest depth, formed when dunes become revegetated and basin between dunes fills with water.
(2) Oxbow Lakes – intermediate depth, formed from abandoned river channels.
(3) Thaw Lakes – shallowest depth, formed as ground subsides and ice rich soils thaw.

Moulton (1998) classified five types of lakes based on potential fish access from the Colville River delta and this naming convention is regularly used:

(1) Tapped Lakes – lakes with an active connection to a river channel during the summer.
(2) Low Perched Lakes – lakes having an obvious high-water channel that floods annually.
(3) High Perched Lakes – lakes without an obvious high-water channel that floods infrequently.
(4) Drainage Lakes – lakes with an active connection to creek(s). Typically a large thaw lake on a tundra stream.

(5) Tundra Lakes – lakes without a connection to a drainage network.

All lakes being investigated in this study are defined as Moulton’s tundra lakes, which are equivalent to Bendock’s thaw lakes (K113, K203, K209 and K214). The term ‘lake’ is differentiated from ‘pond’ by Bendock’s 1.8 m threshold maximum depth.

The origin of tundra lakes follows the thaw lake cycle as defined by Hopkins (1949) and others (Carson and Hussey, 1962; Britton, 1966; Billings and Peterson, 1980). The medium for the thaw lake cycle is the large quantities of ice in the upper layers of permafrost within the Alaska coastal plain. Sellmann et al. (1975) reported up to 80% interstitially segregated ice in the top 3-4 m of permafrost so the upper layers of permafrost on the Alaskan Arctic Coastal Plain contain large quantities of ice. As this upper ice rich soil thaws due to a thermal disturbance, such as a change in vegetation or a large snowdrift, small ponds begin to form. The ponded water eventually reaches a sufficient depth to have standing water over the permafrost, which results in subsidence. As the permafrost subsides, thermal erosion also occurs along the shore and small basins gradually form. These smaller basins eventually coalesce and form a larger basin. The newly formed basin continues to subside and grow in dimension until it finally breaches a drainage divide. The lake basin then drains and the process begins anew.

The geomorphology of these tundra lakes displays a distinct feature. Nearly all lakes are roughly elliptical with a prominent long northwest-southeast axis. The orientation of the lakes is theorized to be a result of differential erosion from the wind-driven currents, which elongate the lakes normal to the prevailing winds along the northwest-southeast direction (Carson and Hussey, 1962). Sellman et al. (1975) found that thaw lakes on the Alaskan Arctic Coastal Plain have an average major axis of 1.21 – 2.30 km and an average minor axis of 0.68 – 1.10 km.

Most of the lakes on the coastal plain are shallow. A study of the area inland from Barrow, Alaska, using a synthetic aperture radar technique, found 23% of lakes are more than 2.2 m deep, 10% are between 1.5 m and 2.2 m deep, 60% of lakes are between 1.4 m and 1.5 m deep and 7% are less than 1.4 m deep (Jeffries et al., 1996).

The thermal structure of the study lakes is cold monomictic (Wetzl, 2001) as the lakes are ice-covered most of the year and do not have sufficient depth to stratify in the summer months (Figure 4). This category retains most Arctic and some mountain lakes where circulation is limited to the summer months. Surface ice begins to form when the temperature of the water reaches 0 °C. Surface ice forms best when significant surface heat loss is allowed such as a clear and cold night. After an ice cover has frozen, the lake is isolated from the effects of wind and the lake inversely stratifies with the colder, less dense water at 0 °C above the deeper and denser water, which is at 3.98 °C. Heat input from solar radiation is minimal in the winter due to the low sun angle and the high albedo of the snow cover preventing radiation transmission through the ice. Yet, despite the isolated conditions, evidence points towards under-ice water currents in lakes in closed basins without inflow and outflow. Small convective cells of density currents generated by the relatively large amount of sediment heat are responsible for the winter under-ice water movement (Welch and Bergmann, 1985). In the summer, water temperatures are more influenced by solar radiation than air temperature (Miller et al., 1980). Water column temperature differences are minimal in the summer due to winds circulating water and the temperature profile is regularly isothermal.

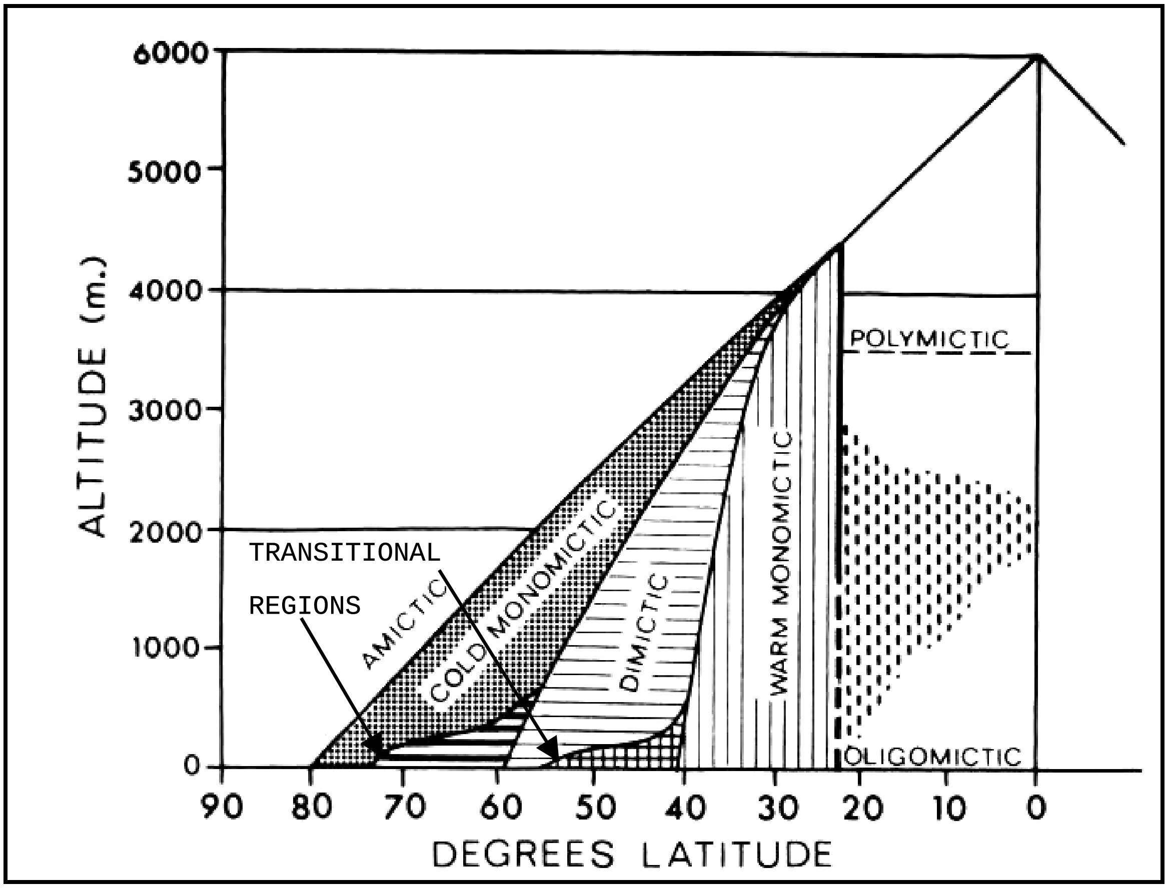

Figure 4: Arrangement of thermal lake types corresponding to latitude and altitude (taken from Hutchison and Loffler, 1956).

From November until mid-July, the lakes are typically covered by ice (Zhang and Jeffries, 2000). Two types of ice form over freshwater lakes: clear ice and white ice. Clear ice forms when ice gradually freezes at the ice-water interface. Clear ice is notably more translucent than white ice. This is due to the gradual formation process of clear ice leading to an efficient exclusion of gases, ions and nutrients (Pounder, 1969). White ice forms as a result of the quick freezing of flooded snow on the ice surface. White ice usually forms early in the winter when the ice sheet is thin allowing the minimal snow loading to stress the ice sheet to failure and cause flooding. Using a heat-transfer model, Zhang and Jeffries (2000) found that the historical (50-year) annual maximum lake ice thickness has varied between 1.33 m and 2.47 m. The historical mean maximum ice thickness was found to be 1.91 +/- 0.21 m.

When the maximum water depth exceeds the maximum ice thickness, a thaw bulb or talik gradually forms beneath the lake basin because the freezing front does not penetrate into the permafrost (Brewer, 1958). In shallower basins (<2.0 m) a thaw bulb does not develop because the winter ice cover freezes to the lake bottom (Lachenbruch, 1963) and thus the minimum condition for talik formation does not exist.

The lake’s ice cover begins to melt once the average daily air temperature is above O °C and usually is completely gone by mid-July (Hobbie, 1980). The rate of lake thaw is mainly determined by the thickness and albedo of the ice (Hobbie, 1973). In the process of thawing, the ice sheet candles, moats and eventually fragments into pieces, which are pushed to shore in the local direction of prevailing wind.

Tundra lakes are ecologically defined as oligotrophic, or low in nutrients and primary production, which has limiting effects throughout the food chain (Sierszen et al., 2003). This is a result of the arctic environment and a corresponding short ice-free season for normal productive processes to occur. However, arctic lakes are productive in the ice-free summer season and daily primary production is comparable to other ecosystems that are reasonably productive (Hobbie, 1980). Thus, there is an adequate food supply for habitation during the short ice-free period. Sierszen et al. (2003) reported benthos as the basis for the artic lake food web because the oligotrophic conditions reduce phytoplankton resources in the lakes so the planktivorous fish must find alternatives.

Generally, the Alaskan Arctic Coastal Plain has a low diversity of higher trophic plants and animals (Truett and Johnson, 2000). However, the microorganisms of tundra lakes are remarkably similar to temperate lakes. Bacteria are just as abundant but their activity is lower due to the colder temperature (Hobbie et al., 1980). The same phytoplankton species exist in tundra lakes just as found anywhere else in the world but again their activity is lower (Hobbie, 1980).

The dominant primary producers within a typical tundra lake ecosystem are a sedge (Carex aquatilis) and a grass (Arctophila fulva) which occupy the shallow littoral regions of the pond. Microalgae within the sediments, mostly diatoms and blue-green algae, are also important primary producers although they are found in limited numbers. The algae are grazed by zooplankton such as Daphnia and fairyshrimp, which are then consumed by predaceous zooplankton such as Cyclops and Heterocope, which occupy the top of the food web in lakes without fish. Ninespined stickleback, found in 91% of tundra lakes (Moulton, 1998) will feed on these microorganisms and will serve as a food source themselves in any lake with larger piscivorous fish (Alexander et al., 1980).

Primary productivity in tundra lakes is limited by phosphorous, not nitrogen (Pretenki et al., 1980). Phosphorous levels are controlled primarily by interaction with the surface sediments, and because tundra lakes are shallow, the ratio of sediment surface area to water volume is high and allows for frequent interaction between the two at the interface (Hinzman et. al., 1998). Chemical interactions between sediment and water are further enhanced in the summer when wind and wave action can suspend the sediment into the water. The mechanism for phosphorous limitation involves dissolved reactive phosphorous quickly moving into the sediment where it is absorbed and stored onto a hydrous iron complex. The slow, limiting release of dissolved reactive phosphorous is controlled by its chemical equilibrium with the complex and the free water. Hamilton et al. (2001) also found the lakes of the Canadian Arctic Archipelago to be phosphorous limited.

The light, flocculent sediment contouring the lake bottom is highly organic, made of approximately 80% organic matter (Pretenki et al., 1980) and is a dark brown, unconsolidated material. Due to the high concentration of organic substrate, the sediments contain most of the living organisms within the tundra lake system. Comparing the average living organism density in one cross-sectional square meter of sediment to a similar square meter of liquid water within a tundra pond, Hobbie et al. (1980) estimate, a 150 times greater concentration of living organisms within the sediment. Remarkably, the biota exists within a thin (5-10 cm) thawed layer of sediment throughout the winter. By the end of summer the sediment still remains cold throughout the year but does thaw an additional 20-30 cm. Sediment refreezes from the bottom up but at a slower rate than top down freezing due the permafrost presence. Brewer (1958) suggests that for every 10 cm of sediment depth, sediment temperatures decrease by 2 °C due to the underlying permafrost.

Although the Alaska Arctic Coastal Plain contains an abundance of freshwater lakes and streams, fish habitat is limited because most water bodies are too shallow to support fish overwintering where ice depth can reach 2.0 m (Zhang and Jeffries 2000). Therefore, winter is considered the limiting period for freshwater fish because of restricting habitat. Despite the extremely limited habitat, 21 fish species have been identified in freshwaters within the Alaskan Arctic Coastal Plain. The five most abundant freshwater fish species are ninespine stickleback, arctic grayling, least cisco, broad whitefish and round whitefish (Truett and Johnson, 2000). Ninespine stickleback are easily the most widespread in the region, being found in 91% of lakes with sufficient overwintering habitat (Moulton, 1998).

Dissolved oxygen is essential to the metabolism of aquatic biota (Wetzl, 2001). In summer the wind currents distribute the oxygen derived from the atmosphere throughout the water column and dissolved oxygen levels are at saturation or super-saturation (oxygen is more soluble in water than in the nitrogen of the air). However, under ice, winds are eliminated and decreased levels of dissolved oxygen are expected. The oxygen content under snow and ice cover is a function of the amount of initial storage and the rate of depletion. Any photosynthetic oxygenation is suppressed since algae are unable to receive light through the snow cover over the ice. Consumption of dissolved oxygen is mostly due to bacterial respiration and chemical oxidation at the sediment/water interface and any fish in the water column only contribute minimally to the depletion (Ellis and Stefan, 1989). Pretenki et al. (1980) suggested the high rates of benthic respiration to be the primary mechanism for dissolved oxygen depletion in shallow ponds near Point Barrow, Alaska.

The chemistry of tundra lakes water is determined by numerous and variable inputs. Rooted plants provide most of the organic carbon input by respiration and detritus (Pretenki et al., 1980). Most of the carbon is present as dissolved organic carbon, which is composed of high molecular weight compounds such as humic acids and smaller low molecular weight compounds such as simple carbohydrates and amino acids. High molecular weight compounds are broken down by incoming ultraviolet light or hydrolysis while low molecular weight compounds are used by bacteria.

Summer precipitation is an important chemical input to the lakes as the soils are thawed and chemicals can be leached from the soils. Runoff from rainfall contributes 60 to 80% of the total ion input, whereas snowmelt contributes 20 to 40%. However, winter precipitation as snow is the more important source for biologically important nutrients such as nitrate and sulfate as these nutrients are retained by vegetation (Everett et al., 1989). Pretenki et al. (1980), studying tundra ponds near Point Barrow, found chloride to be the major anion and sodium to be the major cation.

Concentration of salts in the lakes is controlled by abiotic factors, namely the exclusion of solutes from the ice into the water. The exclusion is a result of ice’s crystalline structure, which rejects impurities, such as salts, during growth (Adams, 1981). Belzile et. al. (2002) found that small, less conjugated molecules are retained in the ice, whereas the larger, more conjugated molecules are preferentially excluded. During the winter, ions may be concentrated 30-fold during freeze-up. In the spring, lake water following snowmelt may resemble distilled water (Pretenki et al., 1980). Dissolved organic matter is also excluded from the ice similar to the ions. Aside from concentrating ions and other dissolved matter, the ice exclusion processes also promotes under-ice convection and affects the distribution of material and biota in the ecosystem by giving more availability for organic carbon substrates and nutrients for biota (Belzile et. al., 2002). Another result of the ice exclusion process is the effect of salt concentration depressing the freezing point of the remaining free water.

The seasonal concentration trends of non-nutrient major cations (Na, Mg, Ca) are similar year to year (Pretenki et al., 1980). Conductivity is a function of ion concentrations and the correlation is strong. Rodhe (1949) demonstrated that the change in specific conductance can be used to estimate the proportional concentrations of the major cations with relatively small error based upon the initial concentrations of the major ions.

The concentrations of minor ions such as potassium and iron do not influence conductivity. Potassium reaches maximum concentrations after melt in response to leaching from plants and other organic materials during runoff. Iron reaches its maximum concentration later in July in response to precipitation input leaching iron from the surrounding soils or bottom sediments. Dissolved organic carbon is the largest pool of organic carbon and represents an important constituent of the biogeochemical carbon cycle (Belzile et. al., 2002). Boyd (1959) regularly measured under-ice ion concentrations at Imikpuk Lake, near Point Barrow, and found good consistency in exclusion trends as seen in Figure 5.

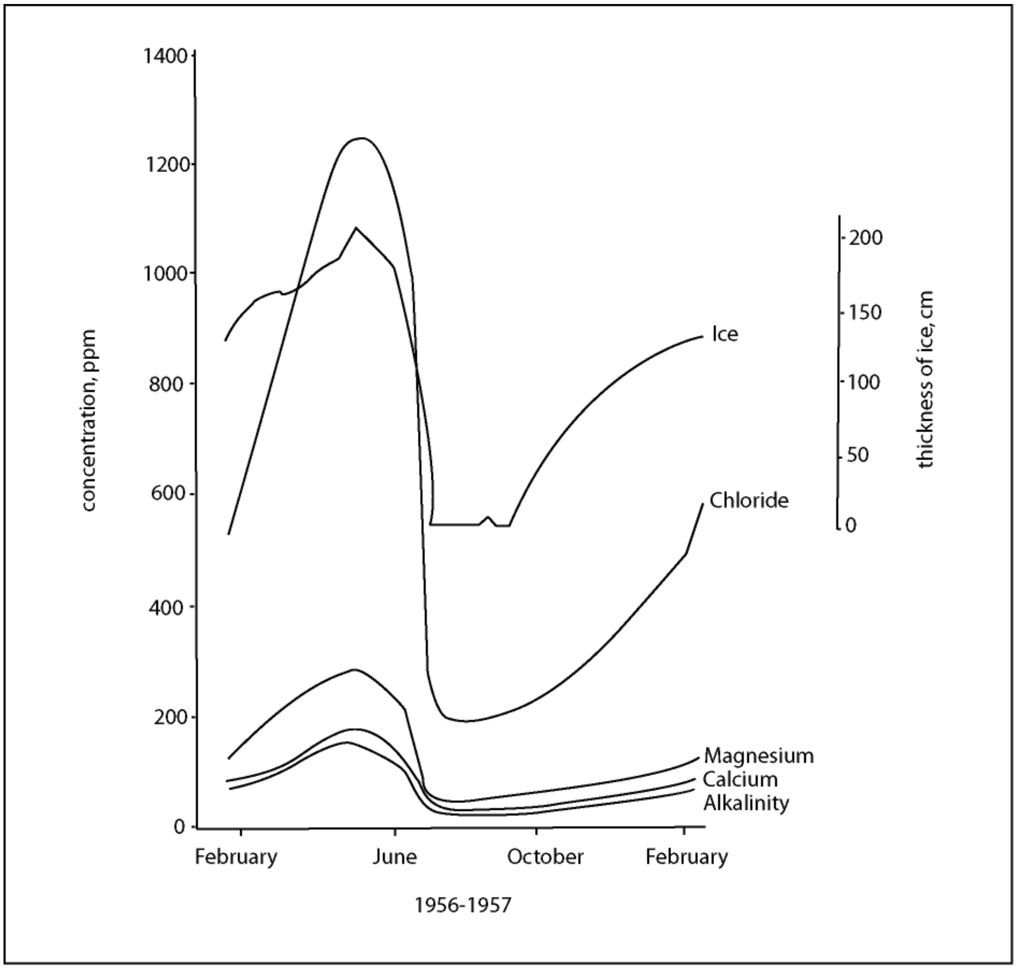

Figure 5: Seasonal change in the chemical composition of Imikpuk Lake, located near Point Barrow, where chlorine is measured as total chlorides in NaCl and calcium, magnesium and alkalinity are measured as hardness as CaCO3 . No iron was detected in the samples (reproduced from Boyd, 1959).

As a summary, Hobbie (1980) lists eleven primary characteristics of arctic lakes and ponds:

(1) Most do not warm above 10 °C and do not stratify.

(2) Those shallower than 1.7 - 2.0 m freeze completely, therefore those shallower than 1.7 - 2.0 m do not contain fish.

(3) The ice cover is usually 1.0 – 2.0 m and lasts 8 - 9 months.

(4) They contain low amounts of available nutrients and low total dissolved salts, however the total inorganic ion concentration is different for drainage basins in different types of bedrock.

(5) Biota are subject to strong physiological stresses.

(6) They are oligotrophic.

(7) Fish are very slow growing, but large fish may live for 40 years.

(8) With few exceptions, zooplankton have a dormant phase in its life cycle.

(9) There are no resident benthic animals that graze on aquatic plants or animals that shred large organic particles or leaves.

(10) The number of animal species is small.

(11) Decomposition rates are slow and large amounts of energy and nutrients are tied up in dead organic matter.

LOCAL METEOROLOGY REVIEW

Meteorological data were collected at Betty Pingo and 2M Repeater meteorological sites to help interpret relationships between environmental factors and the measurements reported at the lakes. Environmental influences on the data are important to characterize since the expected responses at the lakes are slight.

The 2M Repeater site was not fully functional and reporting until mid-winter 2004 and so this review makes use of the data at Betty Pingo site (Kane and Hinzman, 2004), which has been in consistent operation since 1994. Betty Pingo is located east of the lakes and is approximately 20 km from lake K113 and 50 km from lake K209. Despite the lack of close proximity, it is assumed the meteorological data collected from Betty Pingo applies throughout the study area as there are no distinct topographic divides in the area and any weather system moving through likely affects the study area fairly uniformly over time.

The 2002-2003 winter was warmer than the 2003-2004 winter. The surface freezing index for 2002-2003 was 3815.3 °C * d while the freezing index for 2003-2004 was 4491.1 °C * d. The surface freezing index is defined as the annual summation of degree-days colder than 0 °C. Overall, both winters were noticeably warmer than the historical daily maximum temperature averages (Figure 6) collected at the Kuparuk airport’s meteorological site. The 10-day running average temperatures for the 2002-2003 and 2003-2004 winters are about 5 °C colder than the 11-day running average for 1994 to 1998 Olsson et al. (2002) record. Consequently, the ‘deep cold’ season of the 2002-2003 and 2003-2004 winters lasted longer, nearly into April, compared to the Olsson et al. (2002) data.

Coldest temperatures occurred from January to April both winters. Cold temperature arrived later during the 2003-2004 winter compared to the 2002-2003 winter although the 2003-3004 cold period exhibited more persistence (Figures 7 and 8). However, the lower limit of the air temperature sensor is -40 °C so temperatures may have been colder than the recorded -40 °C. As a result, the calculated freezing indexes are slightly under-estimated.

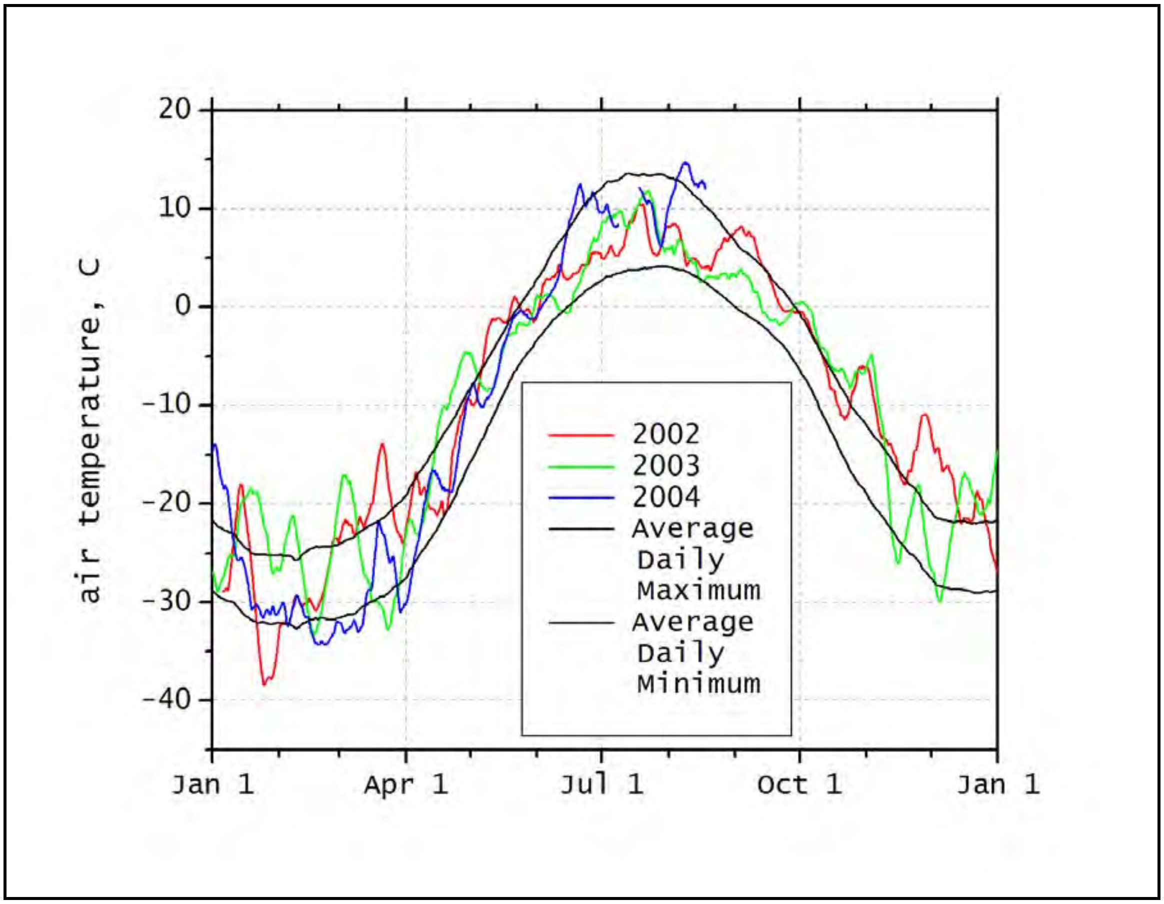

Figure 6: Historical (1983-2003) average maximum and minimum daily air temperatures from Kuparuk Airport Meteorological Tower (data taken from Western Regional Climate Center, 2004) compared to 10-day running averages for 2002 to 2004 at Betty Pingo.

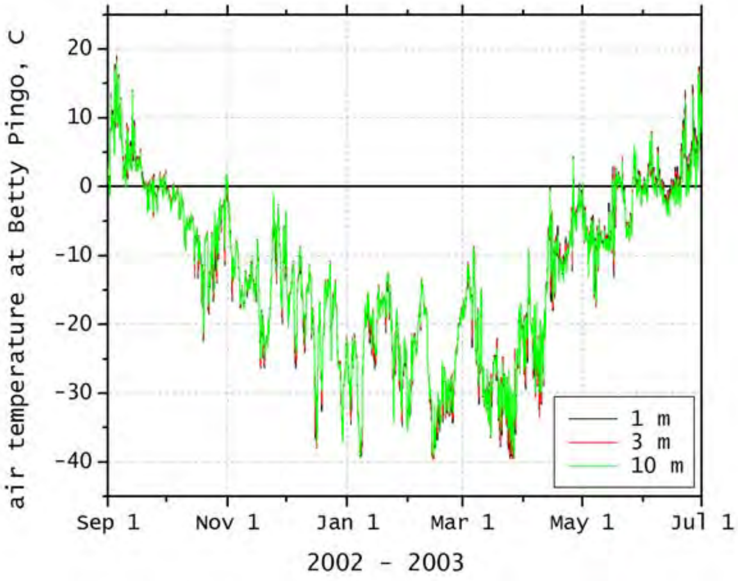

Figure 7: Winter 2002-2003 air temperatures at 1 m, 3 m and 10 m at Betty Pingo Tower.

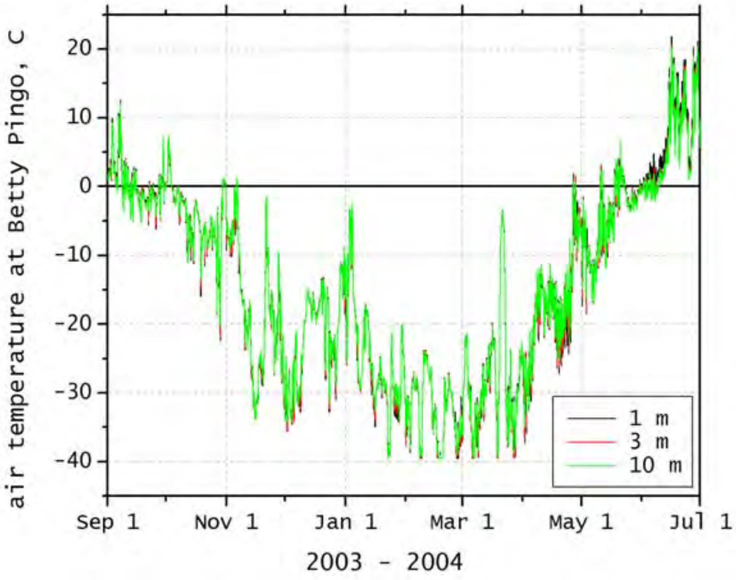

Figure 8: Winter 2003-2004 air temperatures at 1 m, 3 m and 10 m at Betty Pingo Tower.

Initially, ice formation processes are rapid but gradually slow with the increased thermal insulation provided by the thickened ice and especially any snow atop the ice. Measurements of ice thickness are presented in Figures 9 and 10 along with a predicted ice thickness estimate for the 2002-2003 and 2003-2004 winters. The predicted ice thickness was modeled using the Stefan equation (Michel, 1971), which uses variables of surface cover and the calculated surface freezing index. Four surface cover conditions are modeled with related empirically derived coefficients: no snow cover, limited snow cover, moderate snow cover and heavy snow cover (see Table 12 in the Appendix for coefficients). The limited snow cover coefficient most closely resembles the empirical data, particularly in the 2003-2004 winter, so this is the coefficient used in subsequent analyses. A limited snow cover coefficient is expected, as the depth of snow at the lakes is slight. The Stefan equation somewhat overestimates the amount of ice generated by assuming the water is relatively pure and does not account for the lower freezing point of the brine water that exists at winter’s end in the shallower lakes due to the ice exclusion process.

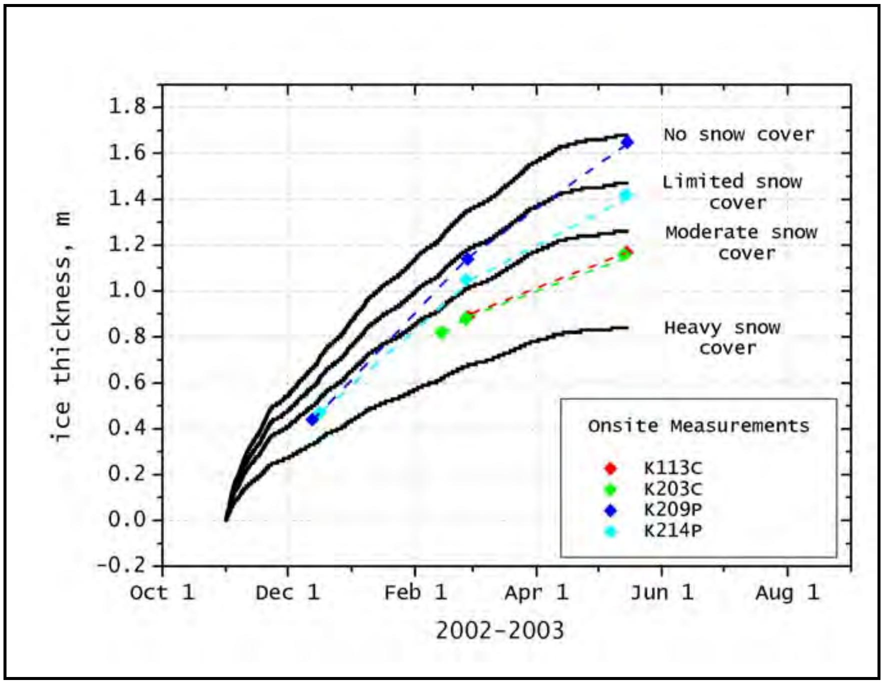

Figure 9: Stefan equation estimate of ice thickness during the 2002-2003 winter plotted with onsite ice thickness measurements at the Kuparuk study lakes.

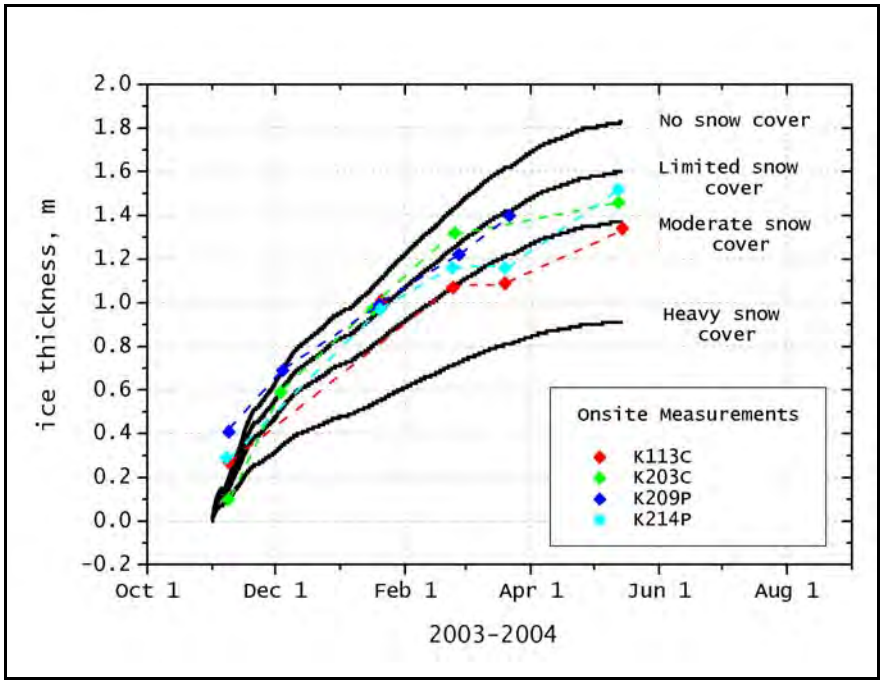

Figure 10: Stefan estimate of ice thickness during the 2003-2004 plotted with onsite ice thickness measurements at the study lakes.

Relative humidity during the 2002-2003 and 2003-2004 winters is high as expected in a cold polar environment and often near 100% saturation (Figures 11 and 12). This is a result of the close proximity of air temperature and dew point in the Arctic. In other words, low air temperature causes a similarly low dew point, and at a low dew point, the atmosphere is able to hold little moisture. Thus, despite the high relative humidity, the atmosphere throughout the Alaskan Arctic Coastal Plain holds little water vapor.

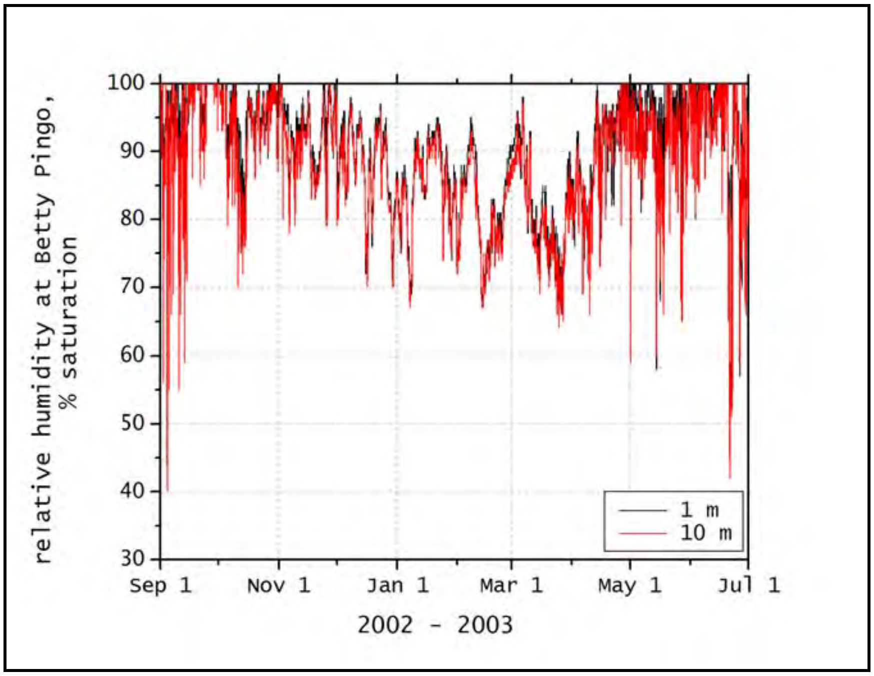

Figure 11: Winter 2002-2003 relative humidity at 1 m and 10 m at Betty Pingo Tower. Relative humidity readings have a 100% saturation upper threshold.

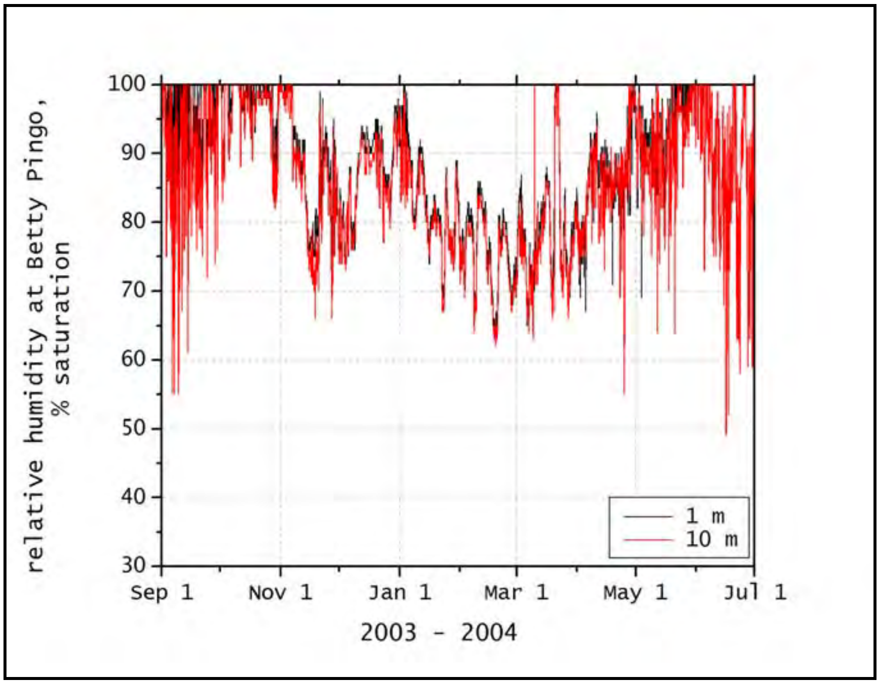

Figure 12: Winter 2003-2004 relative humidity at 1 m and 10 m at Betty Pingo Tower. Relative humidity readings have a 100% saturation upper threshold.

Winds in the area were consistent and strong (Figure 13 and 14). Peak gusts above 15 m/s were recorded both winters. Periods of inactivity such as January 2003 or February 2004 may be attributed to the challenge of gauging wind in the extreme arctic environment. It is likely the anemometer used to measure wind speed accumulated sufficient rime to prevent an accurate measurement at lower wind speeds (<4 m/s) in these two instances. An eventual high wind event (>8 m/s) freed the sensor. The anemometer has a lower threshold value of 0.4 m/s.

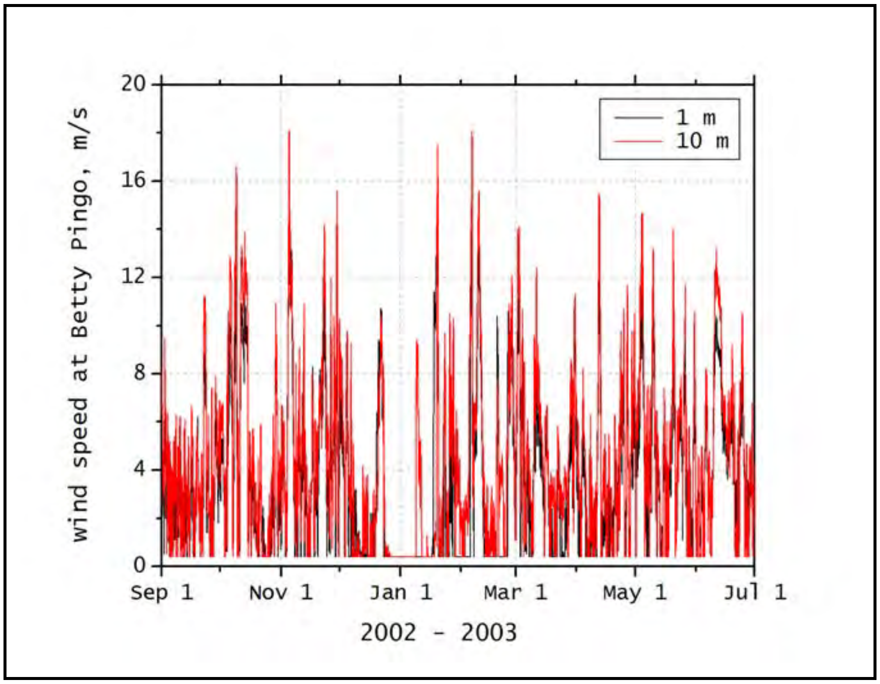

Figure 13: Winter 2002-2003 wind speed at 1 m and 10 m at Betty Pingo Tower.

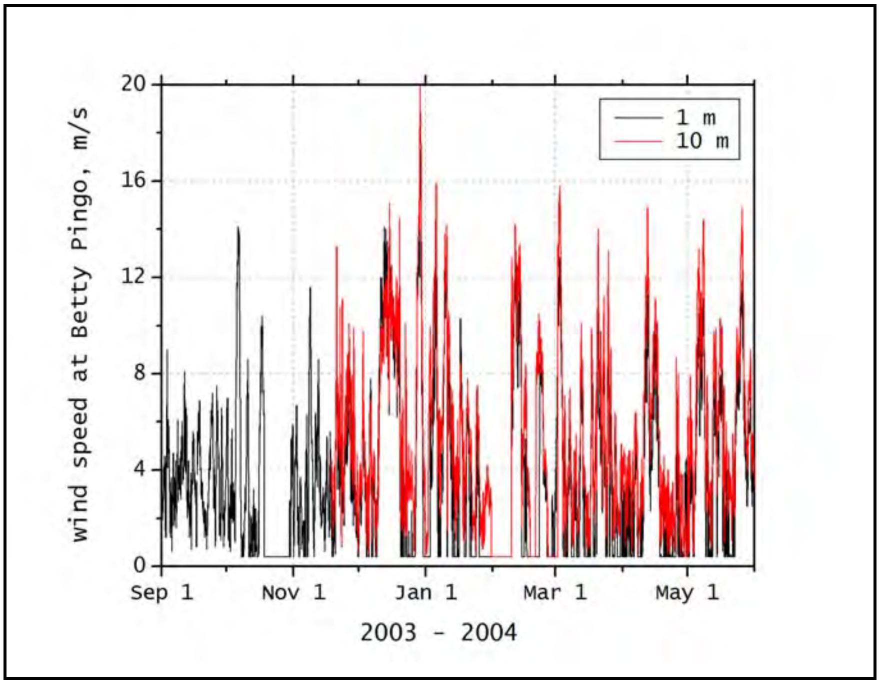

Figure 14: Winter 2003-2004 wind speed at 1 m and 10 m at Betty Pingo Tower.

Precipitation was recorded during the 2003-2004 winter to better understand the relationship of snowpack to the water surface levels being observed in the lakes. Precipitation was measured on a daily basis using an online pressure transducer installed in a Wyoming Snow Gauge adjacent to the Betty Pingo site. Wyoming Snow Gauges generally under report winter precipitation as snow. Figure 15 shows the record for the 2003-2004 winter assuming a zero beginning value November 1, 2003 and eliminating any recorded evaporation from the gauge. Precipitation through the winter months is light and most precipitation throughout the year usually occurs during the relatively wet months of July and August. The proportion of precipitation as rain to precipitation as snow is distributed fairly evenly.

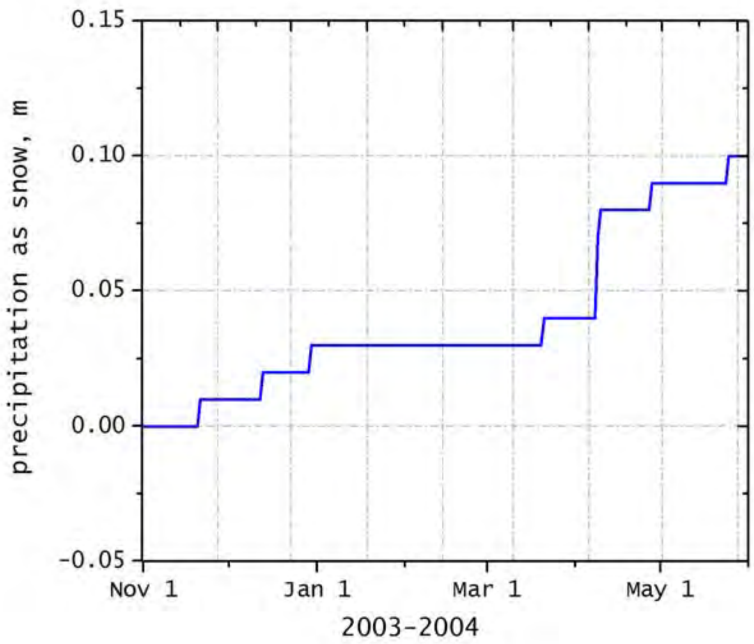

Figure 15: Measured daily precipitation as snow measurements during 2003-2004 winter.

DATA COLLECTION METHODS

Water sampling occurred on-site using hand held water quality meters and off-site using portable devices and full-scale laboratory setups. All sampling devices and meters were calibrated before sampling efforts with NIST-traceable standards to ensure accurate measurements. Five sampling trips were accomplished during the first season of study (December 2002 – August 2003) and six sampling trips were accomplished in the second season of study (September 2003 – June 2004).

METER MEASUREMENTS

In-situ measurements of water temperature, pH, dissolved oxygen, and specific conductivity were recorded using a variety of hand-held meters including Yellow Springs Instruments (YSI), Hydrolab, Hanna, Hach, and Lakewood meters. Table 13 in the Appendix lists the sampling meters used for particular onsite sampling efforts along with lakes sampled and the sampling meters’ calibration date.

In-situ sampling meters consistently recorded water quality variables (temperature, pH, specific conductance, dissolved oxygen) at one-half the free water column depth. In other words, at a depth equivalent to half the distance between the bottom sediment and the bottom of ice (winter sampling) or the top of surface water (summer sampling). Readings on the meters were allowed to stabilize in an attempt to minimize the aeration or sediment disruption caused by the necessity of augering a hole through the ice. Ice thickness was also measured onsite using a metered rod.

BENCHTOP MEASUREMENTS

Benchtop variables were those that required simple, non-laboratory analyses that could not practically be preformed onsite due to harsh conditions. Typically, the analyses were preformed at camp later in the day where instruments and reagents could remain warm and conditions were more conducive to careful measurement. Benchtop variables included alkalinity, turbidity, nitrate and nitrite.

Lake water for these measurements was taken using a peristaltic pump powered by a 12-volt non-spillable battery. The location of collection was at the standard one-half the free water column depth. Lake water was allowed to run through the tubing for a sufficient period before collection to ensure an uncontaminated sample. Approximately 300 to 450 mL of raw lake water was collected in two or three 150 mL plastic Nalgene bottles. The raw water was kept at 2-8 °C until analyses were possible. Benchtop analyses were typically preformed within a few hours after water collection to meet specific analyses holding times. Aliquots were taken from the raw water collection bottle for all analyses. All equipment was thoroughly rinsed by the lake’s raw water before benchtop analyses and was cleansed in deionized water after analyses.

Alkalinity was measured by Hach portable titration method #8203 with 0.16 or 1.6 N sulfuric acid as a titrant depending on the expected alkalinity. Turbidity was measured using a MicroTPI portable turbidimeter as well as a Hach 2100P portable turbidimeter. Turbidity analytical range was 0.002 – 1000 nephelometric turbidity units (NTU).

LABORATORY MEASUREMENTS

Variables analyzed in the UAF WERC laboratory included: metals (sodium [Na], calcium [Ca], magnesium [Mg], iron [Fe] and potassium [K]), nutrients (nitrate [NO_3], nitrite [NO_2] and ortho-phosphate [PO_4]) and organic carbon (total organic carbon [TOC] and dissolved organic carbon [DOC]). Water samples for laboratory analytical testing were collected using a peristaltic pump powered by a 12-volt non-spillable battery. The location of collection was the standard one-half the free water column depth. Lake water was allowed to run through the tubing for a sufficient period before collection to ensure a representative sample.

A single sampling set for laboratory analysis was made of two (one filtered and preserved, one unfiltered and preserved) 150 mL manufacturer-sterilized plastic Nalgene bottles. Duplicate and often triplicate sets were collected onsite for laboratory use. Filtered samples were preserved with 1 ml of 6 N sulfuric acid added before collection while unfiltered samples were preserved with 1 ml of 6 N nitric acid added before collection. This amount was enough to acidify the lake water to a pH near 2.0. Samples were filtered by an in-line AquaPrep 600, 0.45 um, capsule filter at the time of collection.

All samples were kept at the optimum temperature range of 2-8 °C during transportation back to UAF facilities for laboratory analyses. Samples were immediately ultra-acidified on arrival to a pH of less than 2 using phosphoric acid for further preservation. Storage at UAF laboratories was in a 5 °C refrigerator until analysis was possible. The nutrient content (nitrate and nitrite) was analyzed within 12 hours to prevent bacterial consumption. 40 mL aliquots of filtered and unfiltered preserved water were transferred into manufacturer-sterilized glass vials with septum for TOC and DOC analyses.

Unfiltered bottled samples were analyzed for metals and total organic carbon. Filtered samples were analyzed for nutrients and dissolved organic carbon.

Analysis of metals was performed using a Perkin Elmer Analyst 300 atomic absorption spectrophotometer. The instrument was operated in flame mode using an air-acetylene flame for sample aspiration and burning. To perform the analysis, a subset was removed from the container and diluted to the appropriate analytical range (Table 4). The instrument was then calibrated using calibration standards and a calibration curve was derived. Deuterium background correction was used for all samples analyzed at wavelengths of less than 300 nm (Table 4).

Table 4: Laboratory Metals Analyses Specifications.

Analyte	Wavelength (nm)	Background Correction	Analytical Range (ppm)	Standard Lot Number
Na	589	No	0-1.0	B1045104
Ca	422.7	No	0-5.0	B2035080
K	766.5	No	0-2.0	B1055015
Mg	285.2	Yes	0-0.5	B0035160
Fe	248.3	Yes	0-6.0	B2025087

Organic carbon samples were analyzed using an Apollo 9000HS TOC analyzer. The analyzer was calibrated using a commercially available carbon standard. All samples were analyzed by sparging the samples for five minutes with clean air. The samples were then directly injected into the combustion chamber and analyzed.

Laboratory nitrate and nitrite analysis was performed using a colorimetric technique. Total (nitrate and nitrite) nitrogen was measured by first reducing all nitrate in the sample to nitrite using a commercially available cadmium reduction column. The sample was then diazotized using sulfanilamide and coupled with N-(1-napthyl)-ethylenediamine dihydrochloride to form a highly colored dye. This solution was quantized using a Beckman DU520 UV-Visible spectrophotomer operating at 543 nm. The instrument was calibrated using a standard prepared by dissolving sodium nitrate in water. Laboratory analysis of nitrate and nitrite has a lower detection limit of 5 ppb.

CONTINUOUS MEASUREMENTS

Continuous measurement of specific conductivity, water temperature, water level and dissolved oxygen during the 2002-2003 and 2003-2004 winters was achieved by continuously operating stations. Stations at lakes K113C, K203C, K214P and K209P were installed in February 2003 and recorded data until spring breakup in July. Stations at K113C, K214P and K209P were redeployed for the entire 2003-04 winter.

Variables of water level, specific conductance, temperature and dissolved oxygen were transmitted by radio to a base station connected to the Internet allowing changes in near-real time (15-60 minute data intervals) to be observed. Data sets were then reduced and Quality Assurance/Quality Control assessments conducted to detect data error. Two specific conductivity sensors and two dissolved oxygen sensors floated within the free water column approximately 0.35 m above the bottom sediments. Water level was recorded by two pressure transducer sensors anchored into the bottom sediment. Water temperature was typically recorded at 0.3 m intervals by a paired thermistor string throughout the water column with the bottom thermistor anchored in the bottom sediment.

Details of sensors utilized in the study are given in Table 5. Positioning of sensors in relation to the station itself is seen in Figure 16. Table 6 presents the time each station began reporting data. Record of pressure transducer calibrations is given in Table 14 to 17 in the Appendix. Record of sensor change-outs is given in Table 18 of the Appendix.

Table 5: Online sensor specifications.

Sensor	Make	Model	Resolution	Sensor Tolerance
Dissolved Oxygen	Greenspan Technologies / Steven Water Monitoring	DO1200	0.1 % saturation	+/- 2.0%
Pressure Transducer	Honeywell / GeoWatershed Scientific	GWS5B - 5 PSI range	0.001 volts, 0.01153 ft, 0.00352 m	+/- 0.1%
Thermistor	Yellow Springs Instruments	YSI44000	0.01 C	+/- 0.2 C
Specific Conductance	Campbell Scientific	CS547A	0.001 mS/cm	+/- 5.0%

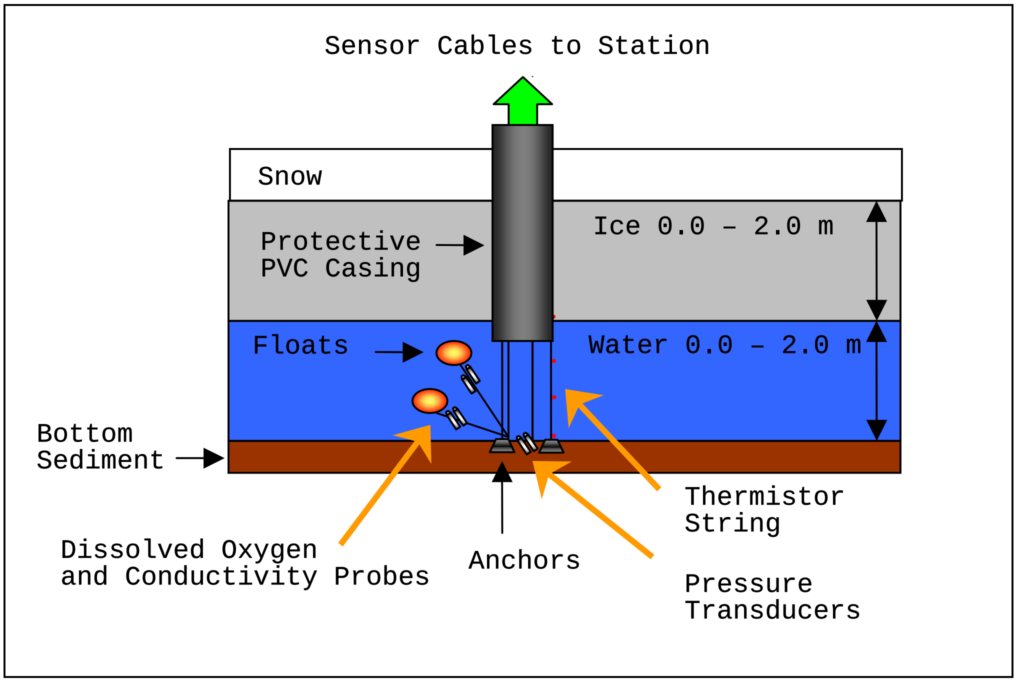

Figure 16: Depiction of station and online sensors operating under-ice.

Table 6: Beginning time of data collection at study lakes.

Lake	Station Installed
K113C	2/15/03 17:00
K203C	2/14/03 22:00
K209P	2/13/03 19:00
K214P	2/9/03 22:00

WATER WITHDRAWAL

Water was withdrawn from the pumped lakes for a variety of uses during both winters. The water was primarily used to create an ice infrastructure of roads for personnel and equipment transportation as well as operating pads and airstrips. Other potential uses of the pumped lakes’ water during the winter included: potable water supply, firewater and drilling fluid. Overall, lake K209P was used as a resource more frequently and at higher volumes than K214P. This was due to lake K209P’s proximity to the primary ice road leading across the Colville River to the Alpine satellite development. Lake K214P, more central in the Kuparuk operating unit, was not pumped as frequently or heavily.

Figures 17 to 20 summarize pumping activities at lakes K209P and K214P during the winters of 2002-2003 and 2003-2004. Note the logarithmic scale for pumping volume. A more detailed record of pumping activity for the 2002-2003 and 2003-2004 winters is given in Tables 19 to 24 in the Appendix.

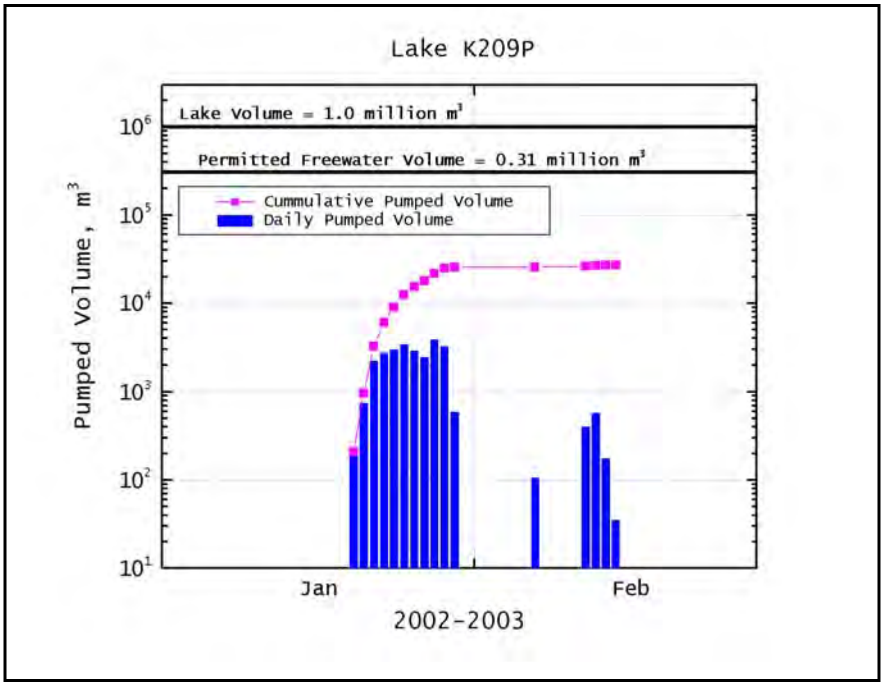

Figure 17: Pumping activity at K209P during the 2002-2003 winter. Cumulative volume withdrawn during the 2002-2003 winter = 26,962 m³.

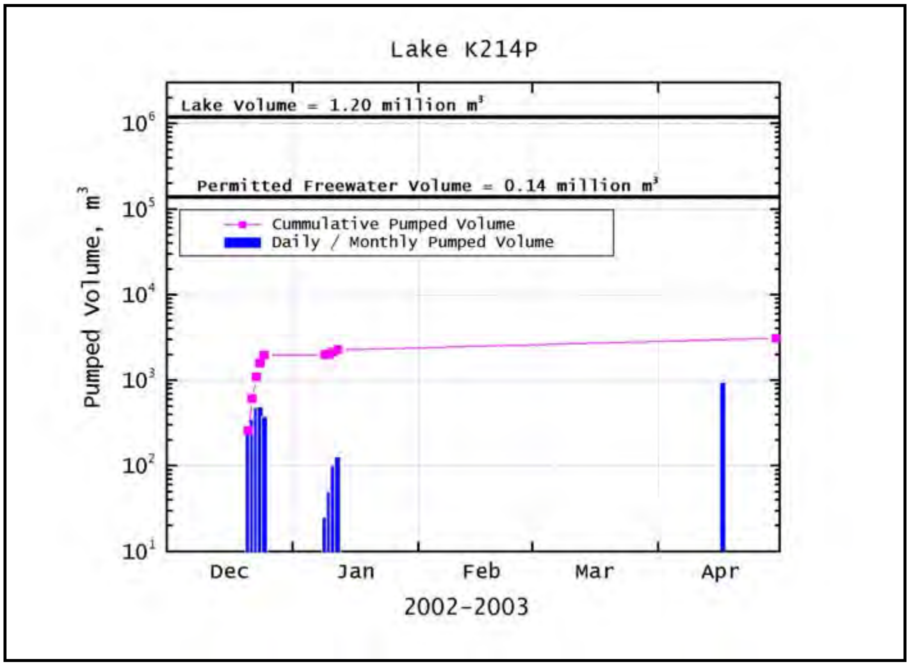

Figure 18: Pumping activity at K214P during the 2002-2003 winter. Cumulative volume withdrawn during the 2002-2003 winter = 3,105 m³.

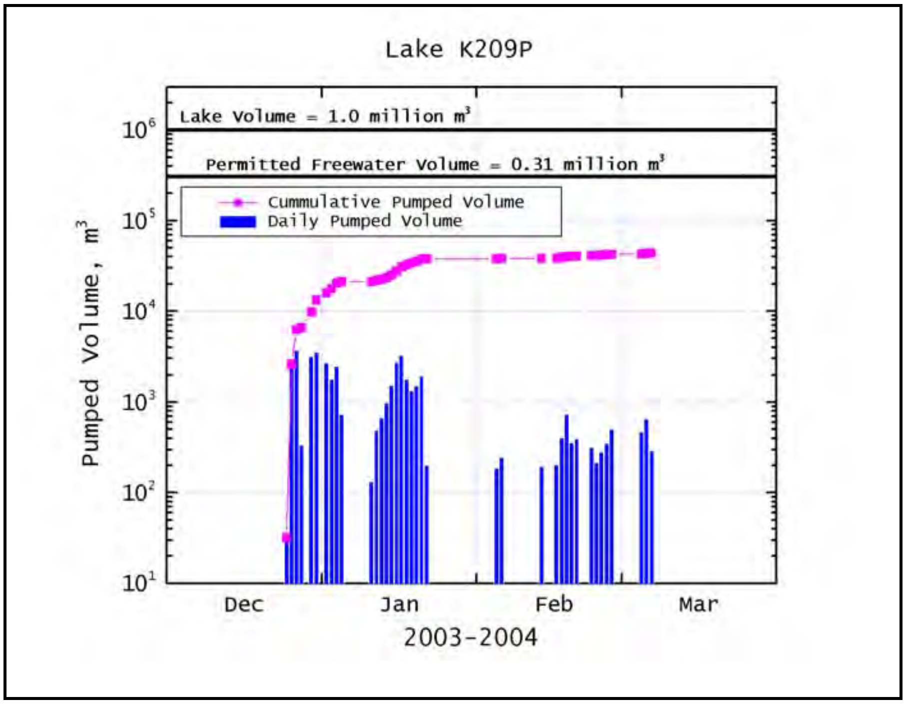

Figure 19: Pumping activity at K209P during the 2003-2004 winter. Cumulative volume withdrawn during the 2003-2004 winter = 43,710 m³.

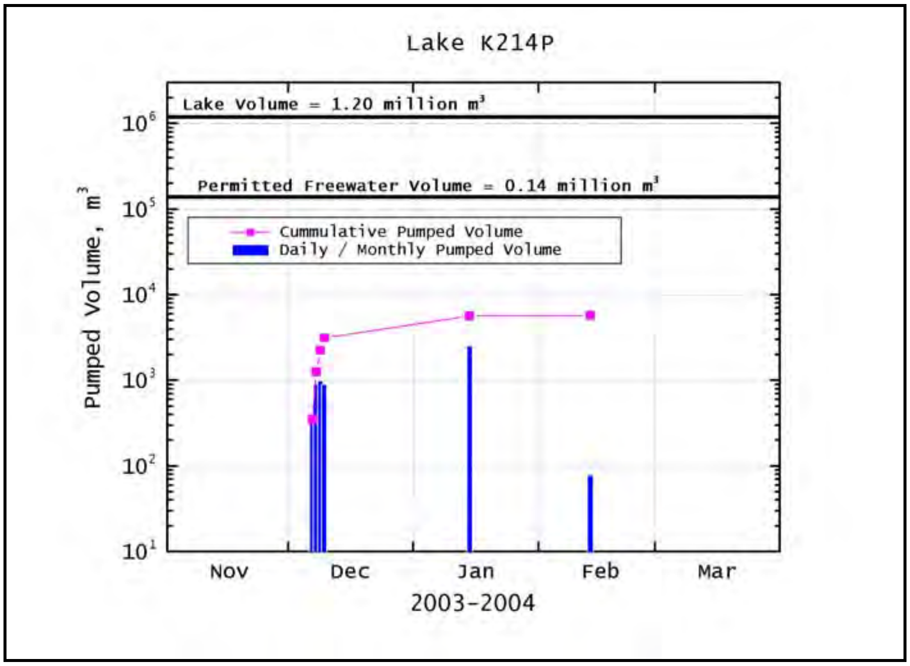

Figure 20: Pumping activity at K214P during the 2003-2004 winter. Cumulative volume withdrawn during the 2003-2004 winter = 5,774 m³.

RESULTS AND DISCUSSION

Water surface levels, specific conductance, dissolved oxygen, water temperature and water quality variables were examined to determine the response from pumping activities. The data is focused on the 2003-2004 winter period since the instrumented stations were recording throughout the entire winter. Pumped lake measurements are compared to control lake measurements, which provide a baseline to detect and measure physical and chemical responses due to pumping activities. Where appropriate, volumes of water withdrawn from the pumped lakes are illustrated.

In the analyses, manual measurements by handheld meters during site visits are also presented to verify the continuous measurements. Continuous measurements were further verified by a paired redundant sensor for each variable. Differences between manual and continuous measurements are attributed to vertical sampling differences in the water column (for instance, the difference between a manual measurement at two feet above sediment compared to a continuous measurement one foot above sediment) as well as lateral change across the lake (for instance, the difference between a continuous measurement at the instrumented station compared to a manual measurement fifty feet north of the station) (UAF, 2005).

PUMPING ACTIVITY

Tundra lakes have been relied upon for large volumes of freshwater since the 1970s when oil activities began on the North Slope. The volumes of withdrawal depend mostly on the requirements of exploration and corresponding ice road. According to industry records (CPAI, 2004), study lakes K209P and K214P were utilized at least during the

2002-2003 and 2003-2004 winter ice road construction seasons and during previous winters.

Pumping activity occurred at lakes K209P and K214P during both 2002-2003 and 2003-2004 winters. Pumping events were of different time duration and different withdrawal volume. Activity ranged from light pumping (<500 m^3/d) to heavy pumping (>2,000 m^3/d). Pumping records were given as an accumulated withdrawal volume over one day or an accumulated withdrawal volume over one month.

Changes in water surface level (WSL) due to water withdrawal volumes were estimated by two methods and these estimates are then used for comparison to the detected changes in WSL. One estimate is based on an assumption of pan or box lake bathymetry as seen in Figure 21. The expected change in WSL was calculated by dividing the volume of water withdrawal by the lake’s surface area. The other estimate, using a conical projection as seen in Figure 22, takes into account a more gradual side contour reaching to the maximum depth of the lake. The expected change in WSL was calculated by dividing the volume of water withdrawal by the projected under-ice surface area of the water. The actual change in WSL detected by the sensor should fall between the range of these two extreme bathymetries. Figures 23 to 25 present bathymetric transects of typical thaw lakes (including study lake K209) near the Colville delta showing that actual thaw lake bathymetry falls between the idealized pan and cone projection (Moulton, 1998). Thus, the detected change in WSL by the instrumented station should fall between the expected change in WSL based on the pan and cone projection.

Figures 26 and 27 present expected cumulative changes in water surface level resulting from discrete pumping events during the 2002-2003 and

2003-2004 winters using the pan bathymetry method. Expected change based on a cone bathymetry is shown in subsequent analyses. Tables 19 to 24 in the Appendix also present expected change in WSL data numerically.

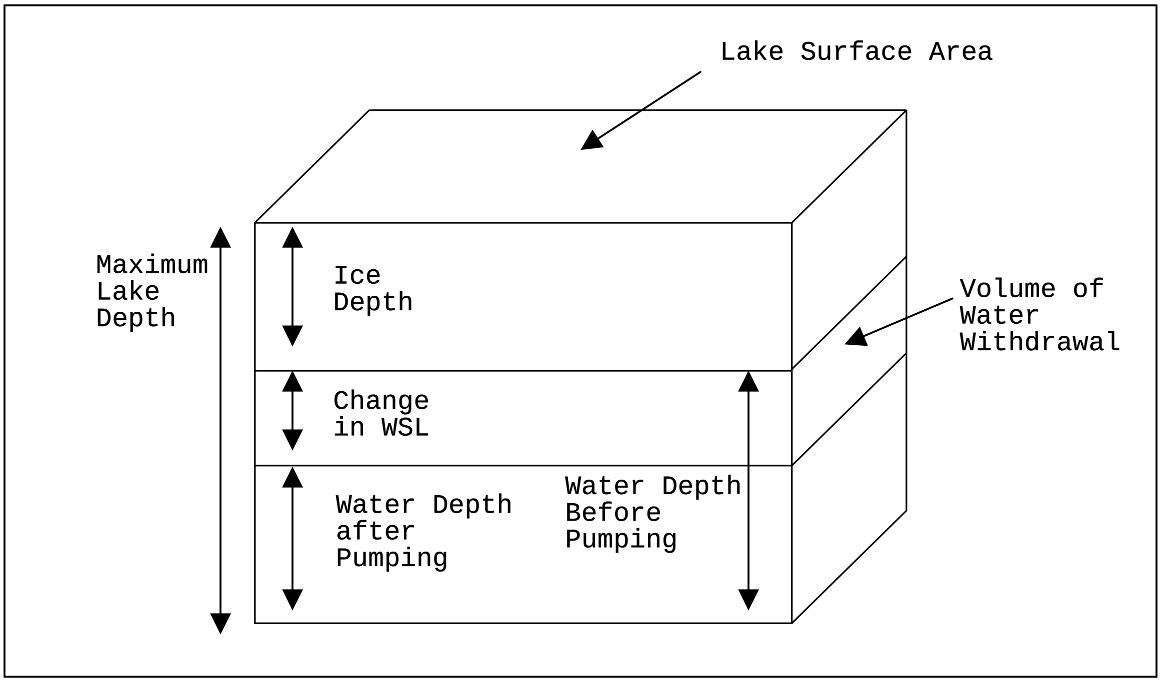

Figure 21: Illustration of pan bathymetry and response in water surface level corresponding to an exaggerated volume of water withdrawal.

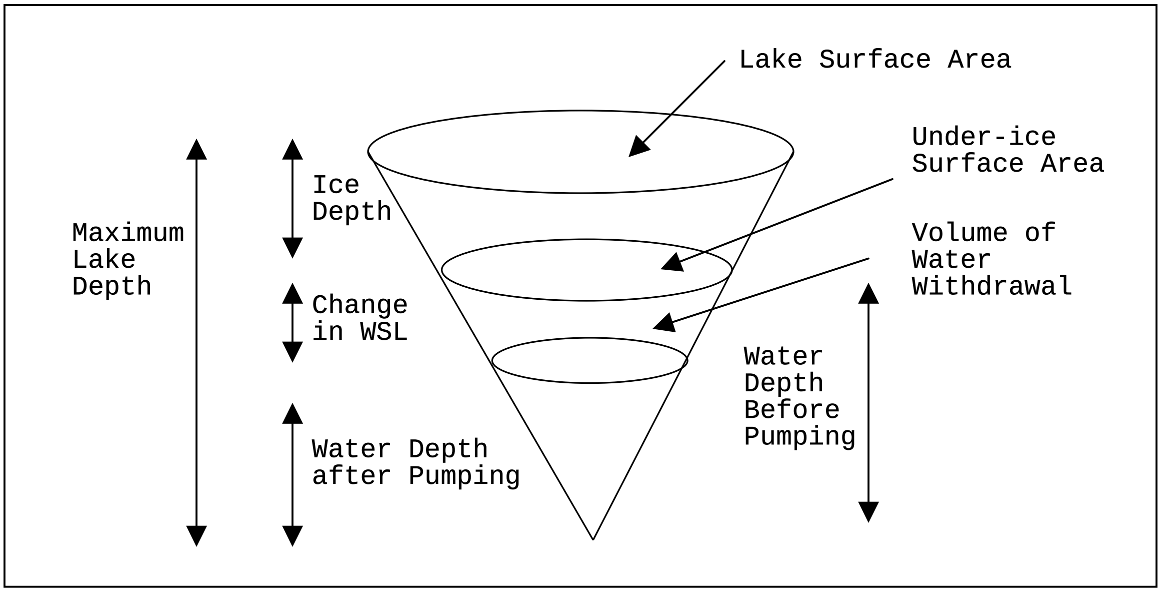

Figure 22: Illustration of cone bathymetry and response in water surface level corresponding to an exaggerated volume of water withdrawal.

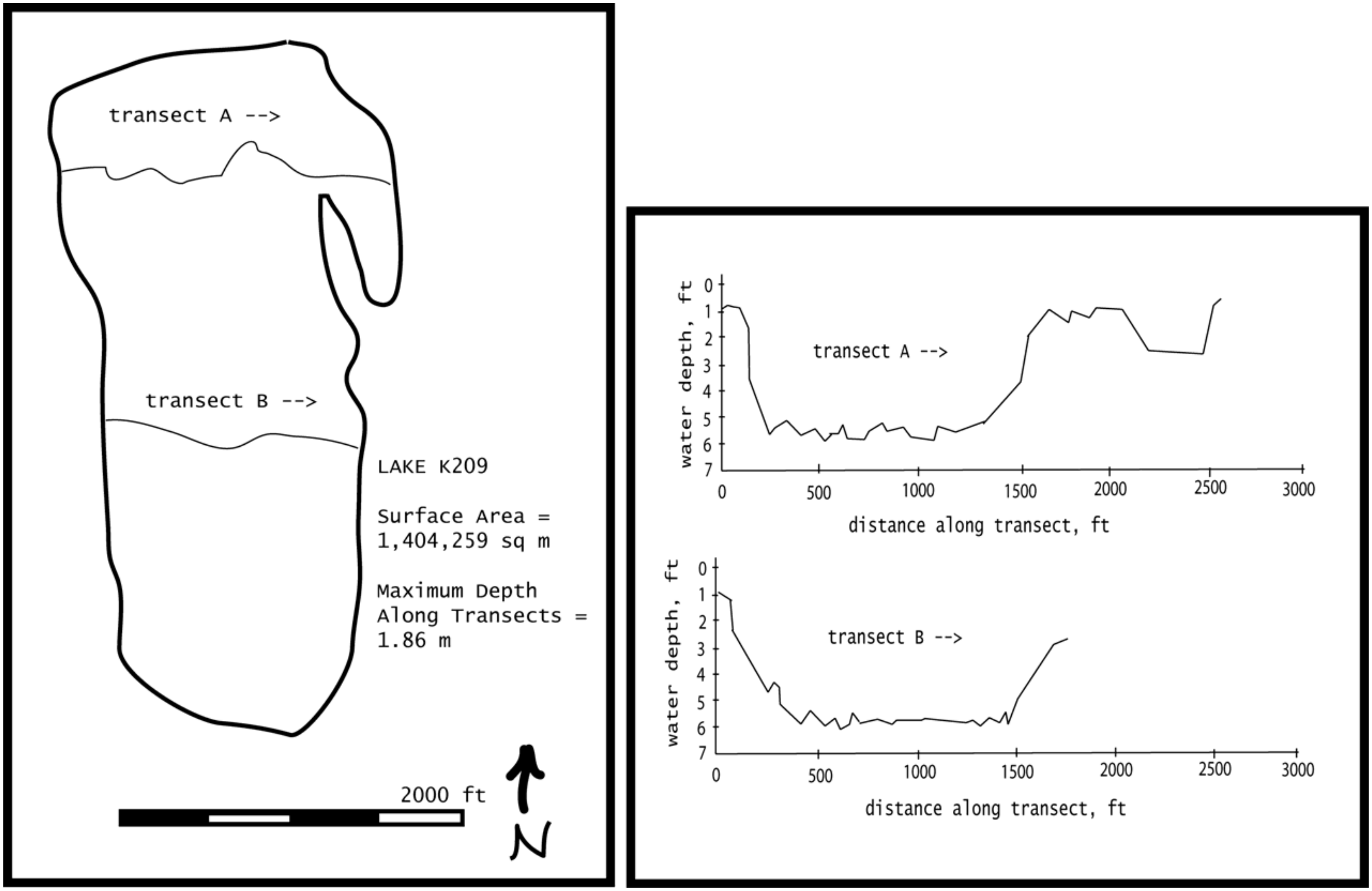

Figure 23: Bathymetric transects of study lake K209P (reproduced from Moulton 1998).

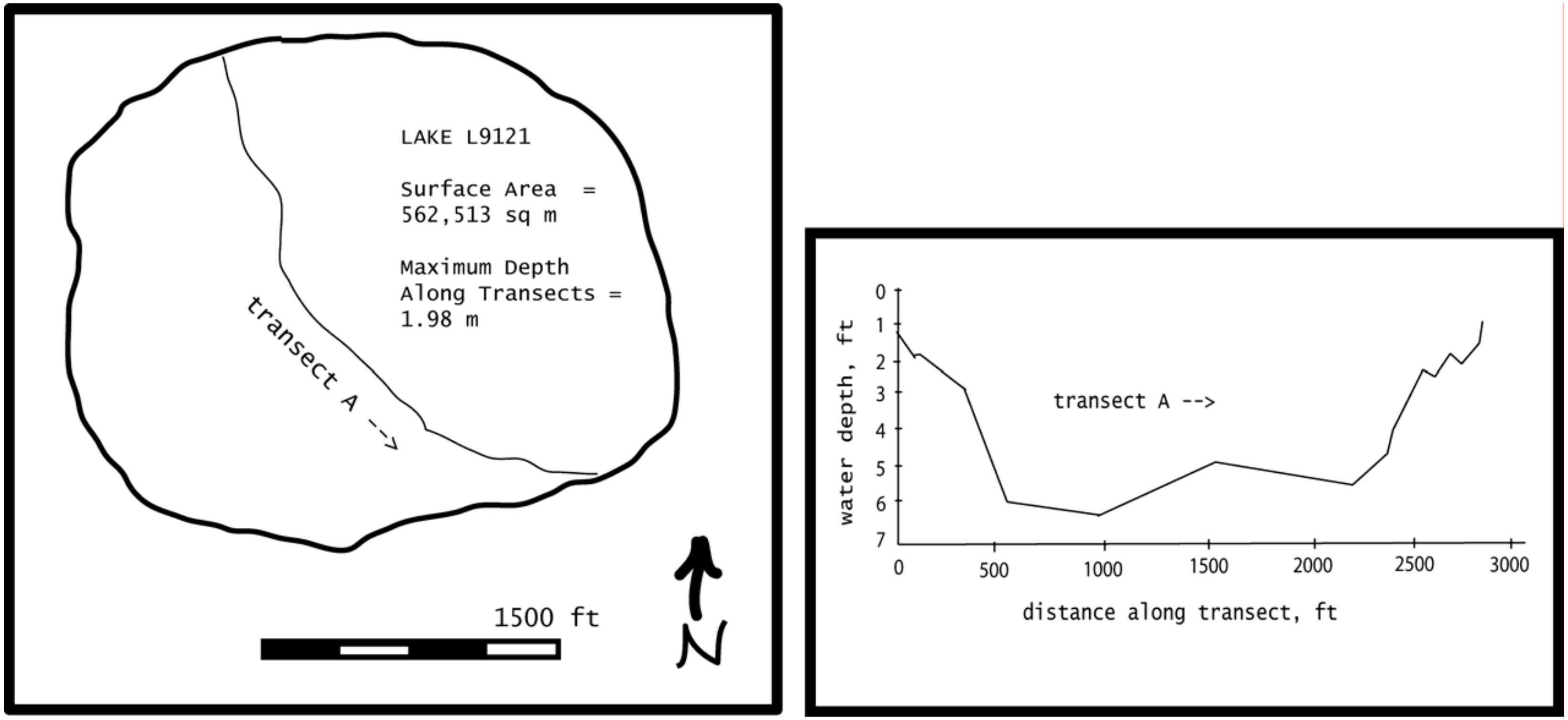

Figure 24: Bathymetric transects of lake L9121, a thaw lake east of the Colville River about 5 km northeast of K209P and 7.5 km west of K214P (reproduced from Moulton 1998).

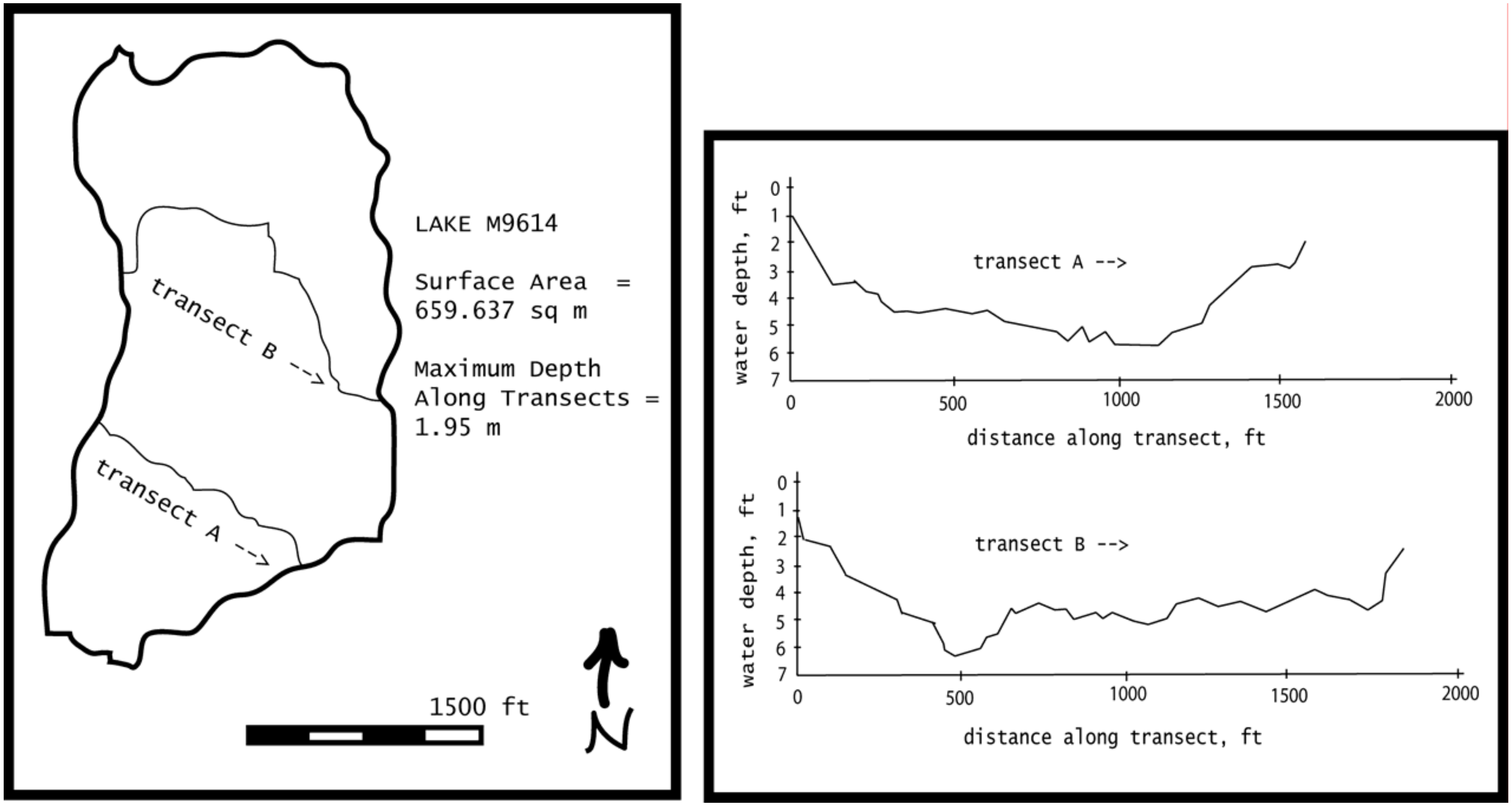

Figure 25: Bathymetric transects of lake M9614, a thaw lake east of the Colville River bounded by the Colville and Kachemach Rivers (reproduced from Moulton 1998). M9614 is about 11 km west by northwest of K209P.

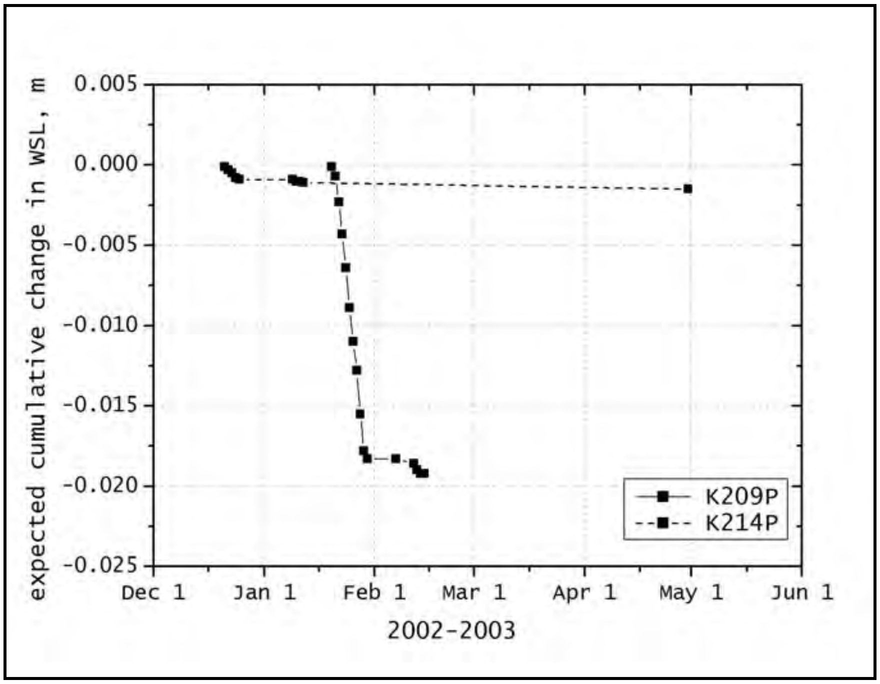

Figure 26: Expected cumulative change in water surface level due to pumping activity during the 2002-2003 winter based on a pan bathymetry.

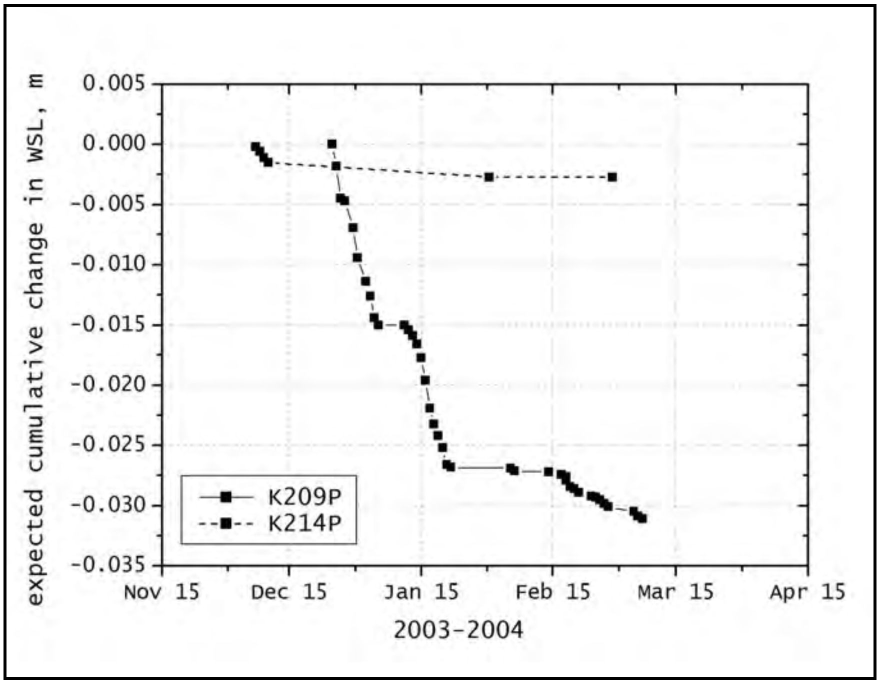

Figure 27: Expected cumulative change in water surface level as a result of pumping activity during 2003-2004 winter based on a pan bathymetry.

As apparent in Figures 26 and 27, the expected water surface level change from winter pumping activity is small. For instance, expected draw-down of WSL at lake K214P from pumping activity does not cumulatively exceed the 0.005 m resolution of the pressure transducer sensor over the course of the 2002-2003 or 2003-2004 winter. Fortunately, lake K209P, with less surface area and higher volumes of water withdrawal, was expected to generate changes in WSL within sensor range. Nevertheless, the expected changes at K209P were still very small and discrete time periods of substantial pumping activity must be integrated for any change of WSL with sensor resolution to be observed. Overall, cumulative pumping amounts at K209P and K214P for winter 2002-2003 and 2003-2004 activities ranged from 0.3 – 2.2 % withdrawal of the total volume and 2.2 – 14.2 % of the permitted volume.

The detection of WSL is further complicated by environmental factors; most significantly, snow loading atop the ice surface increases the perceived WSL (Figure 28). Although this is a correct measurement of the WSL, it does not indicate the WSL of useable water beneath the ice. Thus, it is essential to accurately quantify the snow load to correctly identify the small water surface level changes under the ice. An additional environmental factor that would influence perceived WSL is barometric pressure, but the pressure transducer that ismeasured relative to atmospheric pressure (gauge pressure) so this variable does not influence measurements of water surface levels. . An important note is that snow loading on the lakes does not develop uniformly as snow distribution is formed by the constant strong winds. This has the effect of increasing snow loading at thaw lakes with older well-developed basins. Another impact to perceived WSL may be water trucks moving over the ice but this is difficult to quantify without knowing the exact time of the pumping activity when water trucks were on the lake ice.

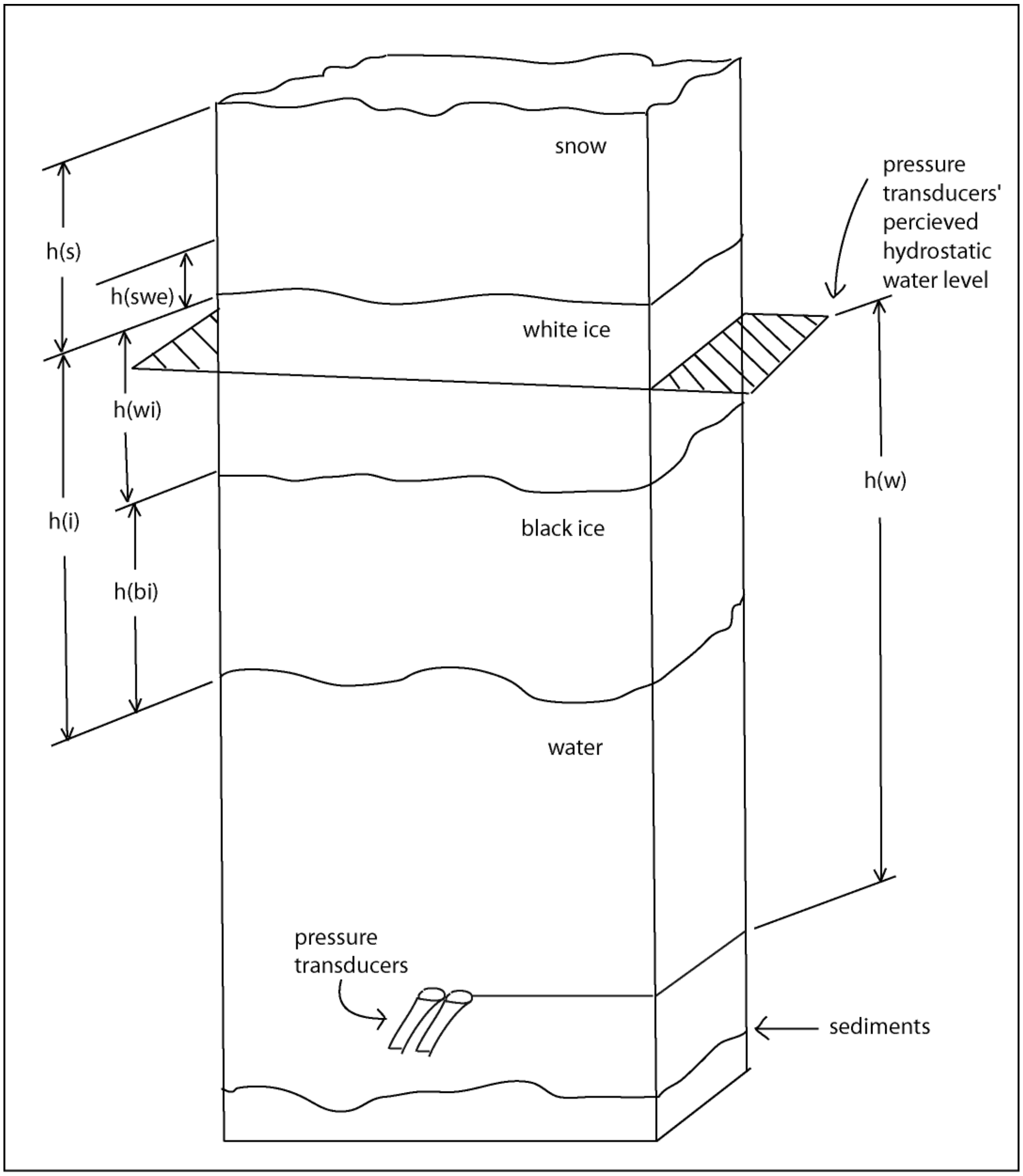

Figure 28: Illustration of perceived water levels at study lakes where h is equivalent to thickness and s = snow, i = ice, swe = snow water equivalence, wi = white ice, bi = black ice and w = water. Illustration is conceptual and without scale.

In attempting to filter out the primary environmental influence of snow loading on WSL, winter precipitation data were obtained from a Wyoming Snow Gauge at the Betty Pingo meteorological site. Trends in WSL at the lakes correlate well with the winter precipitation at Betty Pingo (Figures 29 to 31). Some scatter of the data is observed due to drifting of the snowpack but overall measurements of precipitation and measurements of WSL trend well. For instance, the change in WSL at control lake K113C (+ 8 cm) nearly equals the cumulative snow water equivalent detected at the Betty Pingo meteorological site (+ 9 cm) from November 1, 2003 to May 1, 2004. This is expected since there is no winter water withdrawal at K113C. A similar trend of change in WSL following winter precipitation was observed at lake K214P since little pumping occurred and water surface level change from pumping activities was expected to be less than 0.005 m. In contrast, heavily pumped lake K209P definitively showed an impact from pumping as WSL declines due to pumping.

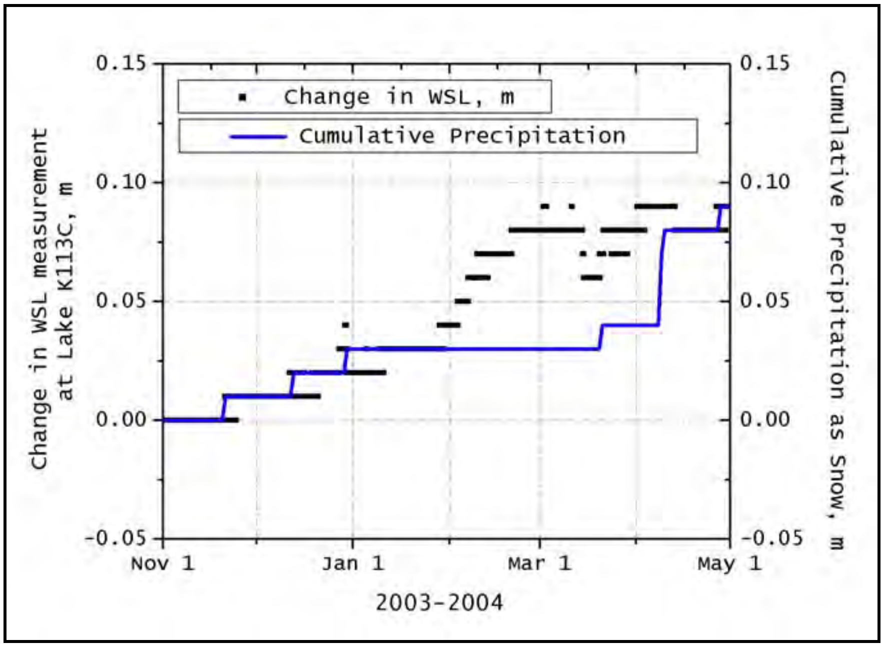

Figure 29: Change in water surface level at lake K113C compared to cumulative precipitation as snow at Betty Pingo during the 2003-2004 winter.

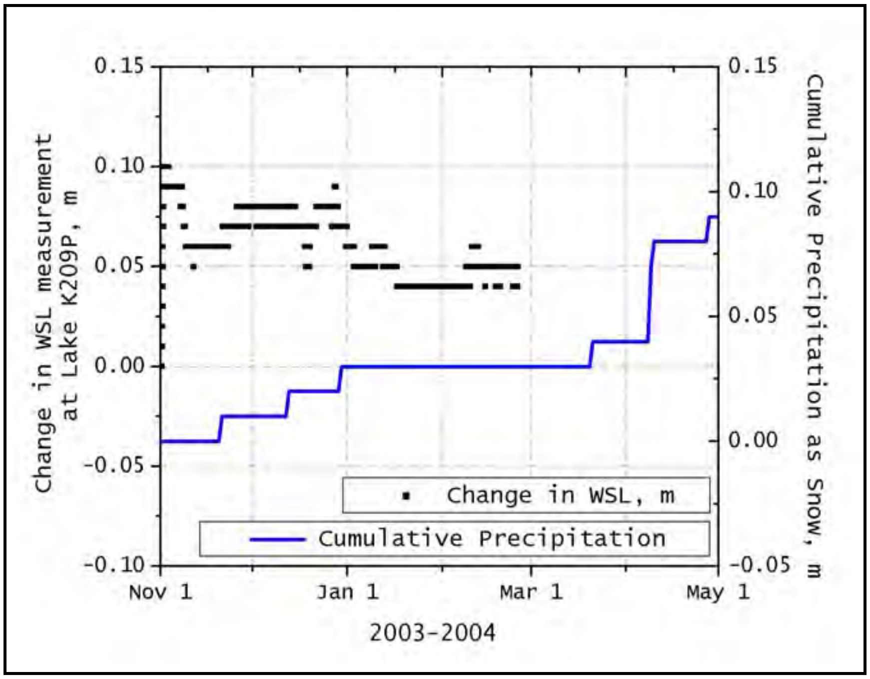

Figure 30: Change in water surface level at lake K209P compared to cumulative precipitation as snow at Betty Pingo during the 2003-2004 winter. Pressure transducers were disconnected in late-February 2004.

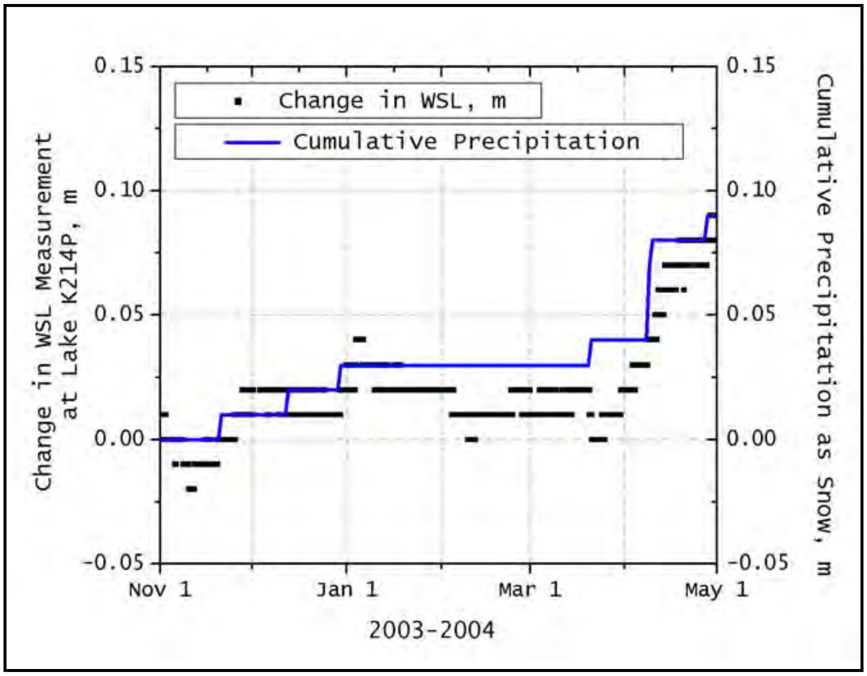

Figure 31: Change in water surface level at lake K214P compared to cumulative precipitation as snow at Betty Pingo during the 2003-2004 winter.

From a different perspective, looking at a water balance of the study lakes during the 2003-2004 winter, the results are not equivalent (Table 7). The lack of a proper water balance is a likely result of a single survey for pre-melt 2004 snow water equivalence at the lakes. Substituting a measurement of 10 cm of cumulative precipitation as snow at Betty Pingo (an average pre-melt snow water equivalence) for the average 2004 SWE, a better balance is achieved.

Table 7: Water balance at study lakes for 2003-2004 winter including detected change in WSL, expected change in WSL based on pan and cone bathymetries and local snow water equivalence.

Lake	Average 2004 SWE, cm	Expected change in 2003-2004 WSL, cm		Change in PT 2003-2004, cm (to nearest 0.5)
		Pan	Cone	
K113C	+ 7.1	0.0	0.0	+ 8.0
K214P	+ 10.0	- 0.7	- 0.8	+ 8.0
K209P	+ 11.3	- 3.1	- 12.8	+ 5.0
K203C	not operational			

LAKE RECHARGE

When investigating the effect of pumping on the study lakes, an outstanding question was, ‘Are the pumped lakes completely recharged each year after pumping by natural hydrologic processes?’. To answer this important question, surveys of recharge were conducted May to June of 2003 and 2004 during spring snowmelt - the dominant, if not exclusive, recharge mechanism for the lakes. Complete recharge was verified by surveys of outlet flow along the lake’s perimeter during spring melt. If an active outlet was observed as the lake became flooded with meltwater, the lake was determined to be completely recharged.

Complete recharge an important determination as pumped lakes might suffer from a reduction in their water volume due to water withdrawal if recharge is not of sufficient quantity. Lack of complete recharge would point towards a non-sustainable pumping practice. All study lakes, both pumped and control, were determined to be completely recharged after the spring melt periods of 2003 and 2004 (Table 8). Figures 32 to 35 illustrate the approximate inlet and outlet locations at each lake observed during 2003 and 2004 spring melt. Specific coordinates of outlets and inlets are given in Table 25 in the Appendix. Select representative photographs of flowing outlets are also given in Figures 76 to 79 in the Appendix. Also quantified in the Appendix: the pre-melt snowpack leading to complete recharge in Tables 26 to 28, the ablation of the snowpack in Tables 29 to 32 and snow survey data and locations in Tables 33 and 34.

Pre-melt snow surveys were conducted May 13-18, 2003 and May 20–22, 2004 at the study lakes. Snowpack was quantified around the perimeter of each study lake at three or four locations and on the lake surface itself. The survey locations were the same in 2003 and 2004. Ablation at K113C Index (referenced as ‘K113C SS1’ and located 500 m north of the lake K113C) and Betty Pingo was monitored daily until the snowpack was depleted.

Observation of lake inlets and outlets occurred immediately after runoff began. Inlet and outlet locations were logged using a Global Positioning System tied to the WGS84 datum. ‘Inlet’ and ‘outlet’ refer to well-defined channel flow with water depth exceeding 0.15 m. ‘General inflow’ and ‘general outflow’ refer to overland flow with maximum water depth not exceeding 0.15 m. Inlet and outlet locations were at similar locations during both 2003 and 2004 recharge surveys.

‘Flooding’ refers to an indeterminate general inflow and/or general outflow.

Table 8: Summary of recharge surveys.

Lake	Complete Recharge?	Recharge Source	Number of Outlets	Number of Inlets	Years surveyed
K113C	Yes	meltwater	2	3	2003 & 2004
K203C	Yes	meltwater	1	3	2003
K214P	Yes	meltwater	3	1	2003 & 2004
K209P	Yes	meltwater	3	3	2003 & 2004

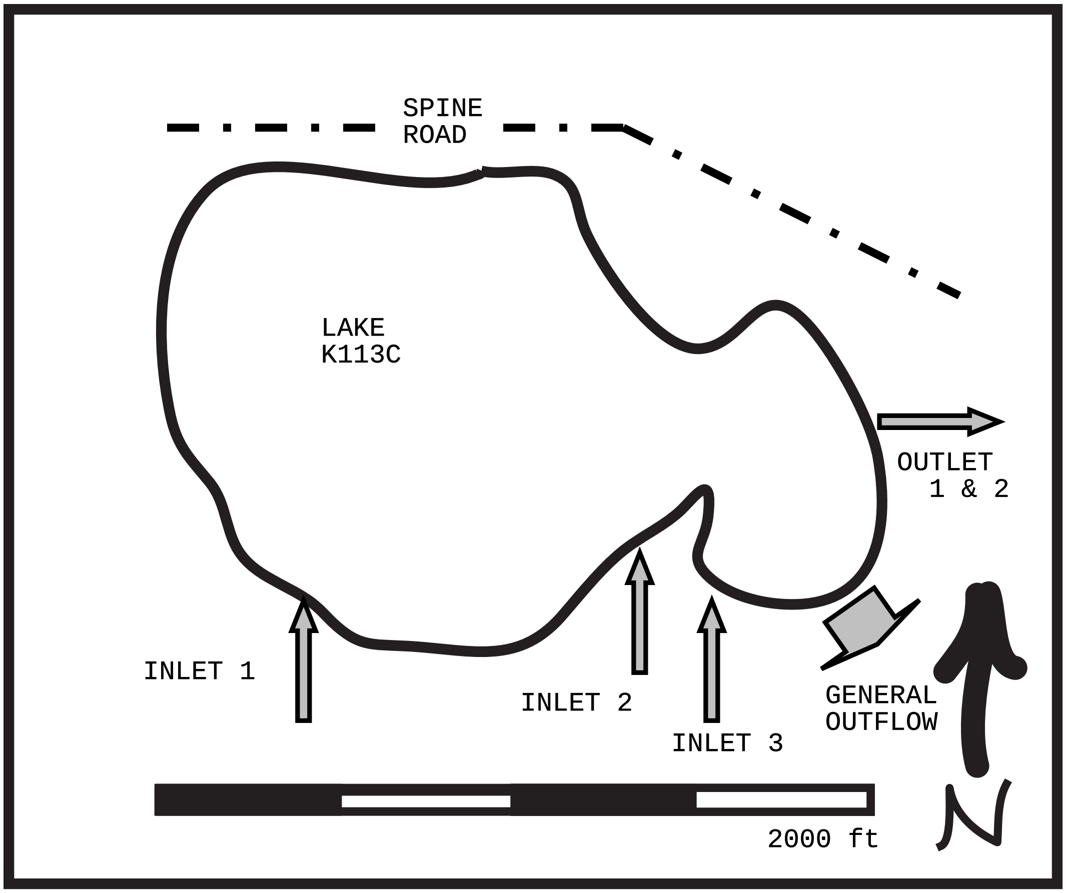

Figure 32: Illustration of flow following spring melt at control lake K113C.

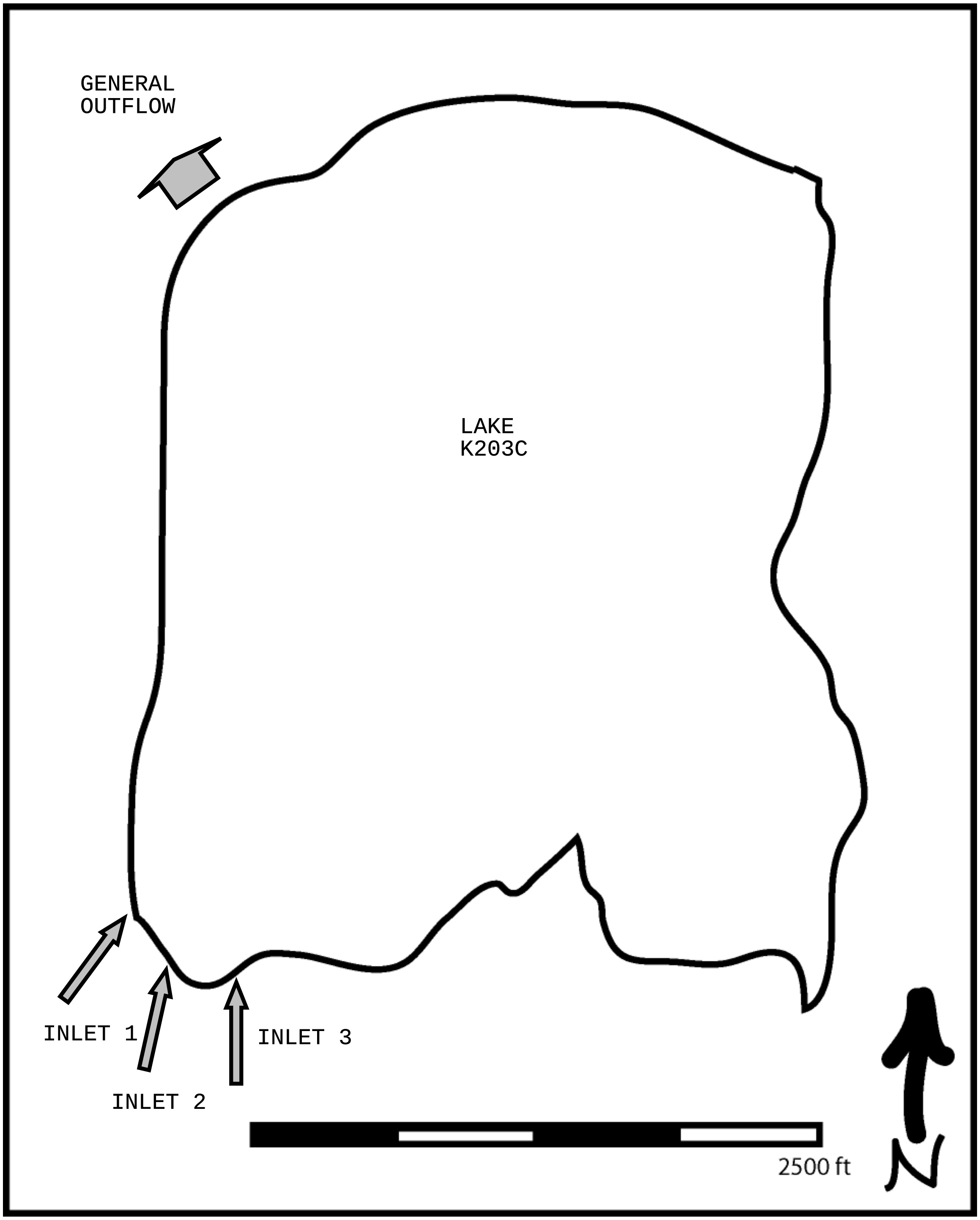

Figure 33: Illustration of flow following spring melt at control lake K203C.

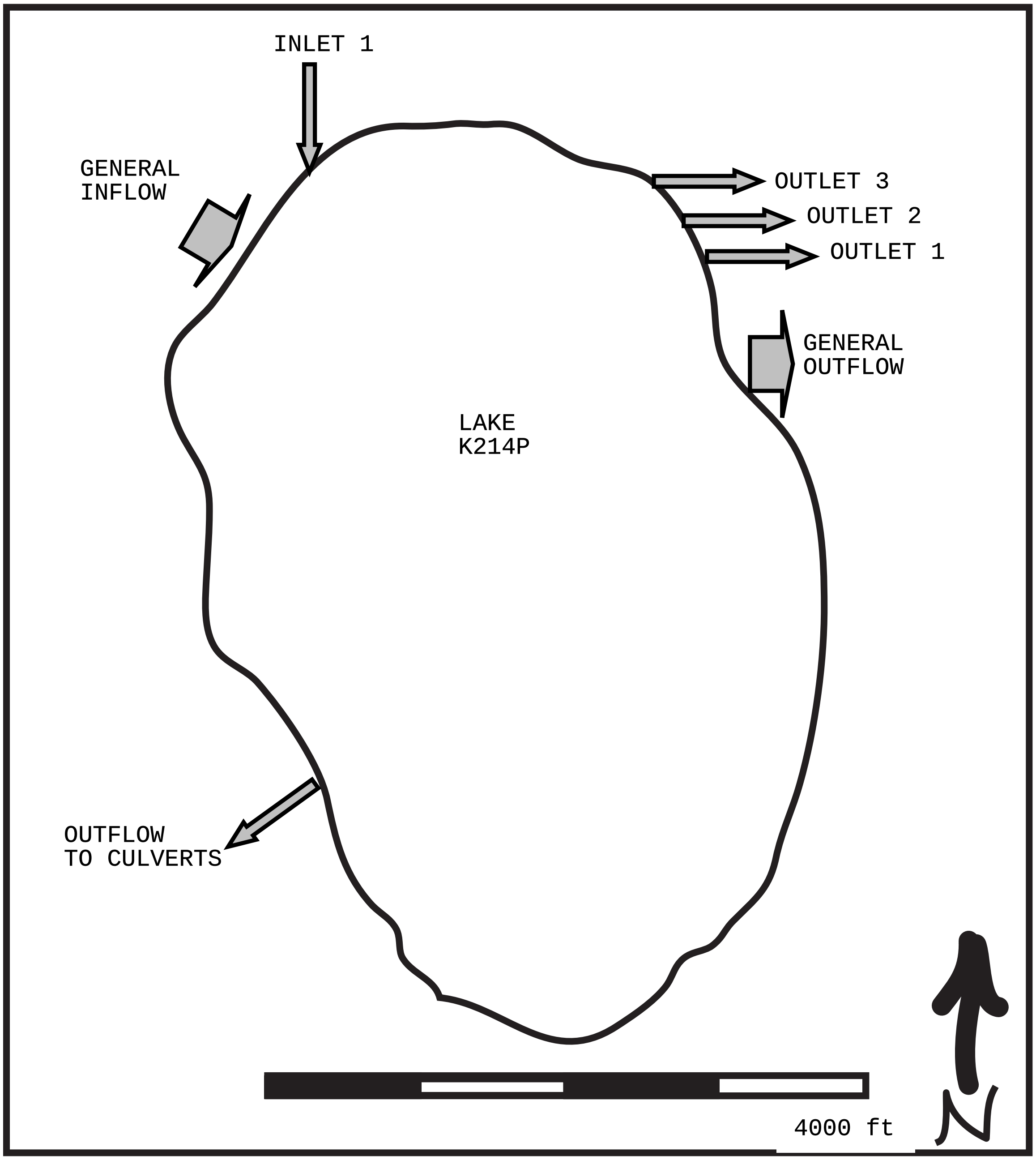

Figure 34: Illustration of flow following spring melt at pumped lake K214P.

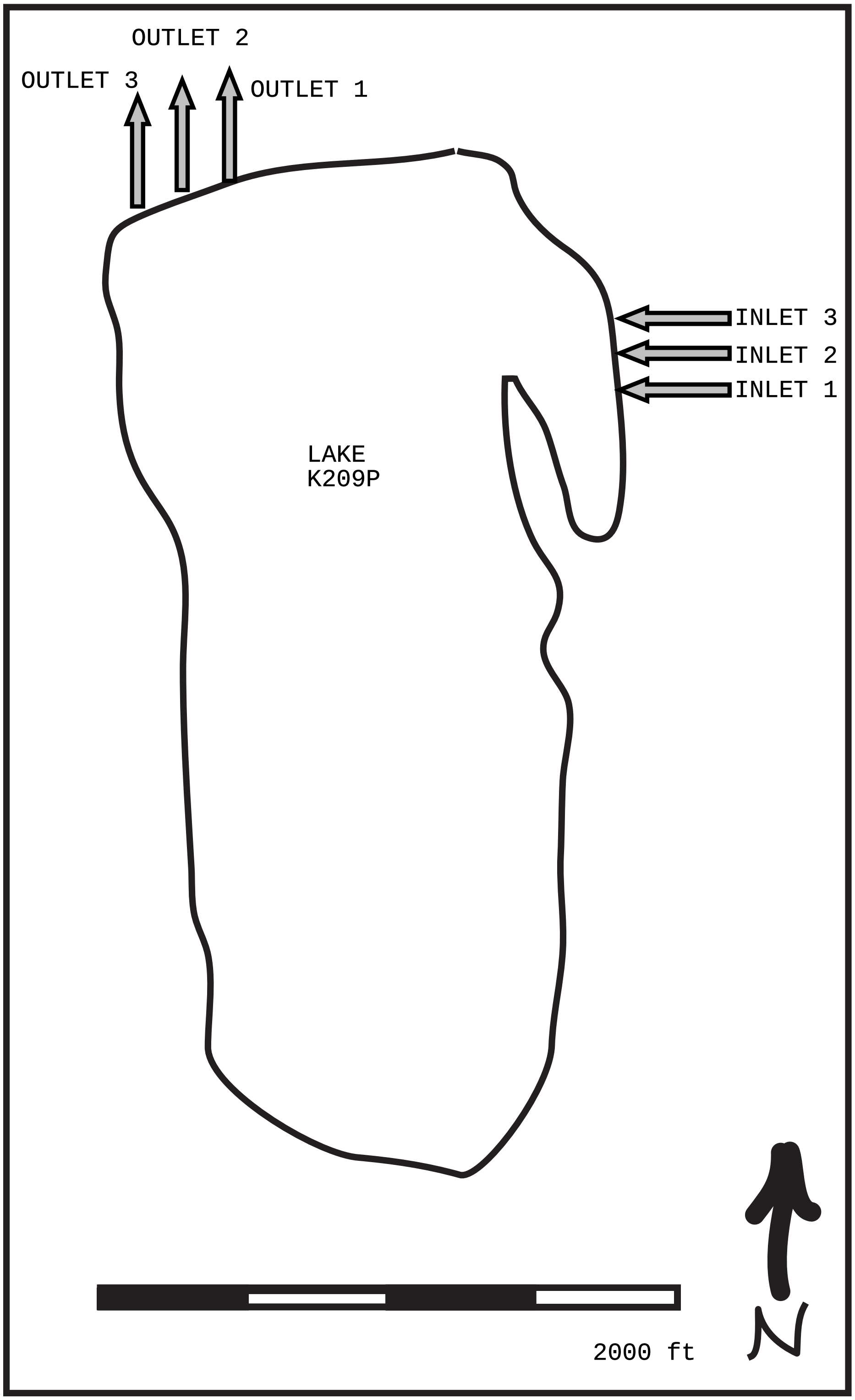

Figure 35: Illustration of flow following spring melt at pumped lake K209P.

WATER SURFACE LEVEL

Water surface levels (WSL) are presented at each study lake while the pressure transducers used to record WSL were operating under-ice and the raft was still in a fixed position (i.e. after ice formation but before spring breakup). Table 9 shows the initial WSL at each study lake referenced to British Petroleum Mean Sea Level (BPMSL) for the 2002-2003 and 2003-2004 winter data collection periods.

Table 9: Water surface levels at Kuparuk study lakes referenced to BPMSL.

Lake	WSL at beginning of 2002-2003 winter data collection (mid-February 2003), m	WSL at beginning of 2003-2004 winter data collection (November 1, 2003), m
K113C	16.240	16.375
K203C	25.315	not operational
K209P	23.640	23.245
K214P	24.860	25.160

WSL is reduced to an elevation change in the pressure transducer measurement in long term plots. The zero value when reducing the data was taken as the initial value after the sensor had stabilized. Viewing WSL by change in elevation rather than WSL referenced to sea level eliminates some survey error and gives more confidence when determining the effects of water withdrawal on WSL at pumped lakes. The method also has the advantage of allowing for finer resolution of

WSL in comparison plots, which helps when attempting to detect small changes between pumped and control lakes.

Figures 36 to 39 show the change in measured WSL at study lakes for the 2002-2003 and 2003-2004 winters. No correction is applied for snow loading. The zero WSL value is taken to be 24 hours after station installation for the 2002-2003 winter and 0:00 AM November 1, 2003 for the 2003-2004 winter. Values of WSL change were processed to remain consistent when sensors were replaced in mid-winter. Winter precipitation is treated on a similar basis of change in most plots and the assumed zero values are identical.

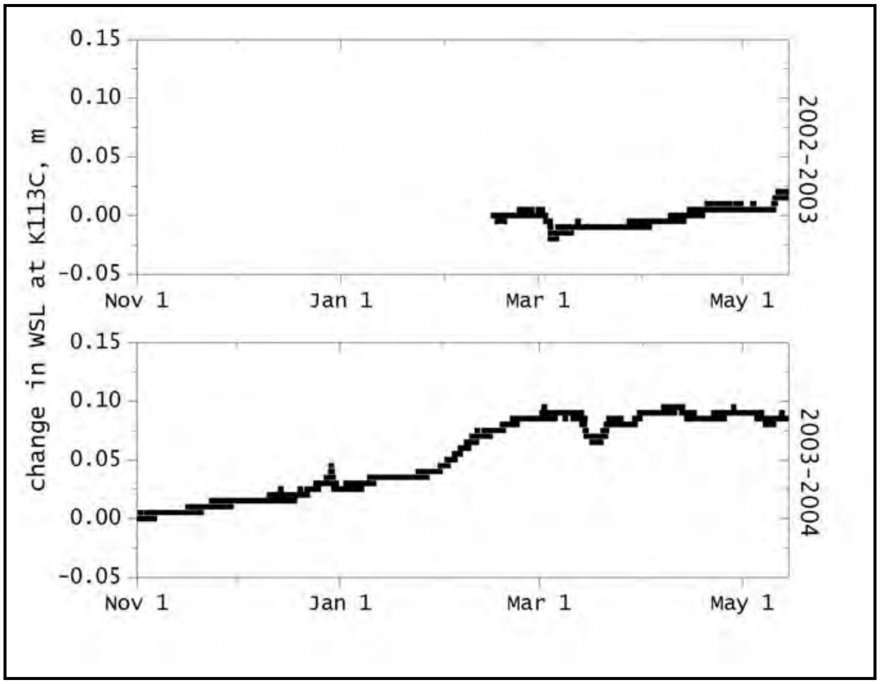

Figure 36: Change in water surface level at control lake K113C throughout 2002-2003 and 2003-2004 winter data collection periods.

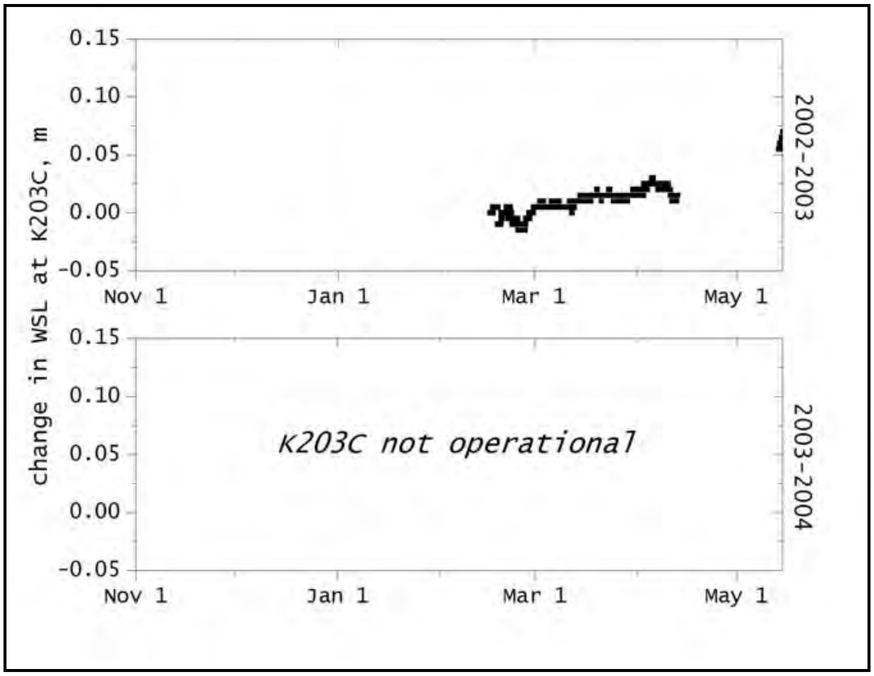

Figure 37: Change in water surface level at control lake K203C throughout 2002-2003 and 2003-3004 winter data collection periods. The 2003 data gap was due to temporary loss of telemetry.

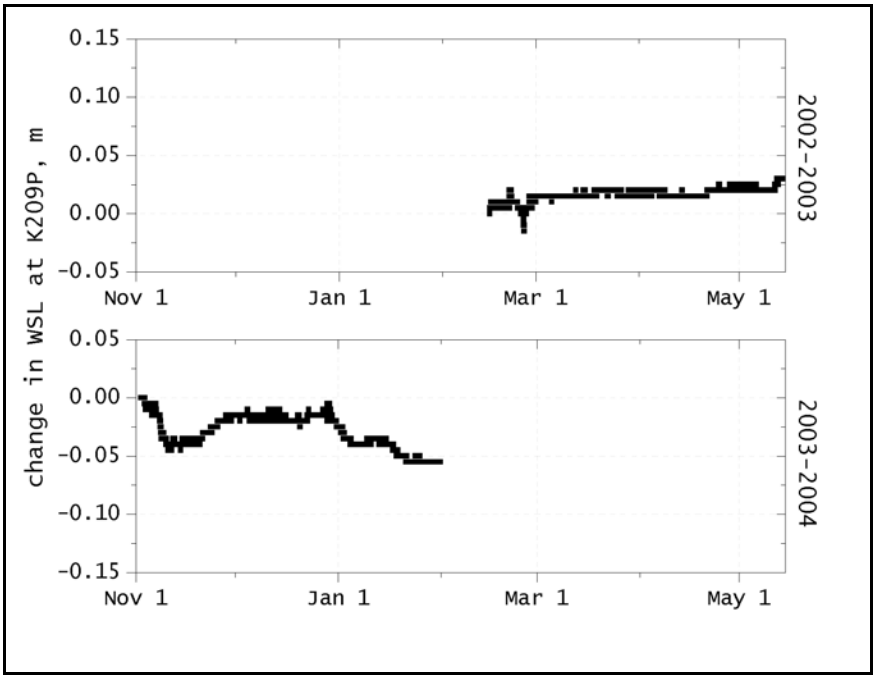

Figure 38: Change in water surface level at pumped lake K209P throughout 2002-2003 and 2003-3004 winter data collection periods. The pressure transducer at K209P was disconnected in late-February 2004.

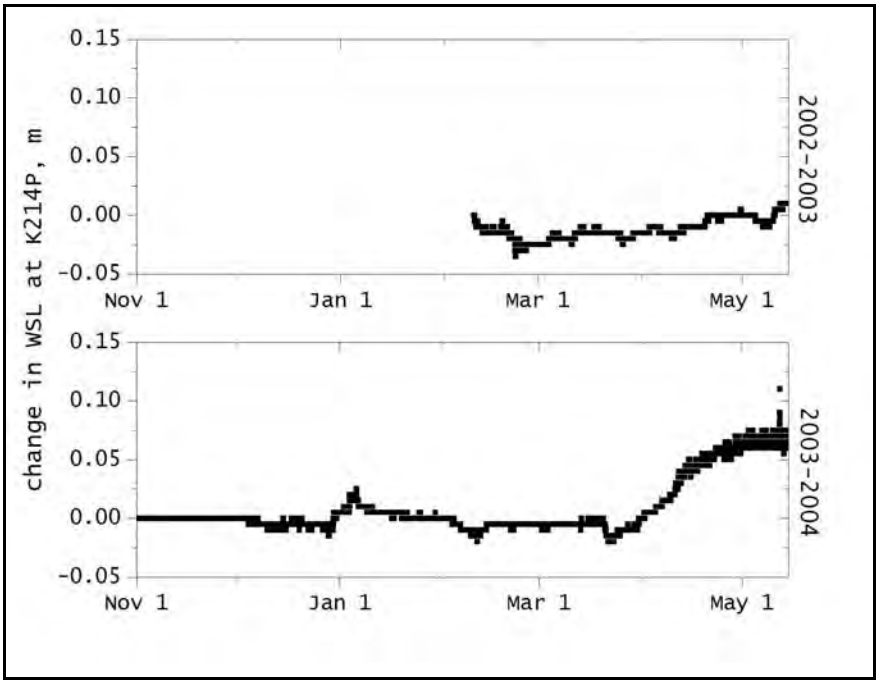

Figure 39: Change in water surface level at pumped lake K214P throughout 2002-2003 and 2003-2004 winter data collection periods.

Readily apparent in the WSL measurements is an increasing trend at K113C, K203C and K214P. The trend follows precipitation as snow collects on top the lake ice surface. Although K209P does indeed receive a similar load of snow, it was heavily pumped as a freshwater resource in 2004, so K209P does not see the same response to snow loading as the other lakes, which were not pumped, or only in a very limited capacity (i.e. K214P in Figure 41). K209P shows a cumulative change in WSL due to pumping. This is a detected change due to significant pumping activity at lake K209P. Further, the detected WSL change at K209P is between the pan and cone bathymetry estimations of WSL change as expected (Figure 40).

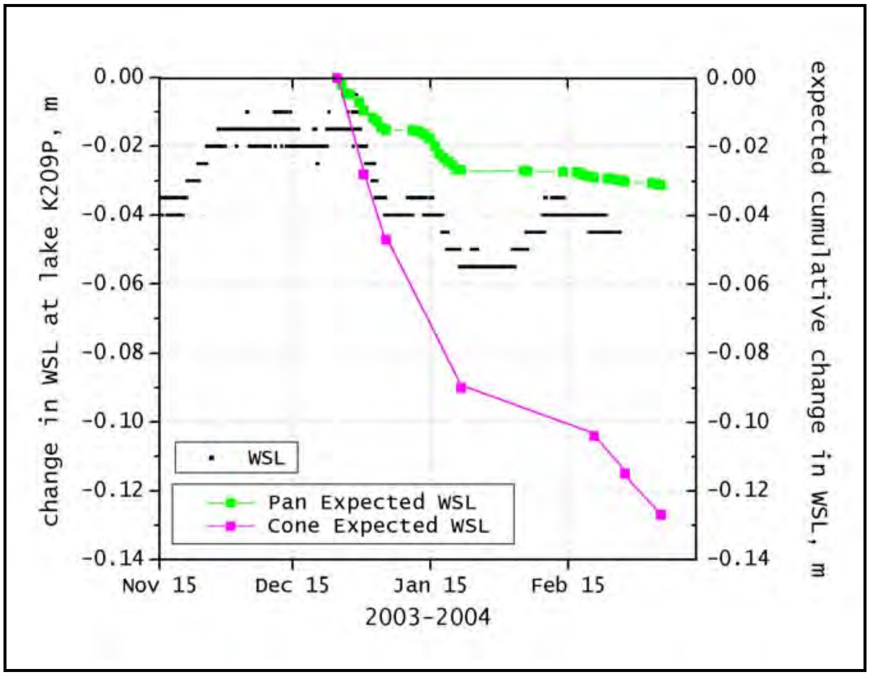

Figure 40: Detected change in WSL at K209P shown with expected cumulative change in WSL due to pumping calculated from idealized pan and cone bathymetries.

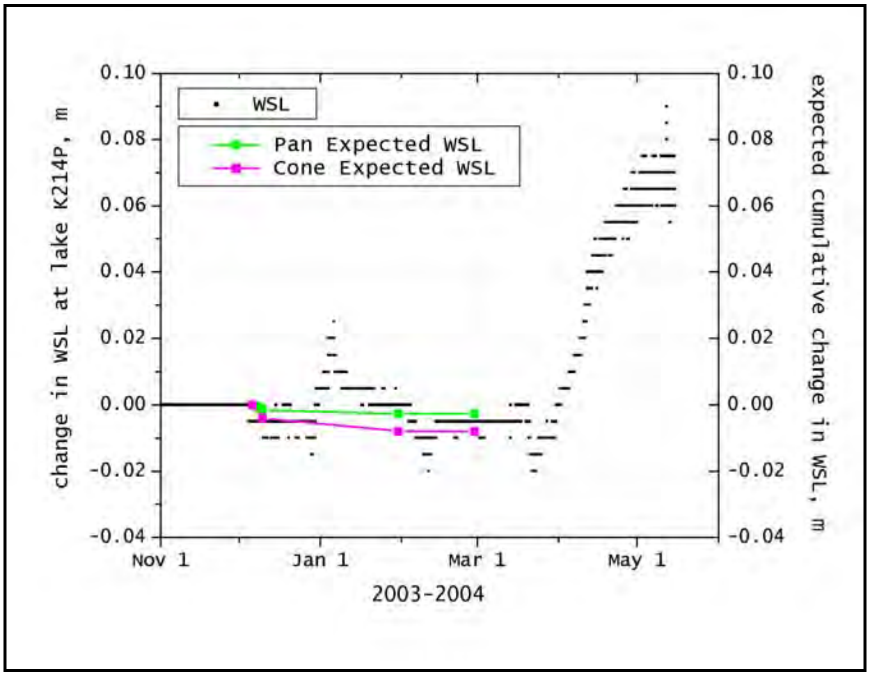

Figure 41: Detected change in WSL at K214P shown with expected cumulative change in WSL due to pumping calculated from idealized pan and cone bathymetries.

Water surface levels at pumped lakes are compared with control lakes in Figures 42 to 46. The lakes are examined at periods of heavier pumping activity. Attention is given to K209P in the 2003-2004 winter since it experienced more frequent and greater pumping activity than K214P (Tables 10 and 11). Daily pumping volumes as well as recorded precipitation as snow measurements are also shown in the figures. All WSLs are referenced to British Petroleum Mean Sea Level (BPMSL).

Table 10: Defined periods of pumping activity at K209P and water withdrawal volume.

LAKE K209P	
Time Period	Water withdrawal volume, m^3
2/13/2003 - 2/15/2003	795.7
12/25/2003 - 12/28/2003	6,587.3
12/30/2003 - 12/31/2003	6,668.9
1/2/2004 - 1/5/2004	7,731.4
1/11/2004 - 1/22/2004	16,588.2
2/17/2004 - 2/21/2004	2,408.6
2/24/2004 - 2/28/2004	1,669.4
3/5/2004 - 3/7/2004	1,419.0

Table 11: Defined periods of pumping activity at K214P and water withdrawal volume.

LAKE K214P	
Time Period	Water withdrawal volume, m^3
4/1/2003 - 4/30/2003	842.6
12/7/2003 - 12/10/2003	3,155.9
1/1/2004 - 1/31/2004	2,539.5
2/1/2004 - 2/29/2004	77.5

Notable in the plots is the most active pumping period of the past two winters for any lake; 16,588 cubic meters of water were removed from lake K209P from January 11-22, 2004. The expected drop in WSL for this event is -0.012 m, a conservative estimate based on ideal pan bathymetry. K209P shows a detected response of -0.02 m in WSL for the event while control lake K113C shows a response of +0.005 m (Figures 46). This validates the ability of online, continuously recording transducers to accurately measure and gauge water withdrawal.

Response in WSL due to pumping can be analyzed in two ways: (1) From a water balance perspective where detected change in WSL should equal the expected change in WSL summed with the change in precipitation, or (2) in direct comparison to the control lake WSLs. Quantitatively, alternative 1 is preferred, while qualitatively, alternative 2 is preferred. In the following analyses both alternatives are examined, however some preference should be given to alternative 2 later in the winter since the projected bathymetry of the remaining water with significant ice depth is difficult to quantify due to highly variable bottom contours without detailed bathymetry across the lakes.

Figure 42 illustrates the WSL response to pumping activity at K214P from December 7-10, 2003. Cumulatively, 3155.9 m³ of water was withdrawn from lake K214P during the time period, corresponding to an expected change in WSL of -0.002 m and -0.004 m for pan and cone bathymetries respectively, both of which are below the pressure transducer sensors’ 0.005 m resolution. Thus, in Figure 42, no significant difference between pumped and control lake is observed as expected.

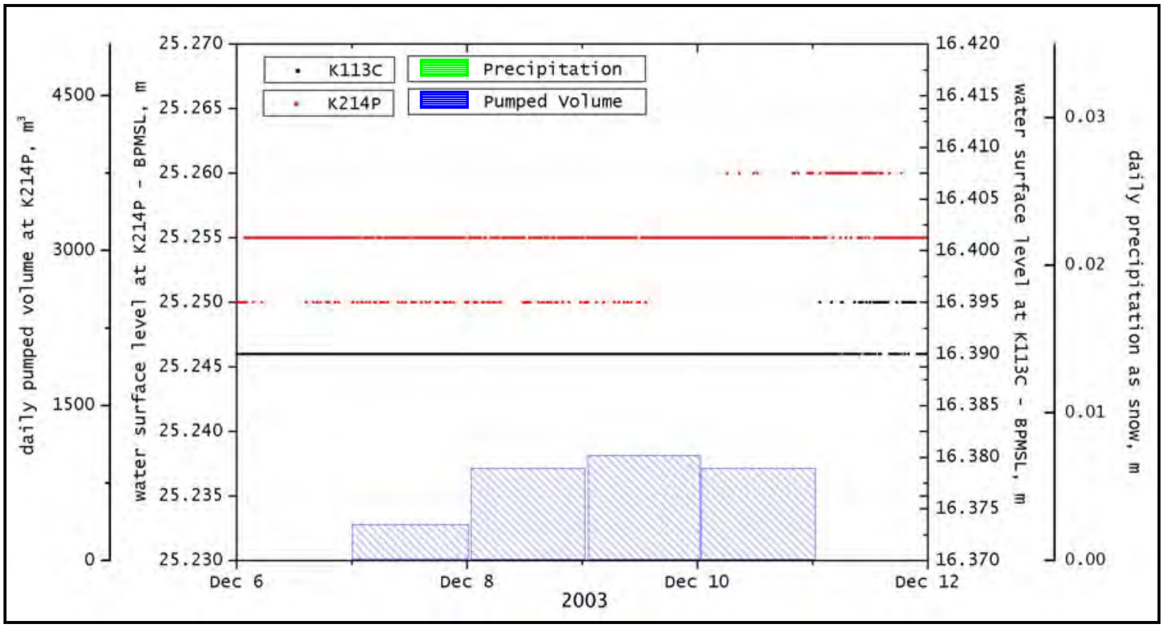

Figure 42: Water surface level at pumped lake K214P during pumping activity December 7-10, 2003 compared to WSL at control lake K113C. Daily precipitation values were taken from the Wyoming Snow Gauge at Betty (no precipitation was recorded in the time period).

In Figure 43, control lake K113C shows an increase of +0.010 m while pumped lake K209P only shows an increase of +0.005 m. The -0.005 m difference at K209P is due to the cumulative water withdrawal or 6597.3 m³ during the time period. The expected change in WSL from 6597.3 m³ of water withdrawal is -0.005 m and -0.014 m based on pan and cone bathymetries respectively. Thus, the water withdrawal at K209P shows the detected response due to pumping agreeably meeting the expected response to pumping. Further, the expectation of WSL in early winter favors a pan bathymetry as previously summarized.

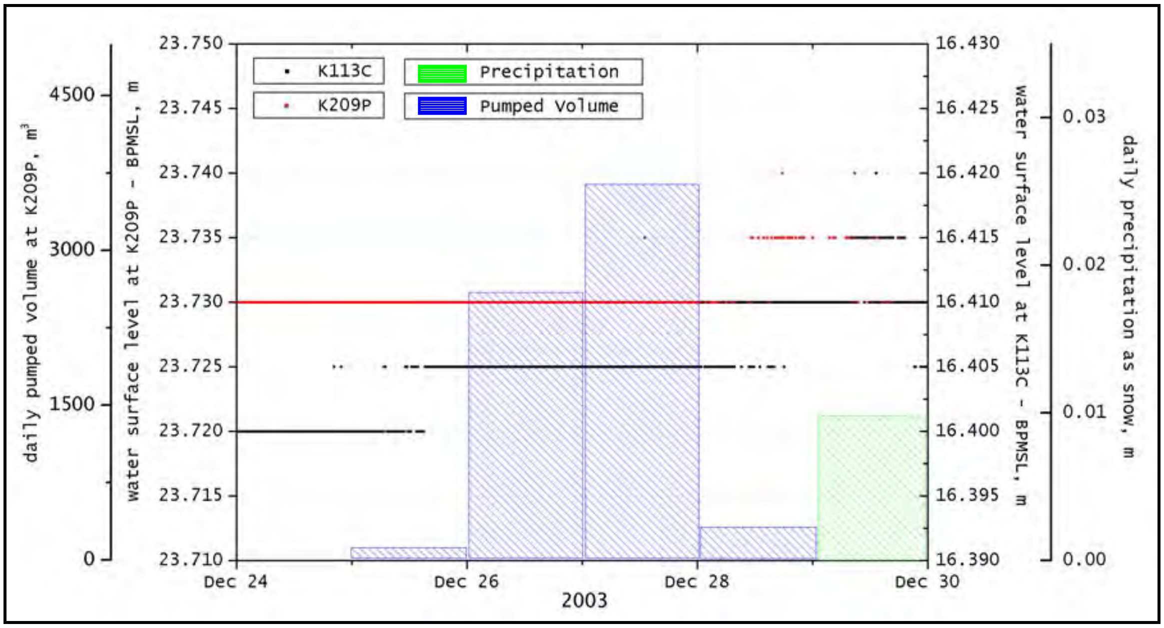

Figure 43: Water surface level at lake K209P during pumping activity December 25-28, 2003 compared to WSL at control lake K113C. Daily precipitation values are taken from the Wyoming Snow Gauge at Betty Pingo (precipitation was recorded December 29, 2003).

Figure 44 shows both control and pumped lake responding to the +0.010 m precipitation input detected at the Wyoming Snow Gauge at Betty Pingo as WSL at both lakes increases +0.005. Thereafter, both lakes see a corresponding decline in WSL, which is unexpected. The expected change in water surface level at K209 in response to the 6668.9 m^3 water withdrawal is -0.005 m based on a pan bathymetry and -0.015 m based on a cone bathymetry. K209P does show the expected decrease of -0.010 m after the pumping event, but a -0.010 m decrease is also seen at K113.

Discrepancies such as this would have benefited from second instrumented control lake as was planned, but was not operational.

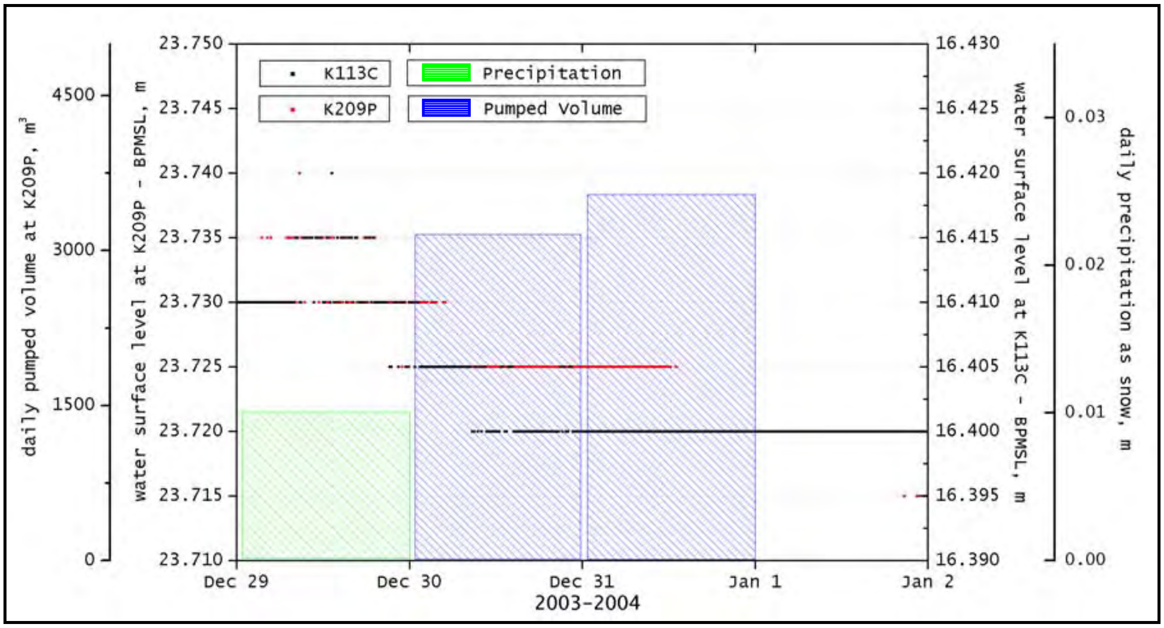

Figure 44: Water surface level measurements at pumped lake K209P during pumping activity December 30-31, 2003 compared to control lake K113C. Daily precipitation values are taken from the Wyoming Snow Gauge at Betty.

Figure 45 shows the expected response to pumping. K209P WSL decreases by -0.015 m while K113C remains generally steady with the lack of any precipitation input. The expected cumulative change in water surface level at K209P in response to the 7731.4 m^3 water withdrawal is -0.006 m based on a pan bathymetry and -0.018 m based on a cone bathymetry.

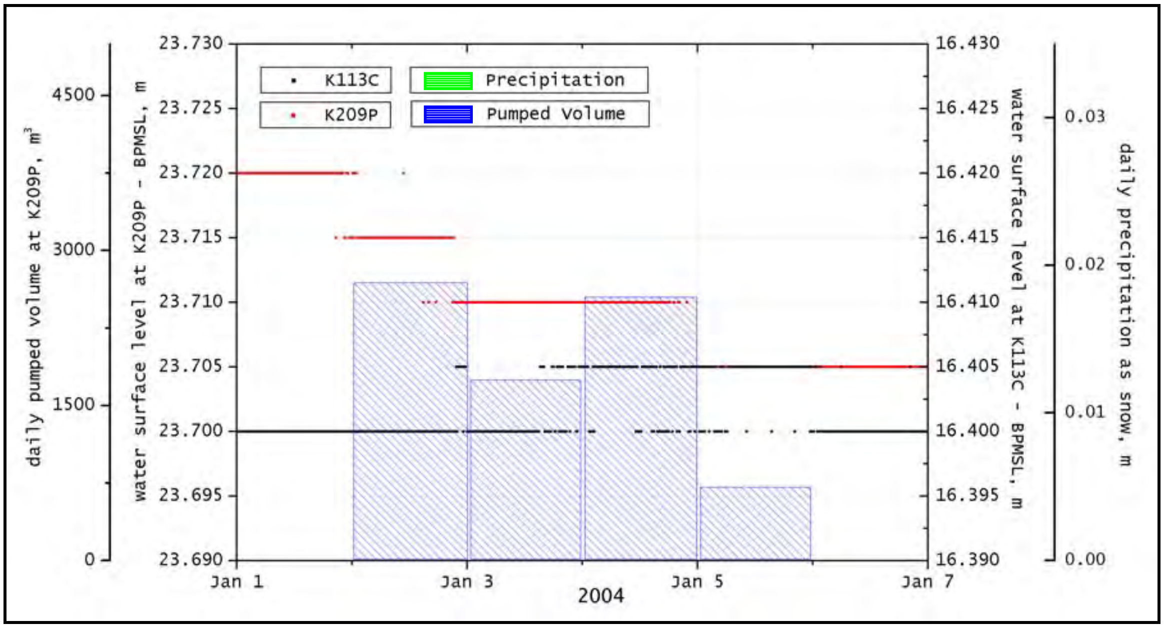

Figure 45: Water surface level measurements at lake K209P during pumping activity January 2-5, 2004 compared to control lake K113C January 2-5, 2004. Daily precipitation values are taken from the Wyoming Snow Gauge at Betty (no precipitation was recorded in the time period).

In Figure 46, sustained and heavy pumping activity January 10-21, 2003 provides an excellent opportunity to view responses to pumping. The expected cumulative change to the 16,588.2 m^3 water withdrawal is -0.012 m based on a pan bathymetry and -0.044 m based on a cone bathymetry. K209P shows a decrease of -0.020 m, which agrees well with the expected WSL change. K113C shows a strong baseline during this period and exhibits good control.

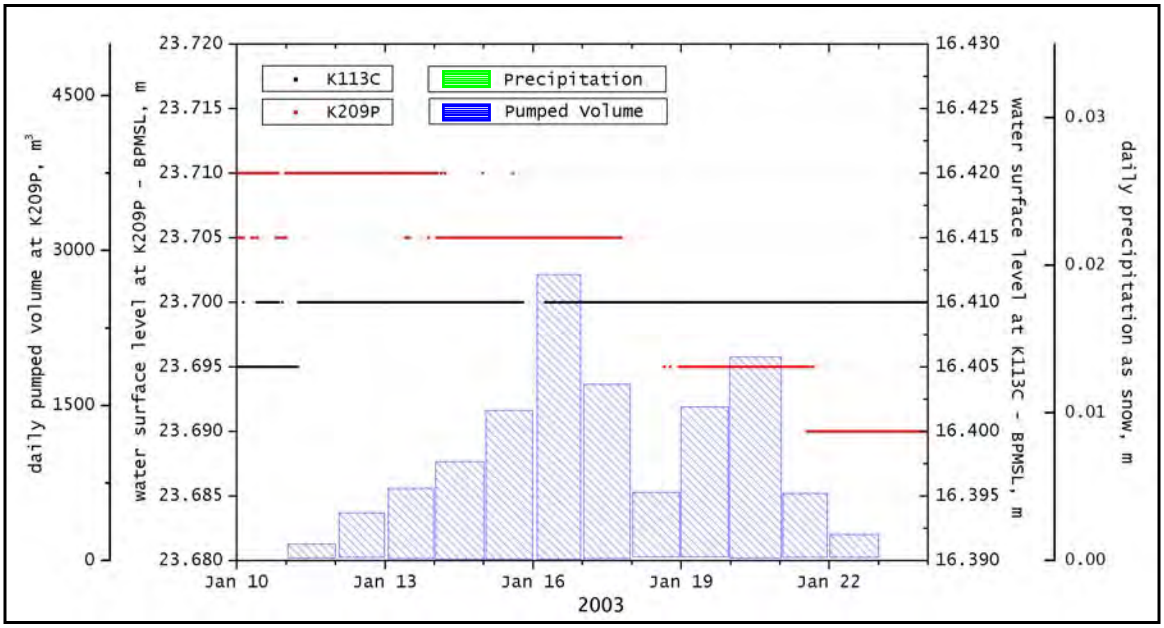

Figure 46: Water surface level measurements at lake K209P during pumping activity January 11-22, 2004 compared to control lake K113C January 11-22, 2004. Daily precipitation values are taken from the Wyoming Snow Gauge at Betty (no precipitation was recorded in the time period).

SPECIFIC CONDUCTANCE

Specific conductance (SC) in arctic lakes is driven by the ice exclusion process during the winter. As the ice grows throughout the freezing season, salts are rejected from the ice into the remaining water below the ice. The ice exclusion process is remarkably efficient as most impurities are excluded during the phase change. It is assumed that the entire mass of solutes within the ice generated is rejected into the under-ice water (Smith, 1999).

In shallow lakes like tundra lakes, the results of ice exclusion are magnified due to the small volumes of water remaining under the relatively large volumes of ice towards the end of winter. The expected result is that lakes with shallower bathymetries will see a faster rise in SC than those lakes with deeper bathymetries. This expectation was shown to be true for the winter 2002-2003 data collection period - February 2003 to May 2003 – with K113C, the deepest lake with a maximum depth of 2.3 m, showing lower SC at the end of winter than the shallower lakes K203C, K209P and K214P with maximum depths of 1.88, 1.86 and 1.75 m respectively.

Figures 47 to 50 show SC measurements throughout the 2002-2003 and 2003-2004 winters at the study lakes. Manual measurements taken during site visits are also given to verify continuous readings in the figures and in Table 35 in the Appendix. Manual measurements agree reasonably well with continuous measurements. The likely source of measurement difference is the vertical differences in concentrations in the water column and lateral differences in concentrations across the lake. Late winter manual measurements are likely higher due to inadvertent agitation of the sediments when sampling. Figures 51 and 52 compare each study lake for SC during the 2002-2003 and 2003-2004 winters.

Notable in the continuous measurements are the 2003-2004 winter readings at lake K209P (Figure 49). SC sees a large exponential increase later in the winter and then goes offline March 21, 2004. The measurements are an observation of minimal under-ice water volume with high salinity and then ice growth eventually intersecting the SC sensors.

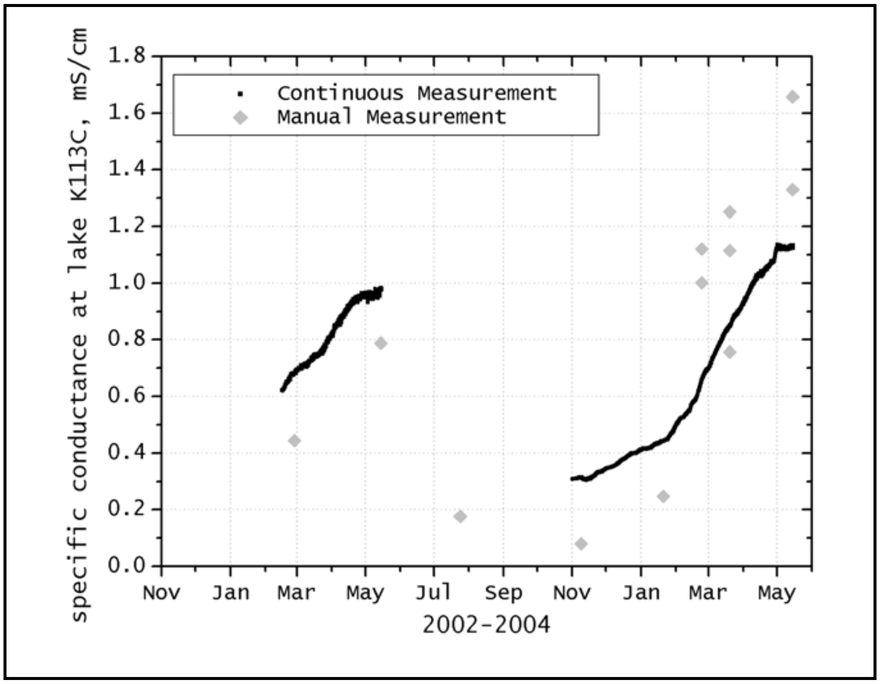

Figure 47: SC measurements at control lake K113C throughout the entire data collection effort.

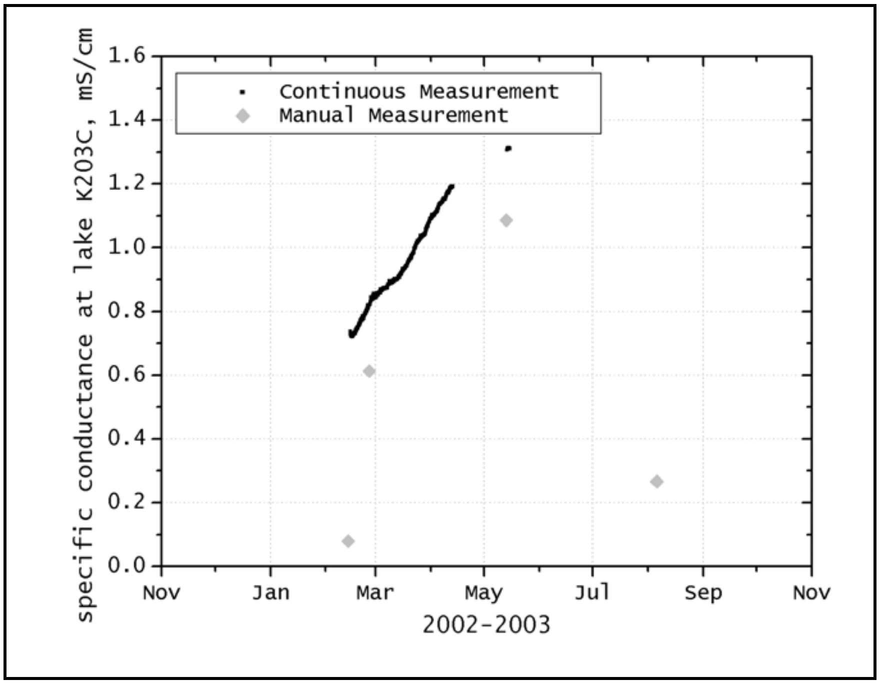

Figure 48: SC measurements at control lake K203C throughout entire data collection effort. The 2003 data gap is due to a loss of telemetry. The station was not operational for 2003-2004.

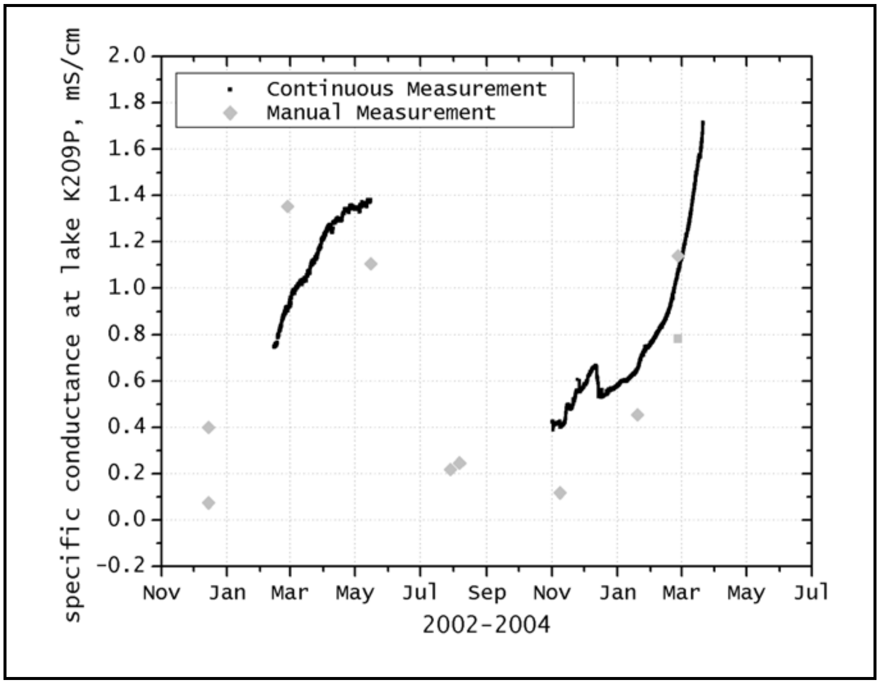

Figure 49: SC measurements at pumped lake K209P throughout the entire data collection effort.

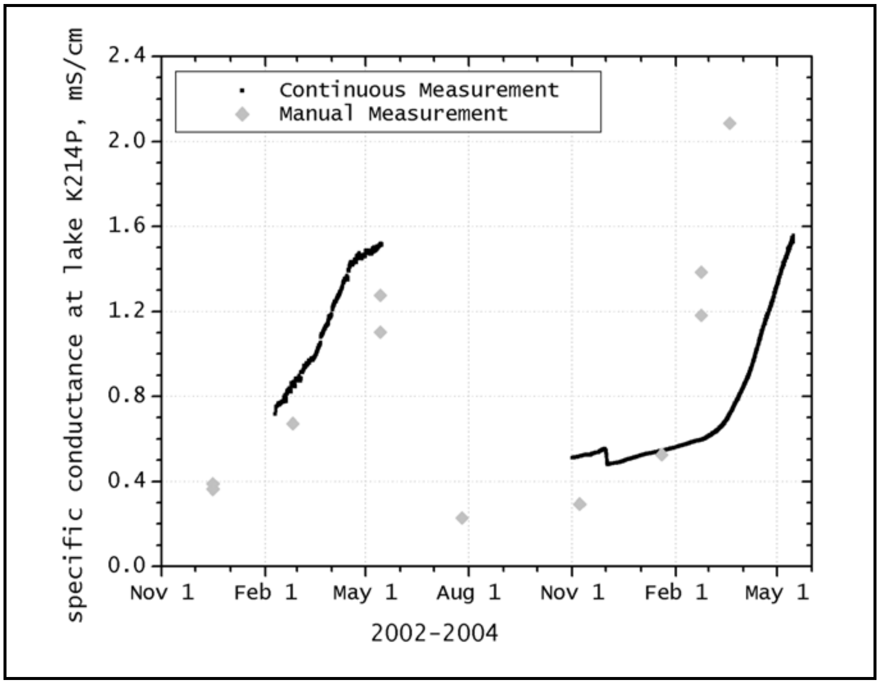

Figure 50: SC measurements at pumped lake K214P throughout entire data collection effort.

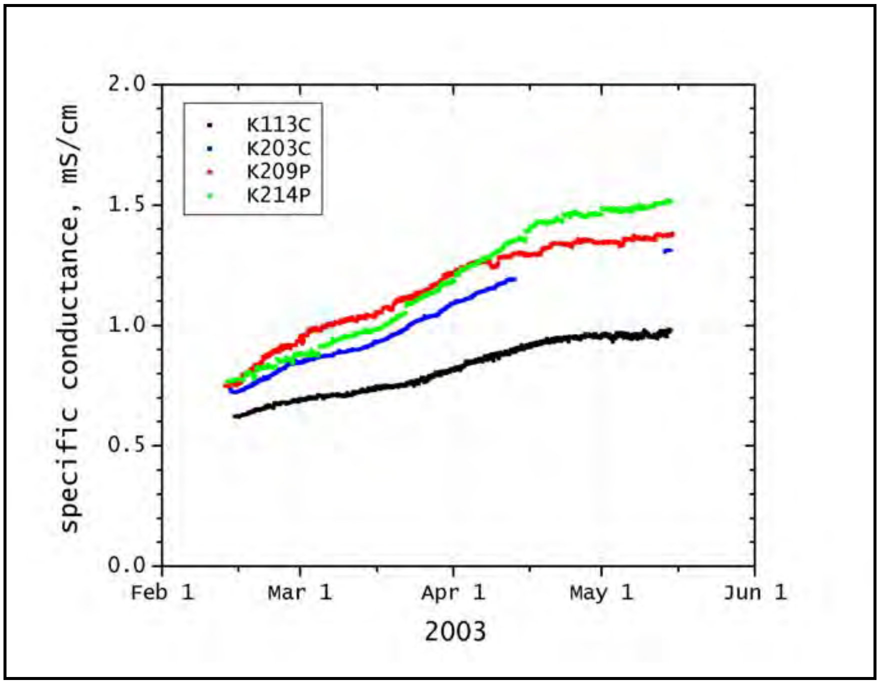

Figure 51: Comparison of SC at study lakes throughout 2002-2003 winter data collection.

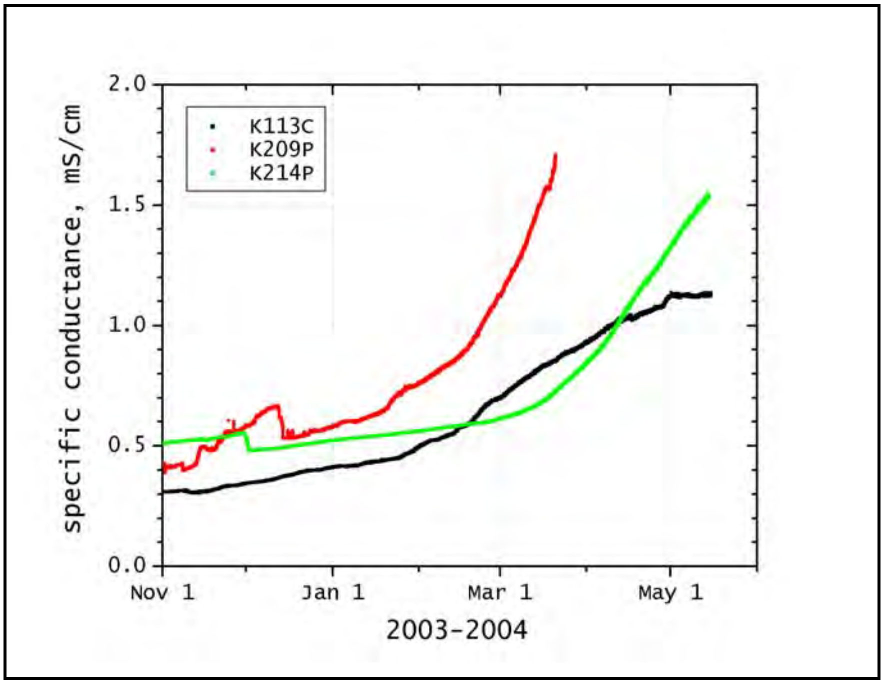

Figure 52: Comparison of SC at study lakes throughout winter 2003-2004 data collection period.

Another interesting feature in Figure 52 is seen at pumped lakes K209P and K214P when SC sees a sudden drop over about a 36-hr period in mid-December 2004 and early-December 2004 respectively (Figure 53). Both lakes show about a significant decrease in SC. This observation is unexpected since the sensor is under-ice and should show an increasing trend from the solutes excluded from the ice. It is unlikely the drop is a result of pumping since no pumping had yet occurred for the 2003-2004 winter. Possibly, the sensors are seeing intruding lower SC snow from atop the ice migrating through fractures in the ice from ice bridging in the early winter.

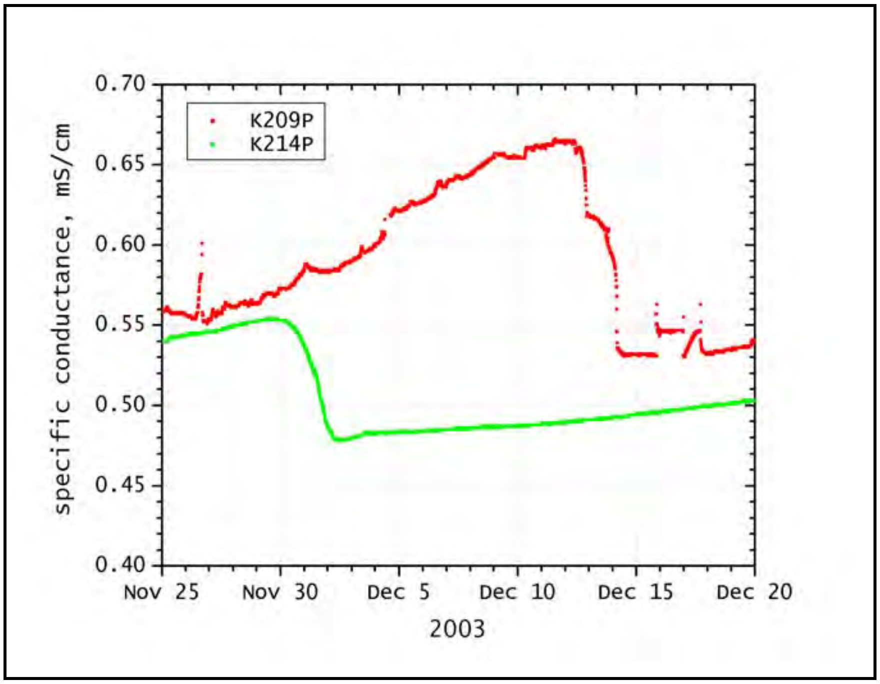

Figure 53: Drop in SC at lakes K209P and K214P.

An important question, similar to whether tundra lakes are hydrologically recharged by spring meltwater, is are tundra lakes chemically reset by spring meltwater? This is an important determination because if the chemistry of tundra lakes is impacted by pumping, then cumulative impacts to chemistry would occur if not chemically reset each spring. Figure 54 shows the response in SC at the study lakes to the introduction of meltwater in the spring of 2003.

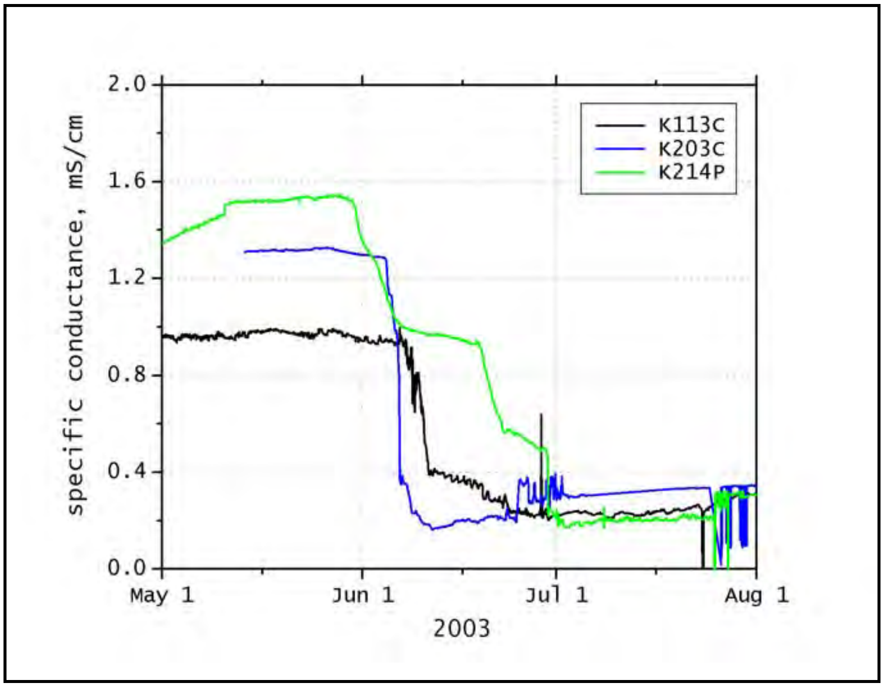

Figure 54: Spring 2003 chemistry flush at study lakes.

The drop in SC at the study lakes in late-May and early-June shows the input from meltwater runoff. The lakes see a decline in SC until the beginning of July when the instrumented stations broke free of the ice and moved to shore by strong winds. After July, the lakes show a gradual increase of SC due to summer evaporation.

Figure 54 therefore illustrates that the study lakes, both pumped and control, are chemically reset by spring meltwater. Essentially the under-ice water is flushed out by the runoff input. The runoff input is of course derived from the winter’s snowfall and is thus at a much lower SC than the under-ice water, which is subject to ice exclusion processes. Figure 54 shows measurements of SC at pumped and control lakes decreasing with meltwater input until the lake system is completely flushed, and thereafter gradually increasing due to summer evaporation. Thus, any chemical impact from pumping would not be cumulative over pumping seasons since the both pumped and control lakes were observed have their lake water essentially chemically reset by spring runoff.

Figures 55 to 59 compare SC at control and pumped lakes during selected periods of heavier pumping. Daily water withdrawal volumes are illustrated in the figures. Although there are some apparent correlations of increasing SC near pumping events, the trend is inconsistent overall. More precise records of exact pumping times and durations would benefit future analyses.

Figure 55 presents SC measurements at lake K214P during pumping activity December 7-10, 2003 compared to control lake K113C. Both lakes show the similar trend of increasing SC due to growing ice and solute exclusion as expected. No effect from pumping is apparent.

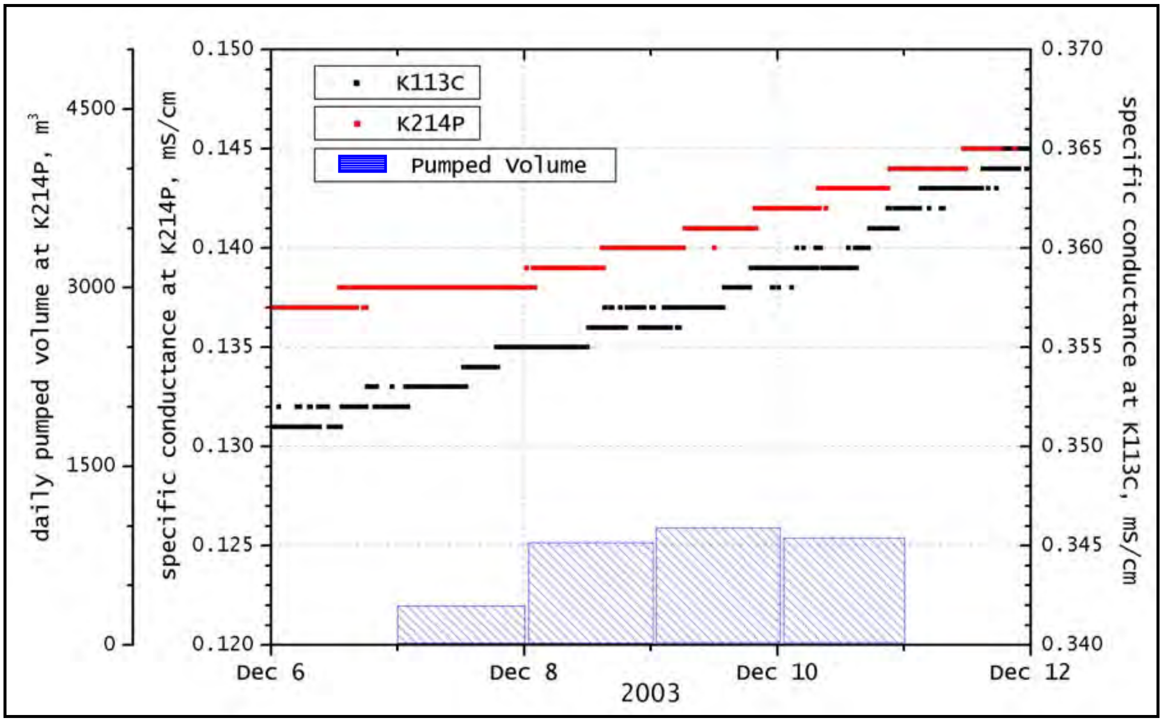

Figure 55: SC measurements at lake K214P during pumping activity December 7-10, 2003 compared to control lake K113C.

Looking at Figure 56, which details SC measurements at lake K09P during pumping activity December 25-28, 2003, an initial observation in SC at K209P is variable increases and decreases in SC measurements. These fluctuations may be a response in SC to pumping, but the increase and decrease is within the variance of the SC sensor so cannot be treated as significant. The fluctuations in SC are generally within +/- 2% of the mean values, which is within the sensors’ 5% accuracy tolerance. Thus, rapid increases and decreases in SC may be due to the accuracy tolerance of the sensor, not pumping activity.

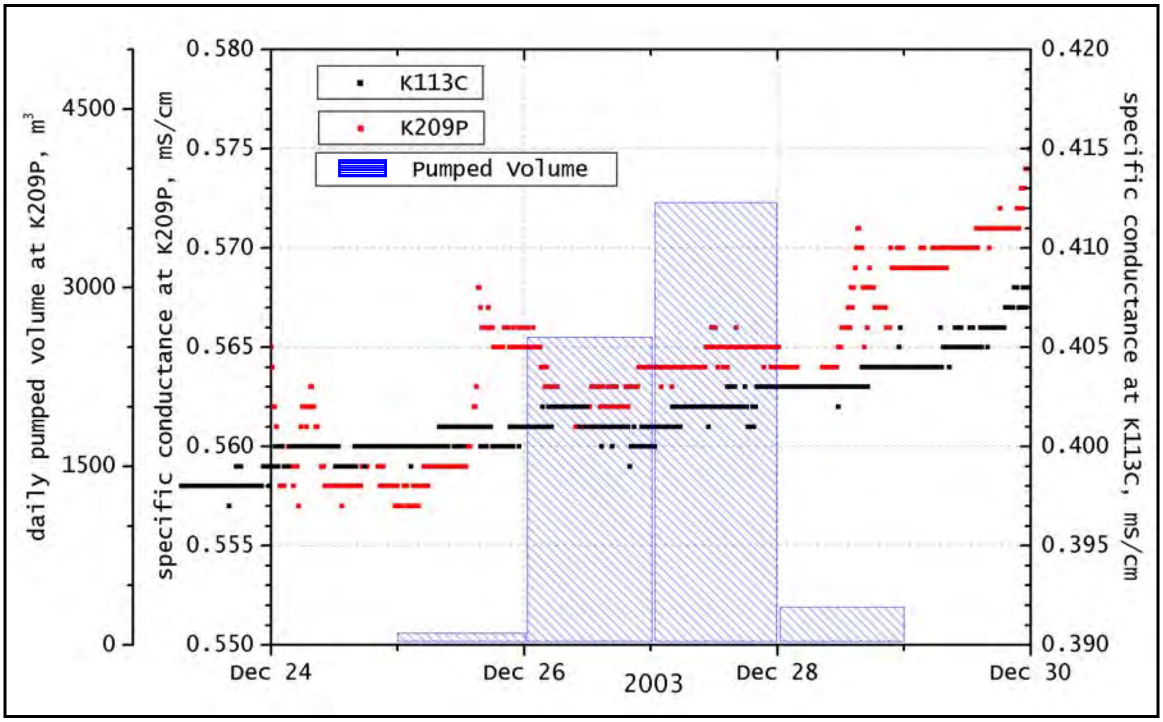

Figure 56: SC measurements at lake K209P during pumping activity December 25-28, 2003 compared to control lake K113C.

Figure 57 presents SC measurements at lake K209P during heavy pumping activity on December 30-31, 2003 compared to control lake K113C. Again, a rapid increase during both days of pumping is apparent in the plot. However, as summarized above, this may be due to the sensors' accuracy tolerance rather than attributed to pumping activity.

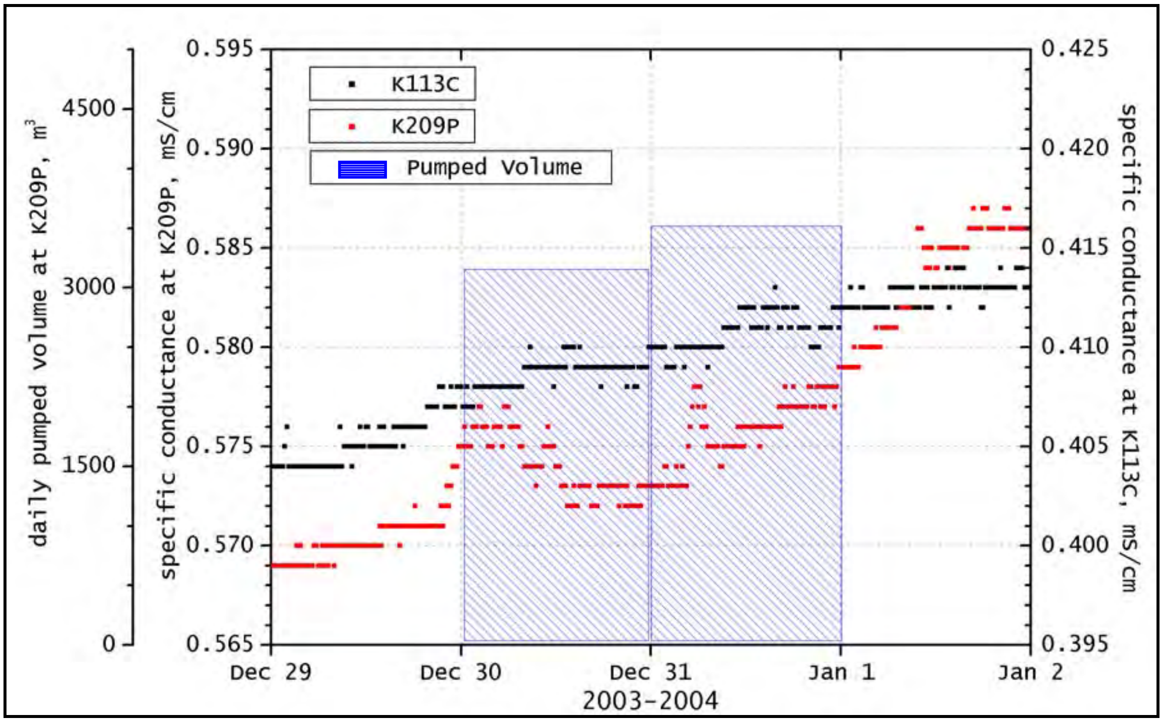

Figure 57: SC measurements at lake K209P during pumping activity December 30-31, 2003 compared to control lake K113C.

Figure 58 shows SC measurements at lake K209P during pumping activity January 2-5, 2004 compared to control lake K113C. Fluctuations such as those in Figure 56 and 57 are not seen in Figure 58. Generally, K209P begins to rise in SC at a greater rate than K113C during this time period. This is due to the shallower bathymetry at K209P and possibly pumping activities. A more detailed understanding of lake bathmetry is essential for future analyses to qualify if differences can be attributed to pumping or simply bathymetric differences.

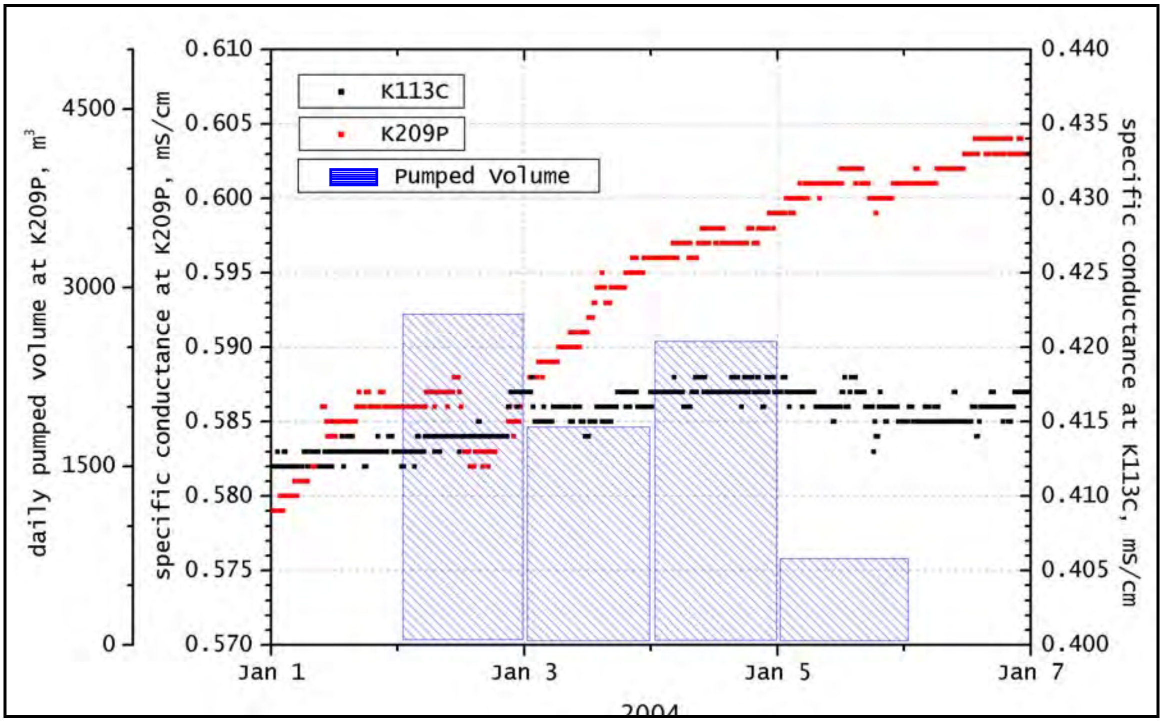

Figure 58: SC measurements at lake K209P during pumping activity January 2-5, 2004 compared to control lake K113C.

The heavy pumping activity at K209P from January 11-22, 2004 is a good opportunity to view potential effects due to pumping. K209P shows a increase about 0.080 mS/cm while K113 shows no increase (Figure 59). This is a result of K209P’s shallower bathymetry and, possibly, the heavier pumping activity at K209P.

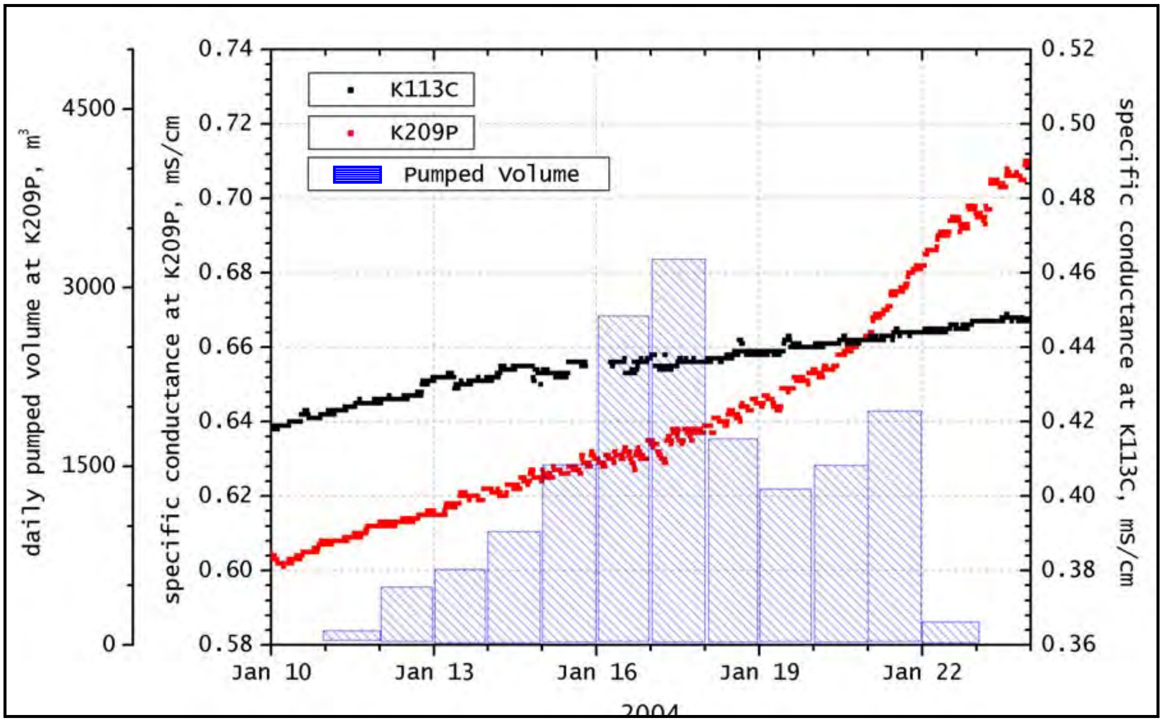

Figure 59: Averaged SC measurements at lake K209P during pumping activity January 11-22, 2004 compared to control lake K113C.

TEMPERATURE

Water temperature was measured by paired thermistor sensors in a vertical profile at 15 or 30 cm increments at the study lakes. Thermistors near the top of the ice show a good correlation to ambient air temperature as expected due to conduction through the ice. Lower thermistors, located in liquid water and near the sediment interface, remain above 0°C as expected. In the subsequent figures, thermistors are referenced to a lake bottom datum then reduced to a measured distance above bottom sediment (ABS).

Investigation of lake temperature was undertaken because pumping might disrupt the conventional thermal structure of the lake by mixing the under-ice water due to pumping agitation. Potential changes to lake temperature would be small since the under-ice water is only stratified 0°C to 4°C topdown. Also, by necessity, the pumping activity occurs a considerable distance from the instrumented station, creating another challenge to observe any potential disturbance.

Thermal profiles of the study lakes at a one-month interval after installation in the winter of 2003 are presented in Figures 60 to 63. Thermal profiles from February 2003 – May 2003 are significantly impacted by the cold weather, below -40°C, lasting into late February. Beginning in March, temperatures warm and the ice gradually warms, rots and is nearly isothermal by the end of the freezing season in mid-May.

Accurate thermal profiles were not available during the 2003-2004 winter because the strong summer winds tangled and disoriented the vertical thermistor sensor string. *In-situ* temperatures were also collected to verify online readings, but these were impacted by the necessity of augering a hole through the ice. Generally, pumped and control lakes show similar thermal profiles and no effect from pumping activity was observed.

Figure 60 shows 2002-2003 winter thermal profiles at a one-month intervals at K113C. K113C shows an unexpected isothermal profile throughout the winter between 0.0 – 1.0°C. No effect from the ambient air temperature conducting through the upper ice is seen at K113C. This may be due to a more compacted, better-insulating snow cover at K113C.

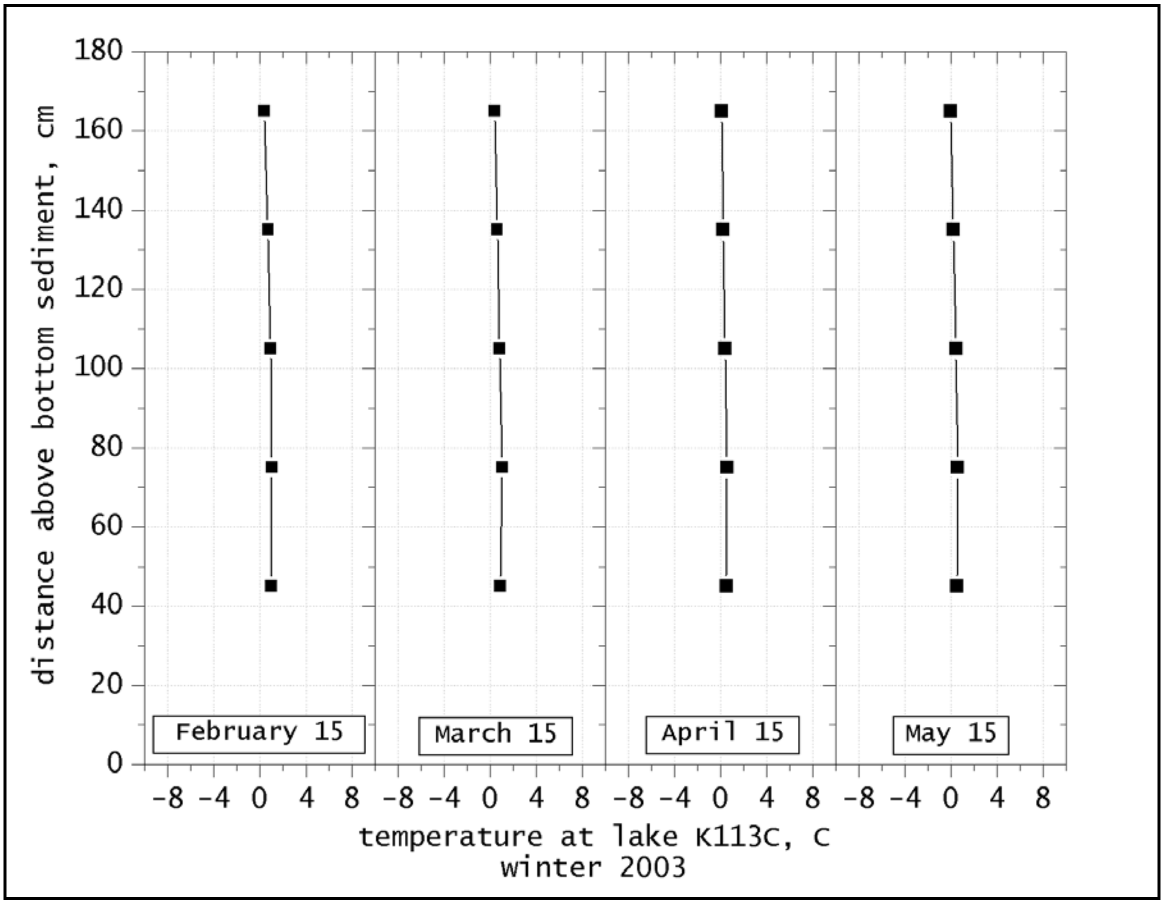

Figure 60: Thermal profiles at control lake K113C during the winter 2002-2003 data collection period.

Figure 61 presents thermal profiles at lake K203C. The profile is nearly isothermal, but some effect from ambient air temperature is seen in the upper thermistor (155 cm ABS) in March and April. The lower thermistors (15, 45, 75 cm ABS) are within the expected range of 0.0 – 4.0°C.

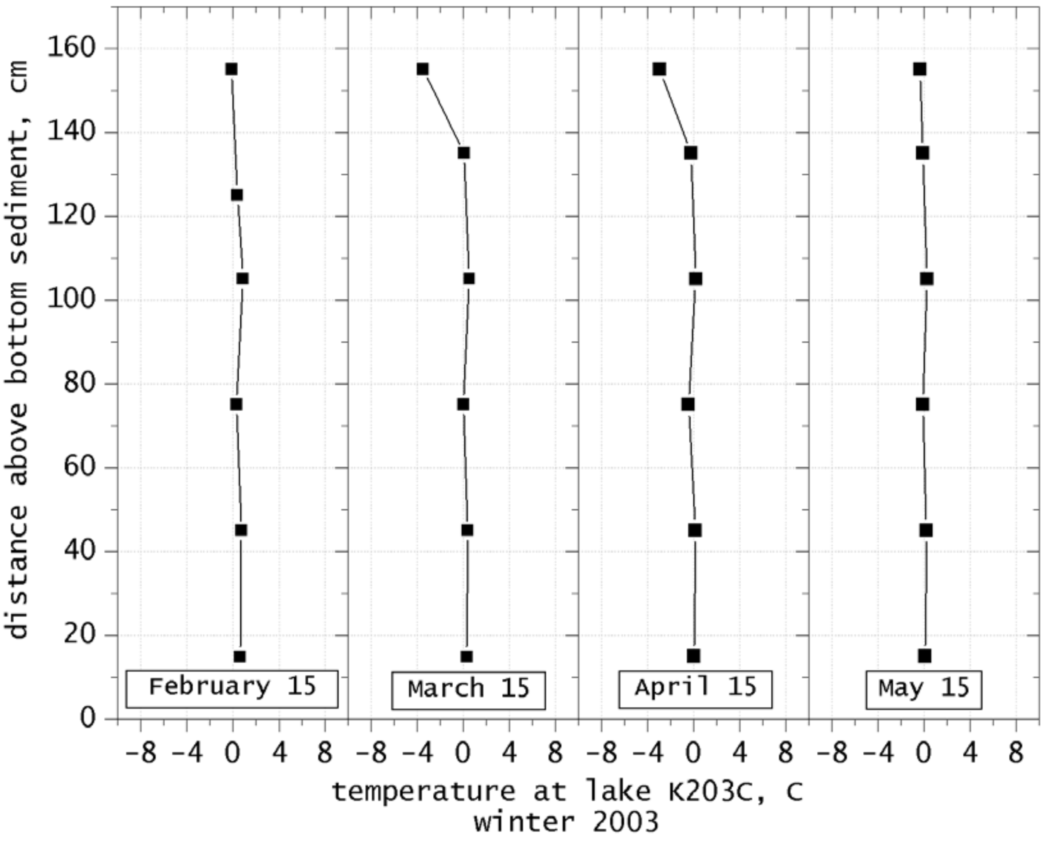

Figure 61: Thermal profiles at control lake K203C during the winter 2002-2003 data collection period.

Figure 62 shows the expected thermal profile for a shallow arctic tundra lake. The upper thermistors are affected by the ambient air temperature. Since the coldest temperatures are in February, the upper profile warms from February on. The lower under-ice water stratifies from 0 – 4°C topdown. Thus, the lower profile shows the lowest water near 4°C since it is the densest. Although the thermal profile at pumped lake K209P deviates from the control lakes, the profile at K209P is what is expected and not an observed effect resulting from pumping activity.

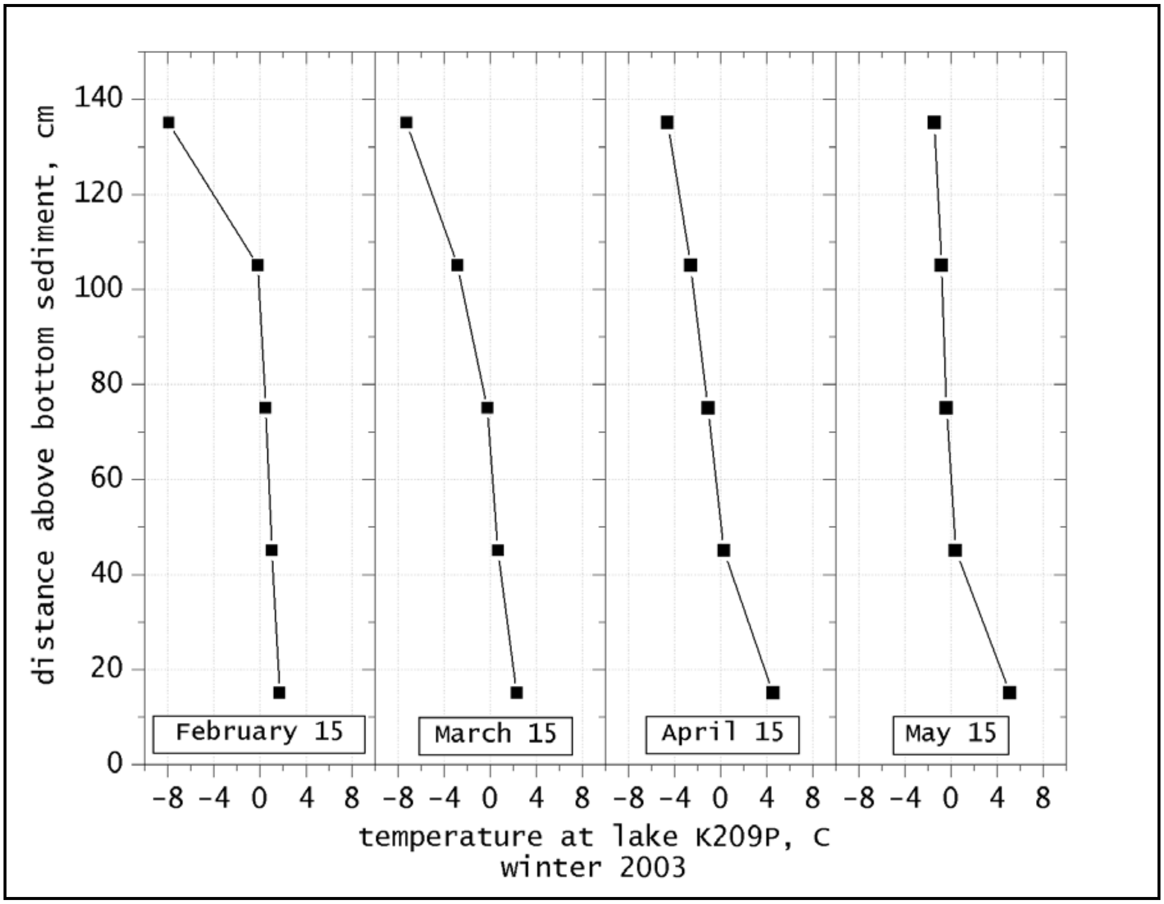

Figure 62: Thermal profiles at pumped lake K209P during the winter 2002-2003 data collection period.

Similar to K209P in Figure 62, K214P shows the expected thermal profile for a tundra lake progressing towards spring in Figure 63. No effect from pumping was observed.

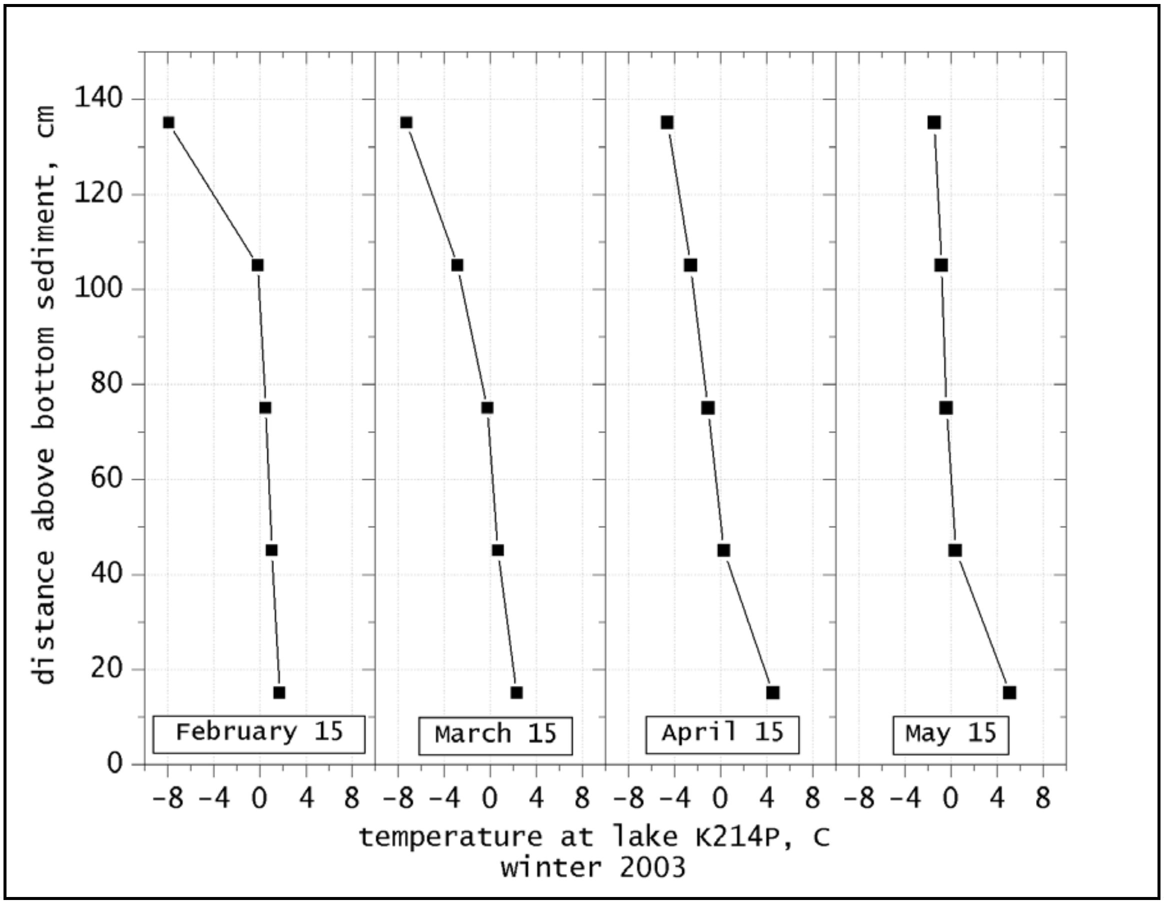

Figure 63: Thermal profiles at pumped lake K214P during the winter 2002-2003 data collection period.

DISSOLVED OXYGEN

Dissolved oxygen (DO) is a difficult variable to accurately measure in any freshwater system and the challenge is compounded when measuring under-ice concentrations in cold and shallow tundra lakes. Due to the cold temperature and limited under-ice volumes for operation, many of the DO sensors malfunctioned on installation. However, some DO data were obtained and generally met with expectations. Dissolved oxygen measurements through the winter are expected to show a gradual depletion in the water column. The depletion is a result of biological oxygen demand and chemical oxidation. Most of the uptake occurs near the sediment interface. *In-situ* measurements of DO were taken on sampling visits, but were affected by aerating the water during augering. Augering was also thought to have oxygenated the water during one site visit, which was measured by the DO sensors and is noted in the figure.

Figures 64 and 65 present dissolved oxygen measurements obtained for the 2003-2004 winter. An initial look at the data shows several rapid increases and decreases in DO concentration. The increases were likely due to the ice fracturing and introducing atmospheric oxygen into the under-ice water. Thereafter, the concentrations gradually deplete as expected. Unfortunately, no accurate DO data were obtained from pumped lakes K209P and K214P so little can be said about effects from pumping.

Figure 64 shows dissolved oxygen measurements at lake K113C during the 2003-2004 winter. Concentrations under-ice in early November were near 30% saturation, but then increased due to auguring onsite near the instrumented station on November 7, 2003. After the event, the expected gradual depletion of oxygen in the water column is observed until the lake became anoxic in April. Later onsite augering (February 19, 2004; March 23, 2004; May 14, 2004) was not detected by the DO sensor.

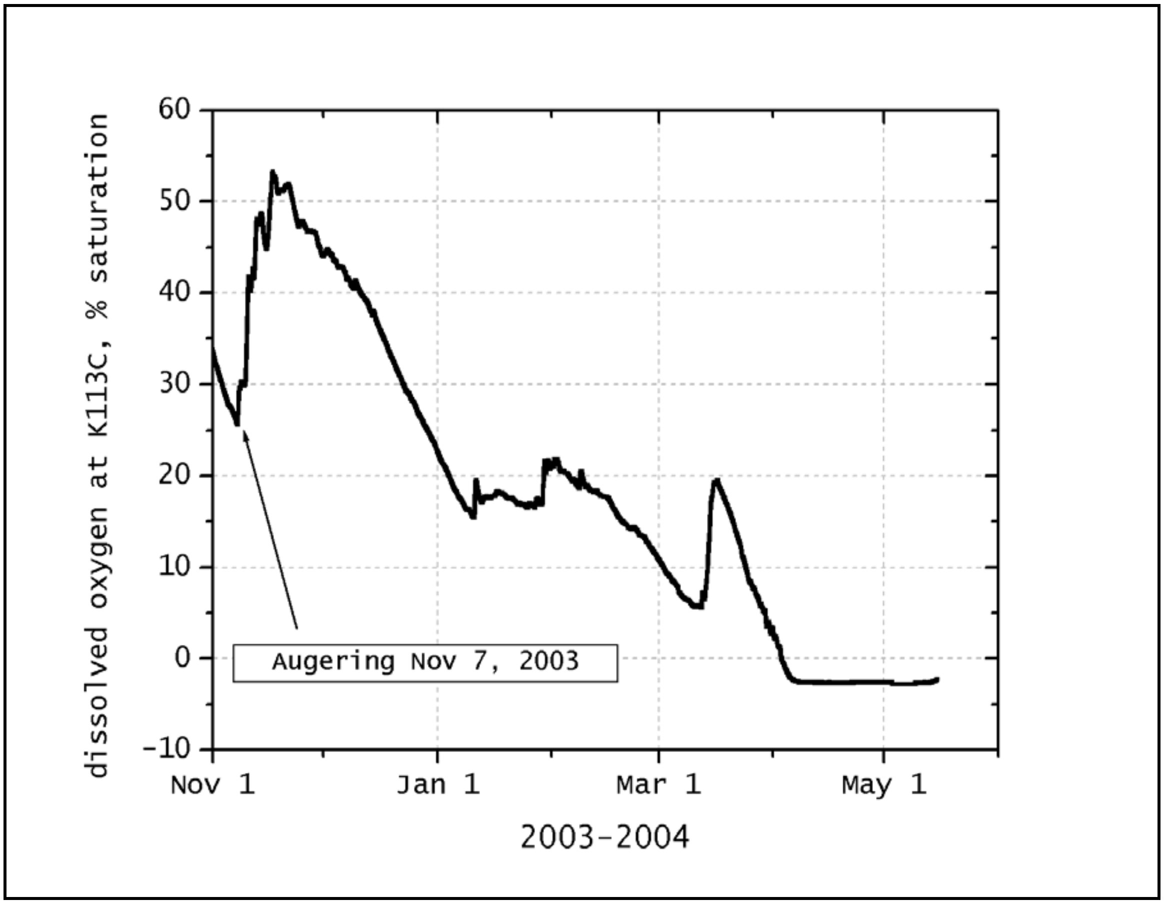

Figure 64: Dissolved oxygen at control lake K113C during 2003-2004 winter data collection.

Dissolved oxygen measurements at lake K203C for the 2002-2003 winter are presented in Figure 65. K203C shows the expected gradual depletion of under-ice DO to anoxic concentrations in April or May.

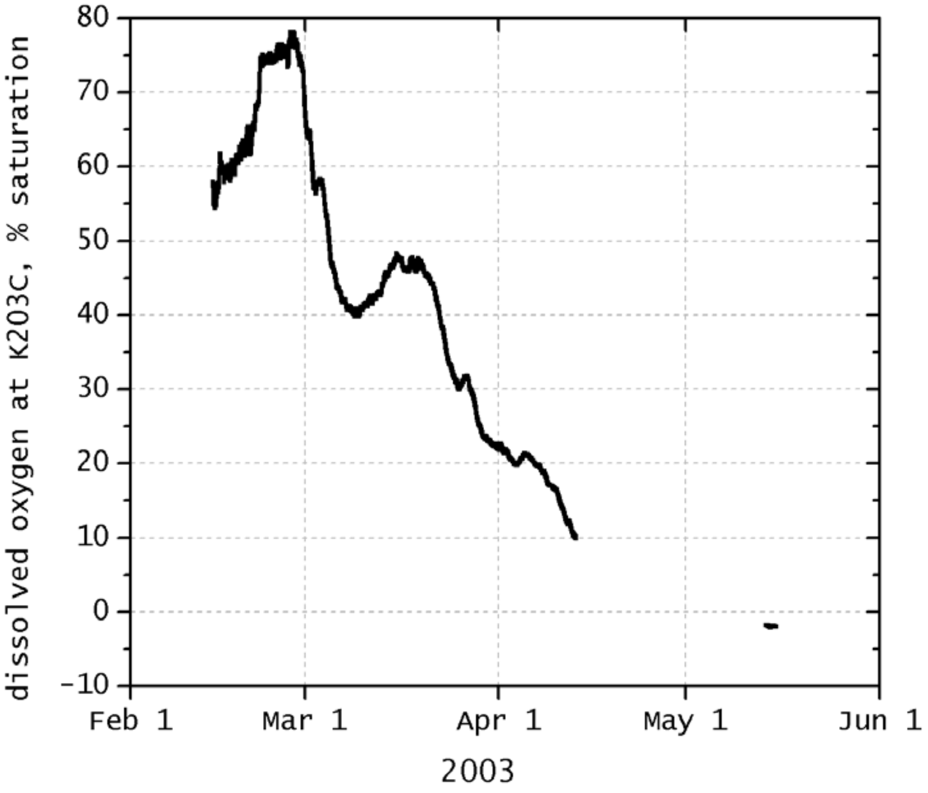

Figure 65: Dissolved oxygen at control lake K203C during 2002-2003 winter data collection. Gap in data due to a lack of telemetry with station.

WATER QUALITY CHEMISTRY

Under-ice concentrations of ions, nutrients, metals and carbon are analyzed for differences observed due to pumping. All ions, nutrients, metals and carbon examined are excluded by ice growth. Consequently, maximum concentrations are observed at the end of the freezing season in May when the ice has reached its maximum thickness. Both pumped and control lakes show this trend of ice exclusion. No statistical deviation in water quality variables between pumped and control lakes was found at 95% confidence. In other words, nutrient (nitrogen as nitrite and nitrate and ortho-phosphate), metal (calcium, iron, magnesium, potassium and sodium) and carbon (total and dissolved organic carbon) concentrations were not significantly affected by water withdrawal.

Measurements of water quality variables are presented in Figures 66 to 75. The raw data can be found in Tables 39 to 42 in the Appendix. Dotted lines are presented as a path to follow data points for each lake and do not represent any data. Three water quality variables were also tested in the laboratory, but found to be below the lower detection limit at both pumped and control lakes. Ortho-phosphate, nitrogen as nitrite and total iron, were consistently below their respective lower detection limits of 0.01 ppm, 0.005 ppm and 0.1 ppm.

All metal, nutrient and carbon plots have vertical error bars representing a 95% confidence interval for multiple (typically duplicate or triplicate) samples. Data for lakes where only one sample was available (thus having 0% confidence) for testing due to contamination is noted in the captions (i.e. mid-May 2003 for lake K203). Manual measurements by handheld meters for pH are also given as a single point reading. An important note is that the May 2004 data point at K214P was likely affected by an amount of sediment in the water sample due to the difficulty in sampling the limited under-ice water volume at winter’s end.

Figure 66 shows measurements of alkalinity during the study period. Alkalinity is expected to increase with ice exclusion of solutes as hydroxide, carbonate and bicarbonate are rejected into the remaining water. The study lakes show the expected response in water quality variables, especially in the 2003-2004 winter where prominent peaking of alkalinity occurs in May 2004 when the ice has nearly reached its maximum extent.

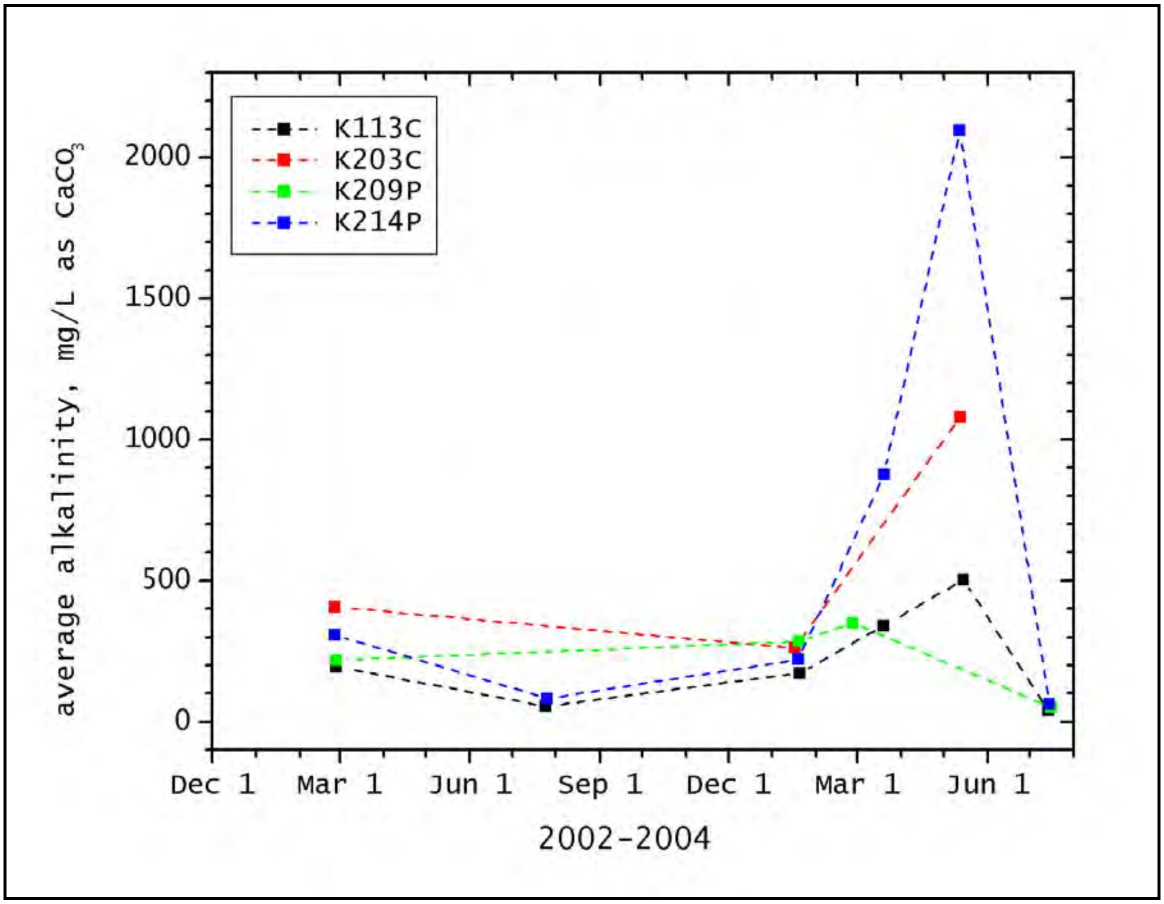

Figure 66: Average alkalinity as $CaCO_3$ at study lakes.

Figure 67 shows measurements of pH from 2002-2004. Measurements of pH are expected to decrease through the winter with ice growth and the accumulation of CO_2 beneath the ice. Thus, low pH occurs in May 2003 and May 2004 for all study lakes. In August 2003, K214P and K113P are within the more conventional 6.0-8.0 pH range as expected with sufficient alkalinity acting as a buffer to acid where K209P and K203C fall into an unexpected range of pH = 5.0-5.5. After the ice decays, K214P and K113C then increase back to a more basic pH as expected since overland flow on the tundra picks up alkaline organic matter and introduces it into the lake water. However, K209P and K203C again show acidic pH values within the 5.0-5.5 range despite the input. It would be possible that K209P and K203C might have a more acidic terrestrial input, but the proximity of K203C and K214P makes this hypothesis unlikely. More than likely, these are erroneous manual measurements introduced by human error during calibration. No effect is observed due to pumping as pH measurements at pumped lakes are bounded by control lakes.

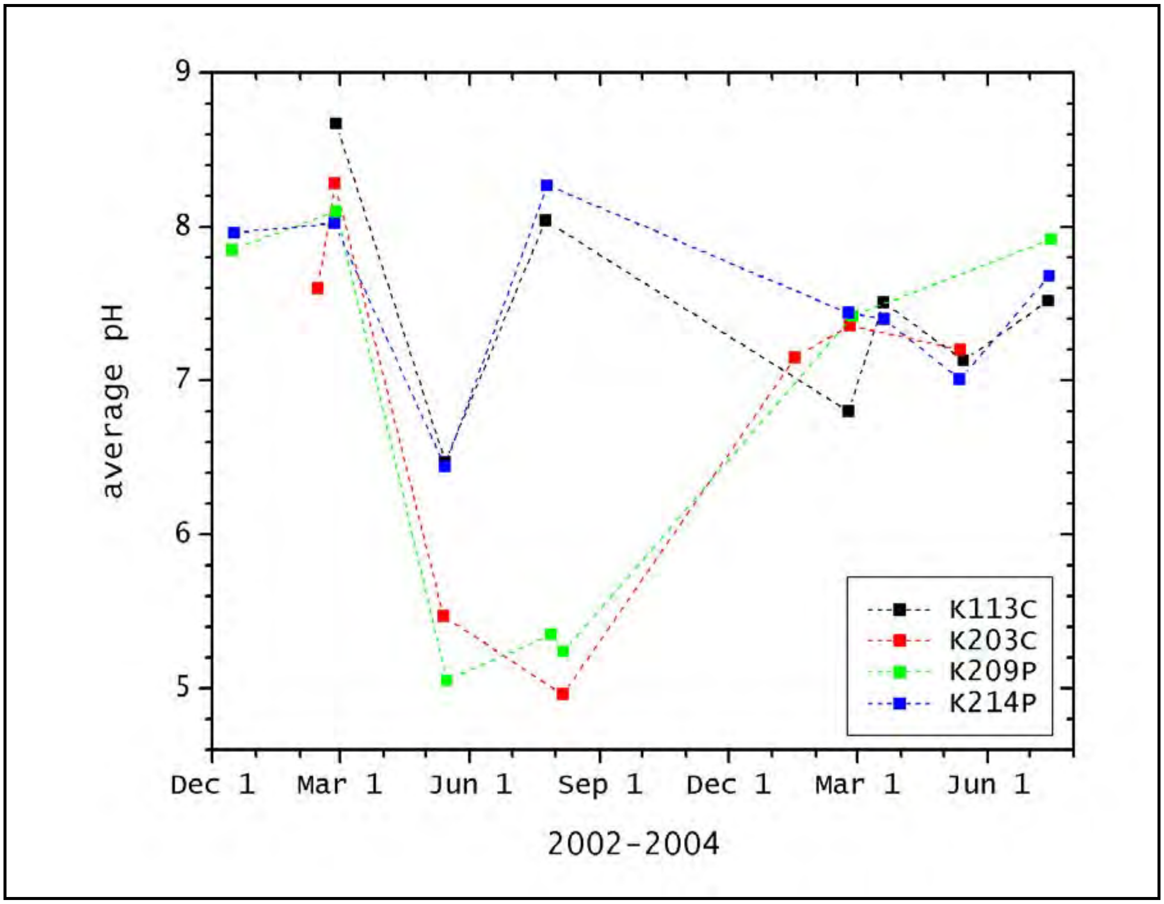

Figure 67: Average pH at study lakes.

Figure 68 shows turbidity measurements taken at all the study lakes during the study period. Turbidity is also affected by the ice exclusion process. Thus, at high ratios of ice volume to water volume, the water is also expected to be more turbid. Turbidity values in May 2004, at peak ice growth, meet the expectation with the highest turbidity values. Three turbidity values must be qualified: the high value for K209P in February 2003 was likely a result of disruption of the sediment from the auger causing an artificially high turbidity value as were the two high values at K203C and K214P in May 2004.

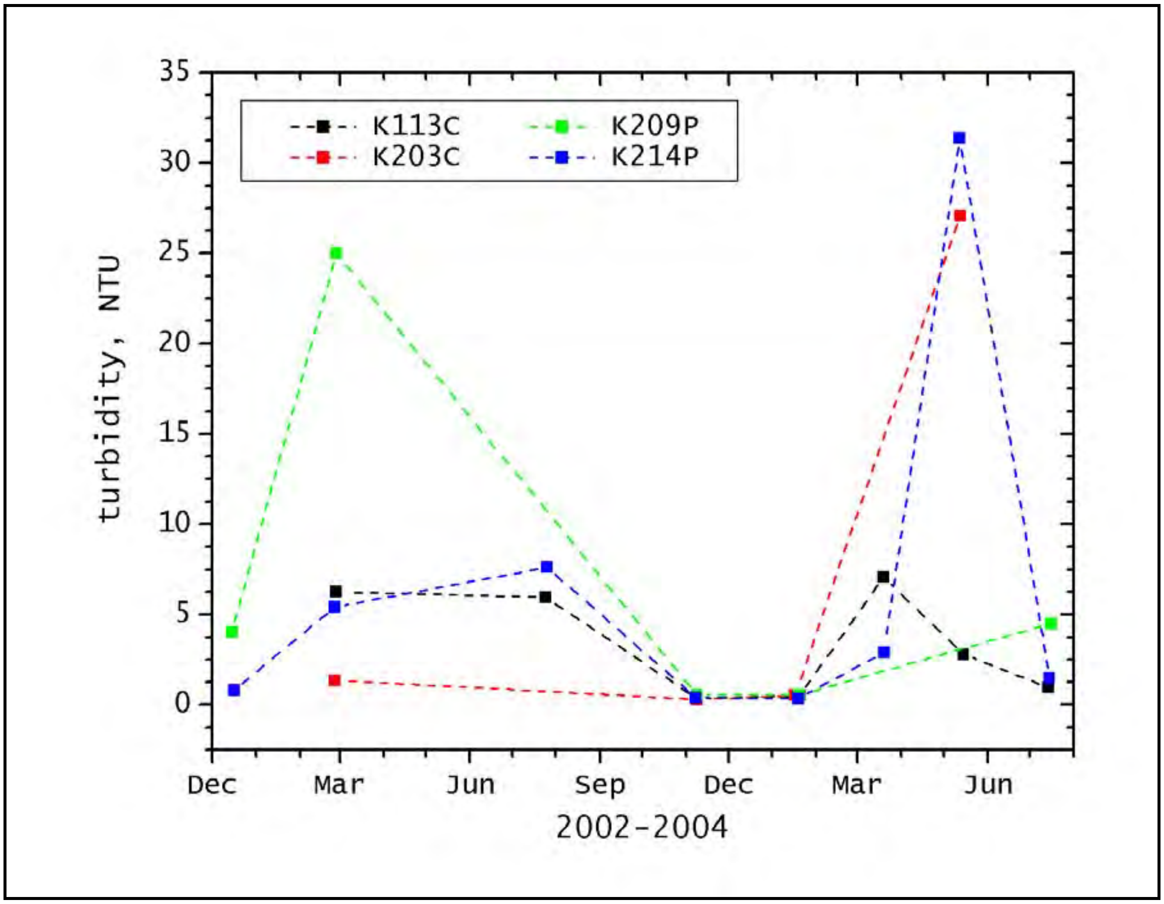

Figure 68: Average turbidity at study lakes.

Figures 69 and 70 show organic carbon concentrations in the study lakes. By comparing total carbon concentrations to dissolved carbon concentrations, it is readily apparent that most organic carbon is in a dissolved form in the lake water as expected. Trends in organic carbon also follow the ice exclusion process.

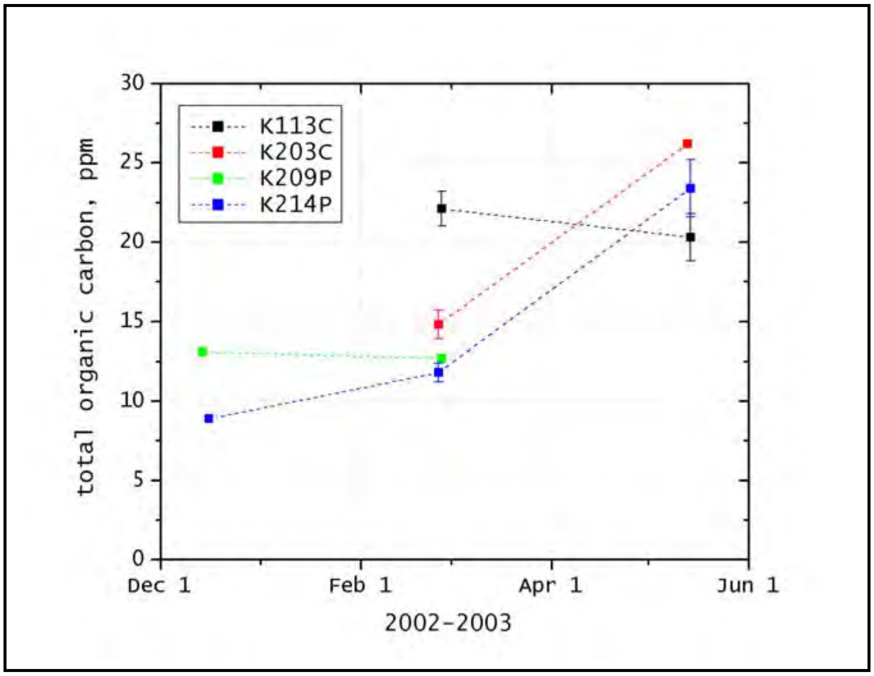

Figure 69: Total organic carbon concentrations at study lakes shown with a 95% confidence interval. K209P and K214P in mid-December 2002 and K203 in mid-May 2003 are represented by single data point.

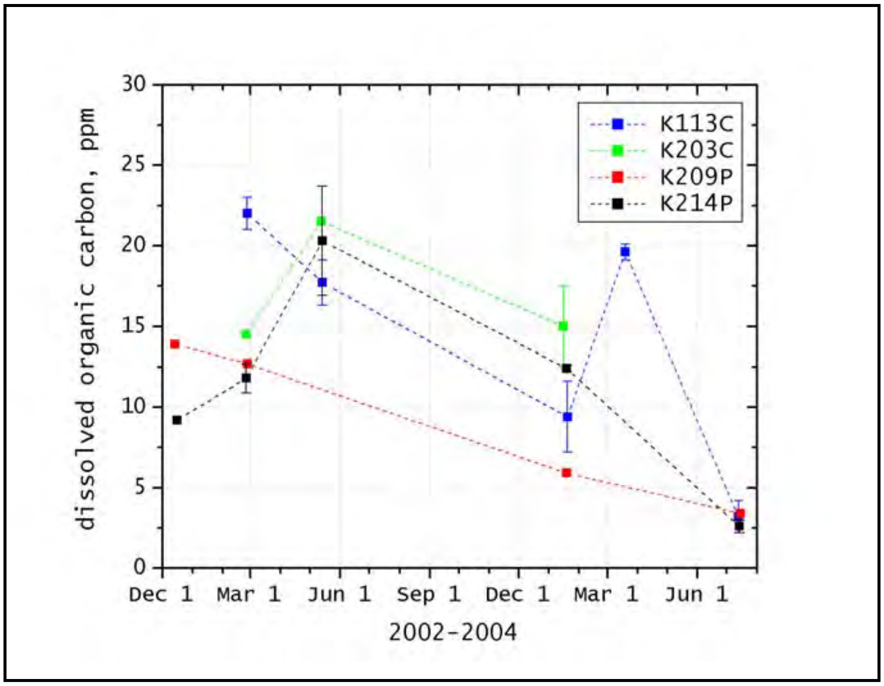

Figure 70: Dissolved organic carbon concentrations shown with a 95% confidence interval. K209P and K214P in mid-December 2002 and K203 in mid-May 2003 are represented by single data point.

Figure 71 shows nitrate concentrations during the study period. Figure 71 also shows nitrate concentrations positively correlated to specific conductance. Nitrate is an important nutrient in the tundra lake ecosystem. The other minor nutrients, nitrite and ortho-phosphate, were consistently below lower detection limits in the laboratory. It is expected that more nitrate than nitrite exists in the system as nitrite concentrations are less than 0.1 mg/L in typical surface waters. Phosphorous is the limiting nutrient for tundra lakes and is therefore minimal as expected. No effect from pumping was observed in any analyzed nutrient.

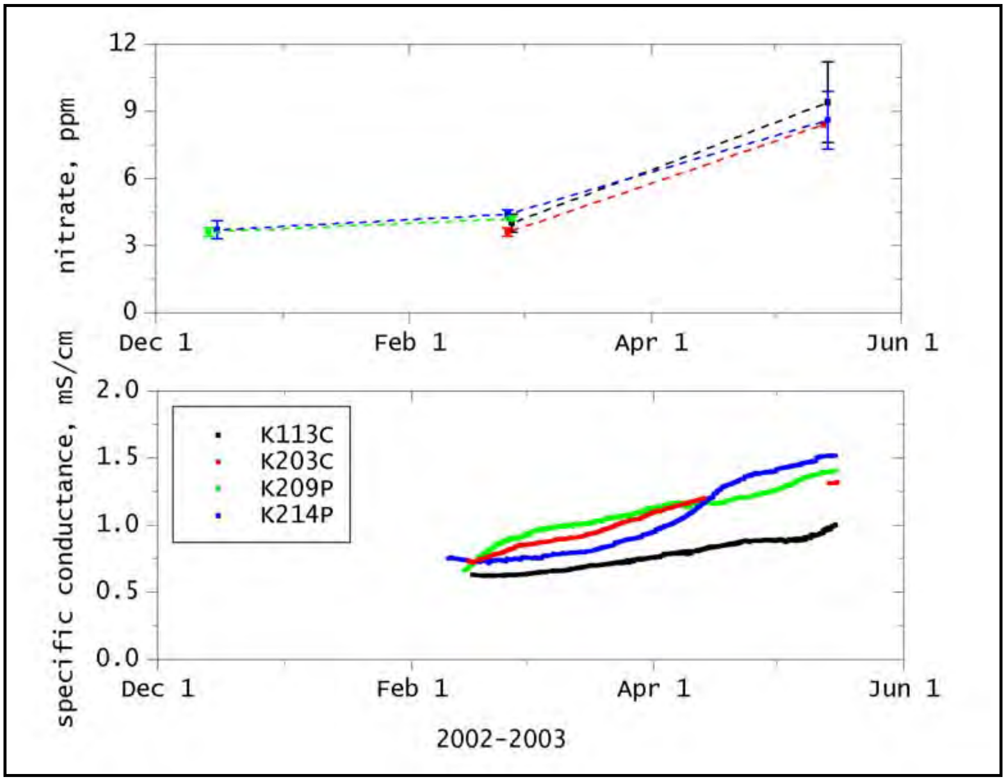

Figure 71: Specific conductance and nitrogen as nitrate measurements shown with a 95% confidence interval. K203P in mid-May 2003 is represented by single data point.

Figures 72 to 75 present measurements of metals at the study lakes. All metals analyzed showed no significance difference at a 95% confidence interval between pumped and control lakes. Iron analyses at pumped and control lakes were consistently below the 0.1 ppm detection limit.

The measurement from mid-May 2004 is less certain than the 2002-2003 winter data since the K214P sample likely contained sediment and K209P could not be sampled due to completely freezing. Lakes were dominated by a calcium and bicarbonate ions. All study lakes generally show predominance in cation concentrations as follows: Ca++ > Mg++ >= Na+ >= K+. This relationship is expected for tundra lakes. Figure 72 also shows how specific conductance measurements positively correlated to calcium measurements. This relationship held true for all the analyzed metals with the exception of iron.

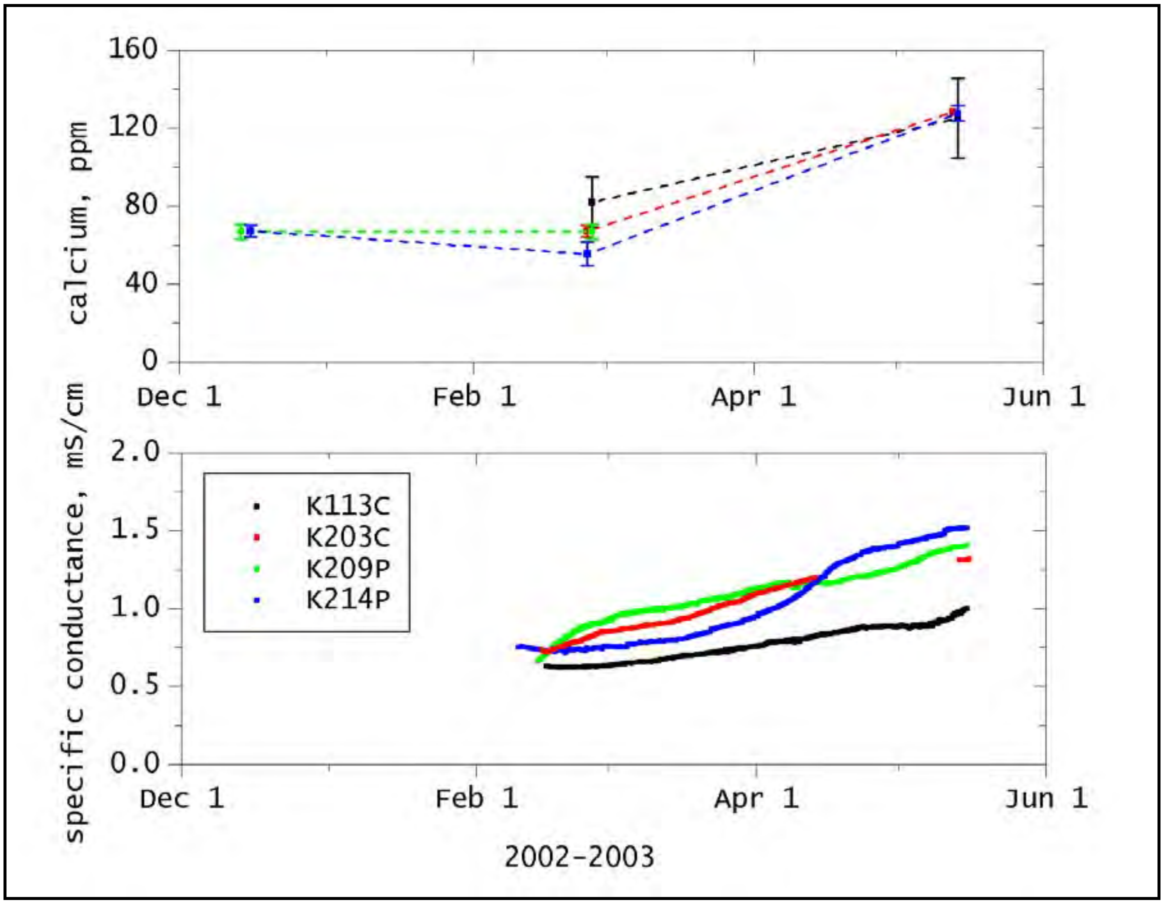

Figure 72: Specific conductance measurements and calcium concentrations at study lakes shown with a 95% confidence interval. K203C in mid-May 2003 is represented by single data point.

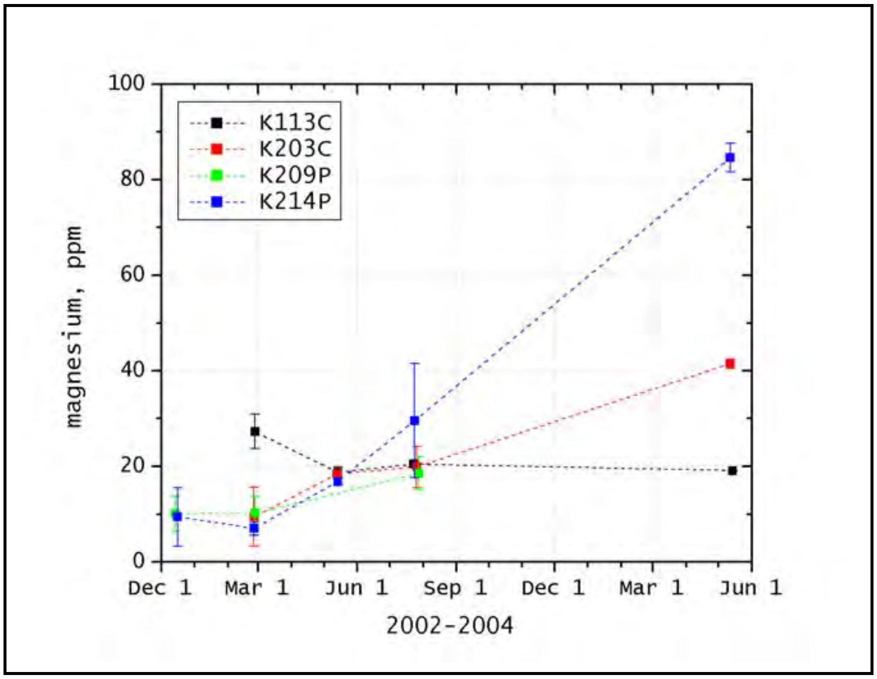

Figure 73: Magnesium concentrations at study lakes shown with a 95% confidence interval. K203C in mid-May 2003 is represented by single data point.

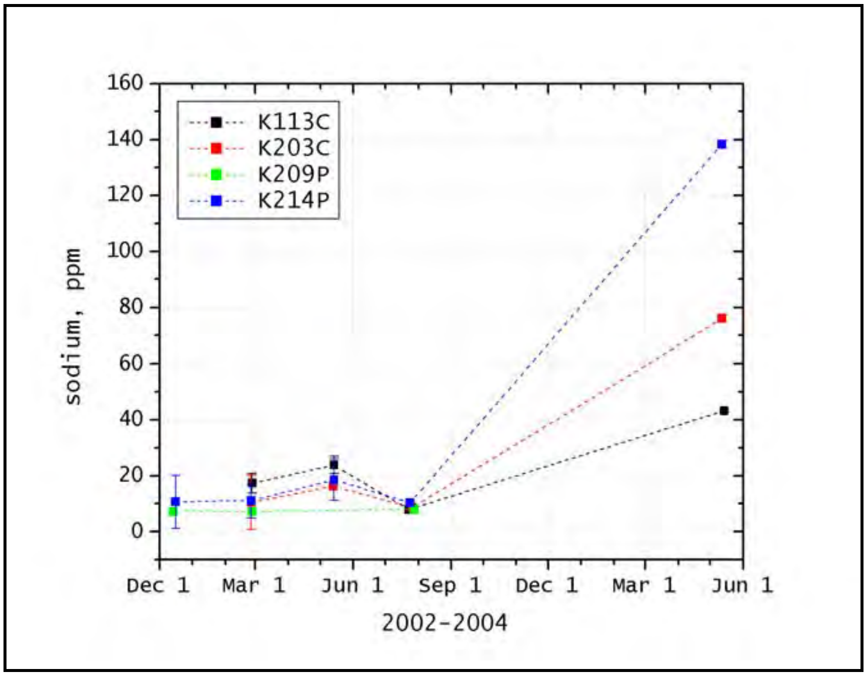

Figure 74: Sodium concentrations at study lakes shown with a 95% confidence interval. K203C in mid-May 2003 is represented by single data point.

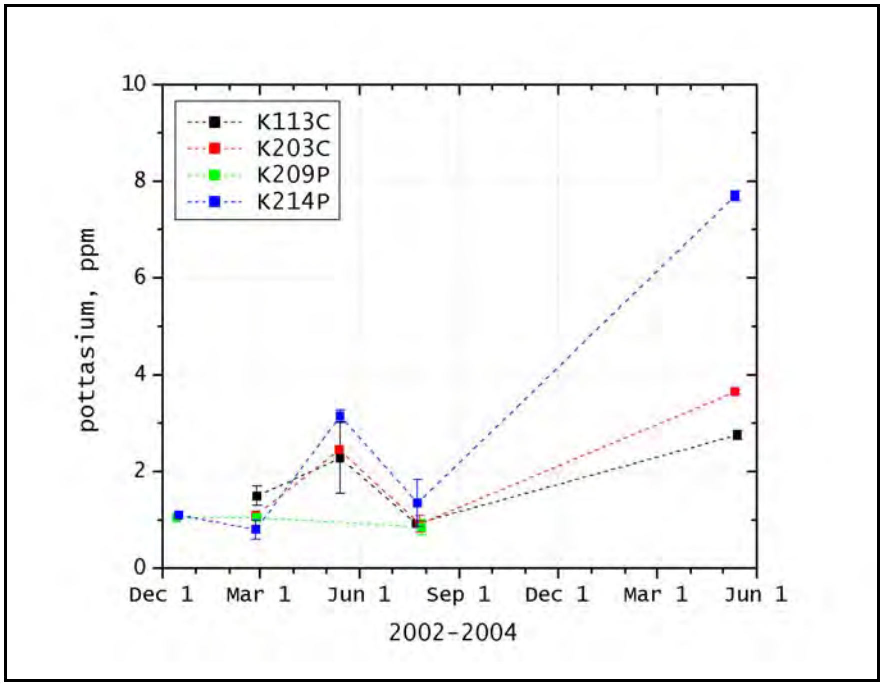

Figure 75: Potassium concentrations at study lakes. K203C in mid-May 2003 represented by is single data point.

CONCLUSIONS AND RECOMMENDATIONS

Tundra lakes on the North Slope of Alaska were investigated during the 2002-2003 and 2003-2004 winters to determine the impacts of pumping activity. Physical changes in water surface level due to pumping were detected using pressure transducers. Chemical differences were not statistically different between pumped and control lakes. Thermal differences between pumped and control lakes were not detected.

By conducting extensive surveys of the study lakes during spring snowmelt, the lakes were verified to be completely recharged after winter pumping activity and summer evaporation left the lakes at a water volume deficit. Complete recharge was verified at study lakes that were pumped two consecutive seasons. Continuation of recharge surveys at lake K209P is recommended if K209P is consistently relied upon as a freshwater resource.

Decreases in water surface level in response to pumping were detected and met reasonably well with expectations. Snow loading atop the ice sheet impacted WSL measurements but was adequately quantified to give acceptable resolution to the small changes in WSL due to pumping. More detailed quantification of the snow load at each lake site is recommended for future studies. Higher resolution records of pumping activity and duration would aid future analyses. It is also recommended that more descriptive bathymetry of study lakes be generated to aid analyses and give more confidence in volume and related estimations.

Some changes in specific conductance were seen during heavy pumping periods; however, the increases and decreases were within the sensor’s accuracy tolerance so could not be firmly attributed to pumping. Measurements of specific conductance through spring breakup showed that the under-ice water is flushed out by the fresh meltwater, which essentially resets the lakes’ chemistry going into summer. Thus, pumped lakes at observe water withdrawal volumes are not likely to incur cumulative deficits in chemistry potentially generated by pumping activity. Understanding vertical differences in the water column and lateral differences across the lake would be beneficial for future studies.

Temperatures in the water column were similar between pumped and control lakes. Thermal profiles at pumped lakes were consistent with cold, shallow arctic lakes.

Water quality variables were not observed to be impacted by pumping. Nitrate, calcium, magnesium, potassium, sodium and organic carbon concentrations were shown to positively correlate with specific conductance.

Dissolved oxygen data was unfortunately of questionable quality due to the difficulty associated with field measurements. The gradual depletion of dissolved oxygen observed at the control lakes meets expectations of under-ice oxygen dynamics. Developing a more robust measurement technique for dissolved oxygen is recommended in future studies. Understanding vertical differences in the water column and lateral differences across the lake would also be beneficial.

In conclusion, at the pumping rates observed during the 2002-2003 and 2003-2004 winters, physical effects due to pumping activity were detected while chemical effects due to pumping were not detected. All lakes were completely recharged by spring snowmelt. All lakes were essentially chemically-reset by the meltwater. Thus, at the observed water withdrawal volumes in 2002-2003 and 2003-2004 ice road construction seasons, current pumping practices cause decreases in water surface level as expected, but little effect to lake chemistry. It is recommended for further study to examine lake dynamics associated with greater water withdrawal to potentially detect more acute physical and chemical changes.

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APPENDIX

Figure 76: Photo of outlets 1 and 2 at lake K113C.

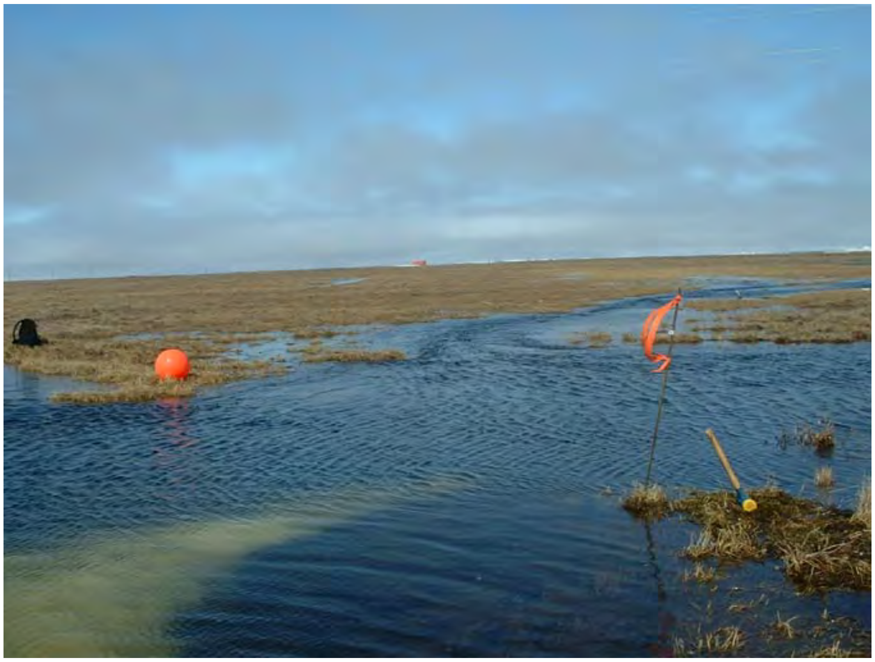

Figure 77: Photo of outlet 2 at lake K214P.

Figure 78: Photo of outlet 3 at lake K214P.

Figure 79: Photo of outlet 2 at lake K209P.

Table 12: Stefan coefficients for lake ice conditions.

Ice condition	Stefan coefficient
No snow	0.80
Little snow	0.70
Moderate snow	0.50
Heavy snow	0.40

Table 13: Schedule of meters used and calibration dates.

Sampling Event	Meter(s) Utilized [Serial No.]	Calibration Date	Online Lakes Sampled	
mid-December 2002	YSI 650 [02J0038]	12/12/2002	K209	
	YSI 30 [00B0064]	12/13/2002	K214	
early-February 2003	YSI 650 [02J0038]	2/8/2003	K203	
late-February 2003	Lakewood [16693]	2/24/2003	K113	K209
	Hach SensIon 1 [0314030]	2/25/2003	K203	K214
mid-May 2003	YSI 650 [02J0038]	5/13/2003	K113	K209
	YSI 30 [00B0064]	5/13/2003	K203	K214
late-July 2003	YSI 650 [02J0038]	7/23/2003	K113	K214
			K209	
early-August 2003	YSI 650 [02J0038]	8/3/2003	K203	K209
early-November 2003	YSI 30 [00B0064]	11/7/2003	K113	K209
			K203	K214
mid-January 2004	Hydrolab MiniSonde [34067]	1/11/2004	K113	K209
	YSI 30 [00B0064]	1/12/2004	K203	K214
late-February 2004	Hannah 991300 [185786]	2/22/2004	K113	K214
	Hach SensIon 1 [3197143]	2/22/2004	K203	
	Hach SensIon 5 [3287130]	2/22/2004	K209	
late-March 2004	Hannah 991300 [185786]	3/19/2004	K113	
	Hach SensIon 1 [3197143]	3/19/2004	K214	
	Hach SensIon 5 [3287130]	3/19/2004		
	YSI 30 [00B0064]	3/19/2004		
mid-May 2004	Hydrolab Quanta [01865]	5/6/2004	K113	
	Hydrolab DataSonde 4a [41423]	5/7/2004	K203	
	Hannah 8733	5/13/2004	K214	
	Thermo Orion [016243]	5/13/2004		

Table 14: Record of pressure transducer calibrations and water surface elevation surveys at lake K113C.

K113 PT1

DateTime	PT S/N	WSL - BPMSL, m	Voltage	PT slope, m/V	PT offset, m	Notes
2/14/03 17:00	GWS5B148	16.239744	1.784	0.807777	-	WSL backcalculated from 5/15/03 survey
5/9/03 12:00	GWS5B148	16.24584	1.791	0.807777	14.79915	Lounsbury Inc. survey
7/24/03 13:00	GWS5B148	16.212312	1.379	0.807777	15.09842	UAF/GWS survey at north side of lake

K113 PT2

DateTime	PT S/N	WSL - BPMSL, m	Voltage	PT slope, m/V	PT offset, m	Notes
2/14/03 17:00	GWS5B131	16.242792	1.835	0.798658	-	WSL backcalculated from 5/15/03 survey
5/9/03 12:00	GWS5B131	16.24584	1.839	0.798658	14.77711	Lounsbury Inc. survey
7/24/03 13:00	GWS5B131	16.212312	1.413	0.798658	15.08381	UAF/GWS survey at north side of lake

Table 15: Record of pressure transducer calibrations and water surface elevation surveys at lake K203C.

K203 PT1						
DateTime	PT S/N	WSL - BPMSL, m	Voltage	PT slope, m/V	PT offset, m	Notes
2/13/03 20:00	GWS5B146	25.295352	1.2	0.827110614	-	WSL backcalculated from 5/15/03 survey
5/12/03 20:00	GWS5B146	25.368504	1.288	0.827110614	24.30319	Lounsbury Inc. survey
8/6/03 0:00	GWS5B146	25.32888	1.023	0.827110614	24.48275	UAF/GWS survey at west side of lake
K203 PT2						
DateTime	PT S/N	WSL - BPMSL, m	Voltage	PT slope, m/V	PT offset, m	Notes
2/13/03 20:00	GWS5B128	25.292304	1.354	0.808076189	-	WSL backcalculated from 5/15/03 survey
5/12/03 20:00	GWS5B128	25.368504	1.45	0.808076189	24.19679	Lounsbury Inc. survey
8/6/03 0:00	GWS5B128	25.32888	1.413	0.808076189	24.40525	UAF/GWS survey at west side of lake

Table 16: Record of pressure transducer calibrations and water surface elevation surveys at lake K209P.

K209 PT1

DateTime	PT S/N	WSL (m)	CR10x measurement (V)	PT calibration slope (V/m)	PT offset (m)	Notes
2/12/03 19:00	GWS5B118	23.646384	1.332	0.835100184	-	WSL backcalculated from 5/15/03 survey
5/15/03 11:45	GWS5B118	23.670768	1.361	0.835100184	22.5342	Lounsbury Inc. survey
8/6/03 14:30	GWS5B118	23.686008	0.77	0.835100184	23.04298	UAF/GWS survey at north side of lake
12/4/03 15:00	GWS5B275	23.731728	1.159	0.82134456	22.77979	new PT, UAF/GWS survey at north side of lake

K209 PT2

DateTime	PT S/N	WSL (m)	CR10x measurement (V)	PT calibration slope (V/m)	PT offset (m)	Notes
2/12/03 19:00	GWS5B209	23.664672	1.878	0.794512102	-	WSL backcalculated from 5/15/03 survey
5/15/03 11:45	GWS5B209	23.670768	1.885	0.794512102	22.17311	Lounsbury Inc. survey
8/6/03 14:30	GWS5B268	23.686008	0.748	0.819413347	23.07309	new PT, UAF/GWS survey at north side of lake
12/4/03 15:00	GWS5B276	23.731728	1.158	0.811799138	22.79166	new PT, UAF/GWS survey at north side of lake

Table 17: Record of pressure transducer calibrations and water surface elevation surveys at lake K214P.

K214 PT1						
DateTime	PT S/N	WSL (m)	CR10x measurement (V)	PT calibration slope (m/V)	PT offset (m)	Notes
2/8/03 22:00	GWS5B130	24.859488	1.187	0.828150744	-	WSL backcalculated from 5/15/03 survey
5/8/03 15:00	GWS5B130	24.85644	1.184	0.828150744	23.87591	Lounsbury Inc. survey
7/28/03 8:00	GWS5B130	24.829008	0.6	0.828150744	24.33212	UAF/GWS survey at west side of lake
12/3/04 20:00	GWS5B278		1.134	0.808901664		new PT, no survey
K214 PT2						
DateTime	PT S/N	WSL (m)	CR10x measurement (V)	PT calibration slope (m/V)	PT offset (m)	Notes
2/8/03 22:00	GWS5B229	24.557736	1.835	0.822368078	-	WSL backcalculated from 5/15/03 survey
5/8/03 15:00	GWS5B229	24.85644	1.839	0.822368078	23.59739	Lounsbury Inc. survey
7/28/03 8:00	GWS5B269	24.829008	1.413	0.833782534	23.84598	new PT, UAF/GWS survey at west side of lake
12/3/04 20:00	GWS5B277		1.131	0.809547398		new PT, no survey

Table 18: Sensor change-out log.

Date	Lake	Sensor 1 Change		Sensor 2 Change	
		From	To	From	To
2/8/2003	K214	*initial install*	DO1 = 14209	*initial install*	DO2 = 014206
2/8/2003	K214	*initial install*	SC1 = 3544	*initial install*	SC2 = 3541
2/8/2003	K214	*initial install*	PT1 = GWS5B130	*initial install*	PT2 = GWS5B229
2/8/2003	K214	*initial install*	TS #1 @ 0.0, 0.5, 1.5, 2.5, 3.5, 5.0 ft abs		
2/12/2003	K209	*initial install*	DO1 = 014214	*initial install*	DO2 = 014208
2/12/2003	K209	*initial install*	SC1 = 3552	*initial install*	SC2 = 3553
2/12/2003	K209	*initial install*	PT1 = GWS5B118	*initial install*	PT2 = GWS5B209
2/12/2003	K209	*initial install*	TS #1 @ 0.0, 0.5, 1.5, 2.5, 3.5, 4.5 ft abs		
2/13/2003	K203	*initial install*	DO1 = 014217	*initial install*	DO2 = 014213
2/13/2003	K203	*initial install*	SC1 = 3616	*initial install*	SC2 = 3617
2/13/2003	K203	*initial install*	PT1 = GWS5B146	*initial install*	PT2 = GWS5B128
2/13/2003	K203	*initial install*	TS #1 @ 0.0, 0.5, 1.5, 2.5, 3.5, 5.5 ft abs		
2/14/2003	K113	*initial install*	DO1 = 014207	*initial install*	DO2 = 014215
2/14/2003	K113	*initial install*	SC1 = 3555	*initial install*	SC2 = 3559
2/14/2003	K113	*initial install*	PT1 = GWS5B148	*initial install*	PT2 = GWS5B131
2/14/2003	K113	*initial install*	TS #1 @ 0.0, 0.5, 1.5, 2.5, 3.5, 7.0 ft abs		
7/23/2003	K113	DO1 = 014207	DO1 = 014210	DO2 removed	
7/25/2003	K214			PT2 = GWS5B229	PT2 = GWS5B269
7/25/2003	K214	SC1 = 3544	SC1 = 3540		
7/25/2003	K214	DO1 = 14209	DO1 = 014212	DO2 removed	
7/26/2003	K203	DO1 removed		DO2 removed	
7/26/2003	K203	TS #1 @ 0.0, 2.5 ft abs		TS #2 @ 0.0, 2.5 ft abs	
7/28/2003	K209	DO1 = 014214	DO1 = 014216	DO2 removed	
7/28/2003	K209			PT2 = GWS5B209	PT2 = GWS5B268
12/3/2003	K214	PT1 = GWS5B130	PT1 = GWS5B278	PT2 = GWS5B229	PT2 = GWS5B277
12/4/2003	K209	PT1 = GWS5B118	PT1 = GWS5B275	PT2 = GWS5B268	PT2 = GWS5B276

Table 19: Records of water withdrawal at lake K209P during 2002-2003 winter and expected immediate and cumulative changes in water surface level based on a pan bathymetry.

Lake K209: 2002-2003 Winter Pumping Season

Date	**Daily Volume, m^3**	**Monthly Volume, m^3**	**Cumulative Volume, m^3**	**Expected immediate change in WSL, m**	**Expected cumulative change in WSL, m**
1/20/2003	209.86	-	209.86	-0.0001	-0.0001
1/21/2003	756.78	-	966.64	-0.0005	-0.0007
1/22/2003	2287.82	-	3254.46	-0.0016	-0.0023
1/23/2003	2763.19	-	6017.65	-0.0020	-0.0043
1/24/2003	3001.67	-	9019.32	-0.0021	-0.0064
1/25/2003	3462.73	-	12482.05	-0.0025	-0.0089
1/26/2003	2928.54	-	15410.59	-0.0021	-0.0110
1/27/2003	2517.44	-	17928.03	-0.0018	-0.0128
1/28/2003	3885.32	-	21813.35	-0.0028	-0.0155
1/29/2003	3240.15	-	25053.50	-0.0023	-0.0178
1/30/2003	596.20	-	25649.70	-0.0004	-0.0183
2/7/2003	107.32	-	25757.02	-0.0001	-0.0183
2/12/2003	410.19	-	26167.21	-0.0003	-0.0186
2/13/2003	581.10	-	26748.30	-0.0004	-0.0190
2/14/2003	178.86	-	26927.16	-0.0001	-0.0192
2/15/2003	35.77	-	26962.93	0.0000	-0.0192

Table 20: Records of water withdrawal at lake K214P during 2002-2003 winter and expected immediate and cumulative changes in water surface level based on a pan bathymetry.

Lake K214: 2002-2003 Winter Pumping Season					
Date	**Daily Volume, m^3**	**Monthly Volume, m^3**	**Cumulative Volume, m^3**	**Expected immediate change in WSL, m**	**Expected cumulative change in WSL, m**
12/21/2002	258.35	-	258.35	-0.0001	-0.0001
12/22/2002	349.77	-	608.12	-0.0002	-0.0003
12/23/2002	481.73	-	1089.85	-0.0002	-0.0005
12/24/2002	491.27	-	1581.12	-0.0002	-0.0008
12/25/2002	378.39	-	1959.51	-0.0002	-0.0009
1/9/2003	24.98	-	1984.50	0.0000	-0.0009
1/10/2003	49.97	-	2034.46	0.0000	-0.0010
1/11/2003	101.45	-	2135.91	0.0000	-0.0010
1/12/2003	126.81	-	2262.72	-0.0001	-0.0011
4/30/2003	-	842.63	3105.35	-0.0004	-0.0015

Table 21: Records of water withdrawal at lake K209P during 2003-2004 winter and expected immediate and cumulative changes in water surface level based on a pan bathymetry.

Lake K209: 2003-2004 Winter Pumping Season

Date	Daily Volume, m^3	Monthly Volume, m^3	Cumulative Volume, m^3	Expected immediate change in WSL, m	Expected cumulative change in WSL, m
12/25/2003	31.80	-	31.80	0.0000	0.0000
12/26/2003	2566.05	-	2597.84	-0.0018	-0.0018
12/27/2003	3663.69	-	6261.54	-0.0026	-0.0045
12/28/2003	335.78	-	6597.32	-0.0002	-0.0047
12/30/2003	3161.45	-	9758.77	-0.0023	-0.0069
12/31/2003	3507.41	-	13266.18	-0.0025	-0.0094
1/2/2004	2711.84	-	15978.01	-0.0019	-0.0114
1/3/2004	1780.65	-	17758.67	-0.0013	-0.0126
1/4/2004	2509.92	-	20268.59	-0.0018	-0.0144
1/5/2004	728.95	-	20997.55	-0.0005	-0.0150
1/11/2004	133.55	-	21131.09	-0.0001	-0.0150
1/12/2004	489.68	-	21620.77	-0.0003	-0.0154
1/13/2004	673.31	-	22294.08	-0.0005	-0.0159
1/14/2004	984.92	-	23279.01	-0.0007	-0.0166
1/15/2004	1546.94	-	24825.95	-0.0011	-0.0177
1/16/2004	2746.50	-	27572.44	-0.0020	-0.0196
1/17/2004	3241.74	-	30814.19	-0.0023	-0.0219
1/18/2004	1775.41	-	32589.59	-0.0013	-0.0232
1/19/2004	1339.46	-	33929.06	-0.0010	-0.0242
1/20/2004	1510.37	-	35439.43	-0.0011	-0.0252
1/21/2004	1947.59	-	37387.02	-0.0014	-0.0266
1/22/2004	198.73	-	37585.75	-0.0001	-0.0268
2/5/2004	186.81	-	37772.56	-0.0001	-0.0269
2/6/2004	246.43	-	38018.99	-0.0002	-0.0271
2/14/2004	194.76	-	38213.75	-0.0001	-0.0272
2/17/2004	202.71	-	38416.46	-0.0001	-0.0274
2/18/2004	321.95	-	38738.41	-0.0002	-0.0276
2/18/2004	405.42	-	39143.82	-0.0003	-0.0279
2/19/2004	727.36	-	39871.19	-0.0005	-0.0284
2/20/2004	357.72	-	40228.91	-0.0003	-0.0286
2/21/2004	393.49	-	40622.40	-0.0003	-0.0289
2/24/2004	314.00	-	40936.40	-0.0002	-0.0292
2/25/2004	214.63	-	41151.03	-0.0002	-0.0293
2/26/2004	282.20	-	41433.23	-0.0002	-0.0295
2/27/2004	353.75	-	41786.98	-0.0003	-0.0298
2/28/2004	504.78	-	42291.76	-0.0004	-0.0301
3/5/2004	472.99	-	42764.75	-0.0003	-0.0305
3/6/2004	655.82	-	43420.57	-0.0005	-0.0309
3/7/2004	290.15	-	43710.72	-0.0002	-0.0311

Table 22: Records of water withdrawal at lake K214P during 2003-2004 winter and expected immediate and cumulative changes in water surface level based on a pan bathymetry.

Lake K214: 2003-2004 Winter Pumping Season					
Date	**Daily Volume, m^3**	**Monthly Volume, m^3**	**Cumulative Volume, m^3**	**Expected immediate change in WSL, m**	**Expected cumulative change in WSL, m**
12/7/2003	349.77	-	349.77	-0.0002	-0.0002
12/8/2003	906.22	-	1256.00	-0.0006	-0.0008
12/9/2003	997.64	-	2253.64	-0.0011	-0.0018
12/10/2003	902.25	-	3155.89	-0.0015	-0.0033
1/31/2004	-	2539.50	5695.38	-0.0027	-0.0060
2/29/2004	-	79.49	5774.88	-0.0027	-0.0088

Table 23: Defined periods of water withdrawal at lake K209 during 2003-2004 winter and expected immediate and cumulative changes in water surface level based on a conical bathymetry.

LAKE K209	
Time Period	**Water withdrawal volume, m3**
2/13/2003 - 2/15/2003	795.73
12/25/2003 - 12/28/2003	6,587.32
12/30/2003 - 12/31/2003	6,668.86
1/2/2004 - 1/5/2004	7,731.37
1/11/2004 - 1/22/2004	16,588.21
2/17/2004 - 2/21/2004	2,408.65
2/24/2004 - 2/28/2004	1,669.36
3/5/2004 - 3/7/2004	1,418.96

Table 24: Defined periods of water withdrawal at lake K214 during 2003-2004 winter and expected immediate and cumulative changes in water surface level based on a conical bathymetry.

LAKE K214	
Time Period	**Water withdrawal volume, m3**
4/1/2003 - 4/30/2003	842.63
12/7/2003 - 12/10/2003	3,155.89
1/1/2004 - 1/31/2004	2,539.50
2/1/2004 - 2/29/2004	77.49

Table 25: Inlet and outlet coordinates at the study lakes after spring melt.

Lake K214		
	Latitude (WGS 84)	Longitude (WGS 84)
Inlet 1	70 17.590 N	149 56.204 W
Inlet	70 17.430 N	149 55.121 W
Inlet		
Outlet 1	70 17.991 N	149 54.953 W
Outlet 2	70 18.015 N	149 55.129 W
Outlet 3	70 17.915 N	149 55.799 W
Outlet	70 17.983 N	149 54.872 W
Outlet	70 16.943 N	149 55.014 W
Lake K113		
	Latitude (WGS 84)	Longitude (WGS 84)
Inlet 1	70 19.074 N	149 19.452 W
Inlet 2	70 19.107 N	149 19.172 W
Inlet 3	70 19.080 N	149 19.044 W
Outlet 1 & 2	70 19.174 N	149 18.748 W
Lake K209		
	Latitude (WGS 84)	Longitude (WGS 84)
Inlet 1	70 13.970 N	150 20.428 W
Inlet 2	70 14.005 N	150 20.414 W
Inlet 3	70 14.146 N	150 20.516 W
Outlet 1	70 14.195 N	150 21.149 W
Outlet 2	70 14.149 N	150 21.608 W
Outlet 3	70 14.092 N	150 21.668 W

Table 26: Average snow water equivalence of snowpack within lake basin before 2003 spring melt.

Lake Basin	Average SWE, cm
K113C	10.33
K203C	10.36
K209P	9.76
K214P	8.30

Table 27: Average snow water equivalence of snowpack within lake basin before 2004 spring melt.

Lake Basin	Average SWE, cm
K113C	7.06
K214P	9.98
K209P	11.27

Table 28: Historical pre-melt snow water equivalence at Betty Pingo.

Year	SWE, cm	Date of Measurement
1996	5.8	19-May
1997	12.9	19-May
1999	9.3	15-May
2000	8.2	20-May
2001	8.3	21-May
2002	7.6	20-May
2003	10.9	17-May
2004	8.1	19-May

Table 29: Ablation at K113C Index Site during 2003 spring melt (site is 100 m north of the Spine Rd and melt was premature due to dusting).

Date	SWE, cm
5/16/2003 12:00	11.50
5/17/2003 12:00	11.51
5/18/2003 14:30	10.04
5/19/2003 9:00	8.84
5/20/2003 13:00	9.57
5/21/2003 17:00	8.34
5/22/2003 13:00	11.73
5/23/2003 11:00	12.95
5/24/2003 13:00	10.14
5/26/2003 19:30	9.16
5/27/2003 14:00	8.99
5/28/2003 10:00	7.26
5/29/2003 10:30	7.49
5/30/2003 12:00	3.01
5/31/2003 12:00	0

Table 30: Ablation at Betty Pingo during 2003 spring melt.

Date	SWE, cm
17-May-03	10.93
18-May-03	10.03
19-May-03	11.52
20-May-03	12.74
21-May-03	12.64
22-May-03	12.67
23-May-03	11.26
24-May-03	9.50
26-May-03	11.07
27-May-03	11.77
28-May-03	11.76
29-May-03	11.49
30-May-03	9.81
31-May-03	10.05
1-Jun-03	8.93
2-Jun-03	7.15
3-Jun-03	6.53
4-Jun-03	0

Table 31: Ablation at Betty Pingo during 2004 spring melt.

Date	SWE, cm
19-May-04	8.1
24-May-04	2.7
29-May-04	1.9
31-May-04	2.6
2-Jun-04	1.9
3-Jun-04	1.3
4-Jun-04	1.1
5-Jun-04	0.5
6-Jun-04	0

Table 32: Ablation at K113C Index Site during 2004 spring melt. Snow survey site is 100 m north of the Spine Rd and melt was be premature due to dusting and decreased albedo of snowpack.

Date	Avg SWE, cm
20-May-04	5.4
21-May-04	5.5
24-May-04	4.2
26-May-04	2.9
28-May-04	1.8
31-May-04	0.7
2-Jun-04	0

Table 33: Results of Snow Survey Transects within lake basins - 2003.

Lake K113C (surveyed 5/14/03)				
Snow Survey ID	Average Depth, cm	SWE	Latitude (WGS 84)	Longitude (WGS 84)
SS1	23.24	5.49	70 19' 24.4" N	149 19' 33.9" W
SS2	34.12	9.59	70 18' 38.5" N	149 19' 00.8" W
SS3	37.50	10.28	70 18' 38.1" N	149 20' 19.7" W
SS4	51.46	15.95	70 18' 49.2" N	149 22' 39.7" W
Lake K214P (surveyed 5/14/03)				
Snow Survey ID	Average Depth, cm	SWE	Latitude (WGS 84)	Longitude (WGS 84)
SS5	27.96	5.23	70 18.968' N	149 56.410' W
SS1	22.54	4.98	70 17' 28.8"	149 55' 02.8"
SS2	50.06	11.91	70 16' 24.7" N	149 51' 34.4" W
SS3	54.42	13.22	70 16' 09.1" N	149 55' 15.8" W
SS4	29.25	6.14	70 17.138' N	149 56.534' W
Lake K209P (surveyed 5/15/03)				
Snow Survey ID	Average Depth, cm	SWE	Latitude (WGS 84)	Longitude (WGS 84)
SS5	24.44	4.84	70 11' 27.1" N	150 19' 13.8" W
SS1	29.70	9.42	70 23' 40.1"	149 49' 05.4"
SS2	40.74	10.14	70 12' 30.1"	150 21' 05.3"
SS4	58.74	16.98	70 13' 45.7" N	150 19' 33.2" W
SS3	36.62	8.61	70 13' 07.6" N	150 23' 11.9" W
Lake K203C (surveyed 5/18/03)				
Snow Survey ID	Average Depth, cm	SWE	Latitude (NAD 27)	Longitude (NAD 27)
ss1	39.34	13.81	70 17' 07.6"	149 51' 39.5"
SS2	32.66	8.88	70 18' 06.2"	149 51' 25.0"
SS3	38.68	11.18	70 16.926'	149 53.526'
SS4	24.18	7.57	70 16.941'	149 48.247'

Table 34: Results of Snow Survey Transects within Lake Basins - May 2004.

Lake K113C (surveyed 5/20/04)

Snow Survey ID	Average Depth, cm	SWE	Latitude (WGS 84)	Longitude (WGS 84)
SS1	13.80	5.45	70 19' 24.4" N	149 19' 33.9" W
SS4	19.50	7.00	70 18' 49.2" N	149 22' 39.7" W
SS3	14.00	5.80	70 18' 38.1" N	149 20' 19.7" W
SS2	16.90	10.00	70 18' 38.5" N	149 19' 00.8" W

Lake K214P (surveyed 5/21/04)

Snow Survey ID	Average Depth, cm	SWE	Latitude (WGS 84)	Longitude (WGS 84)
SS5	16.40	8.10	70 18.968' N	149 56.410' W
SS2	23.00	9.50	70 16' 24.7" N	149 51' 34.4" W
SS3	20.60	8.40	70 16' 09.1" N	149 55' 15.8" W
SS4	36.10	13.90	70 17.138' N	149 56.534' W

Lake K209P (surveyed 5/21/04)

Snow Survey ID	Average Depth, cm	SWE	Latitude (WGS 84)	Longitude (WGS 84)
SS5	38.10	13.00	70 11' 27.1" N	150 19' 13.8" W
SS4	28.10	8.30	70 13' 45.7" N	150 19' 33.2" W
SS3	31.70	12.50	70 13' 07.6" N	150 23' 11.9" W

Table 35: Specific conductance measured *in-situ* at station location at a depth of ½ the free water column under-ice: December 2002 – May 2004.

Lake	**DateTime (AST)**	**Specific Conductance, mS/cm**	**Specific Conductance, mS/cm**
K113C	2/26/03 18:00	444	
K113C	5/14/03 15:00	788	
K113C	7/24/03 9:00	177	
K113C	11/8/03 17:15	134	
K113C	1/20/04 12:00	247	
K113C	2/23/04 20:00	1,120	1,002
K113C	3/19/04 13:35	1,251	1,115
K113C	5/14/04 20:00	1,330	1,658
K203C	2/13/03 13:30	79	
K203C	2/25/03 12:30	612	
K203C	5/13/03 12:00	1,086	
K203C	8/5/03 21:30	267	
K203C	1/16/04 15:45	781	
K203C	2/24/04 12:45	1,137	832
K203C	5/12/04 14:00	2,362	2,520
K209P	12/14/02 18:00	400	
K209P	2/26/03 12:00	1,354	
K209P	5/15/03 14:30	1,106	
K209P	7/28/03 14:30	217	
K209P	8/6/03 12:00	246	
K209P	11/8/03 11:00	117	
K209P	1/19/04 13:30	454	
K209P	2/26/04 16:30	1,140	783
K214P	12/16/02 10:00	363	390
K214P	2/25/03 15:00	672	
K214P	5/14/03 10:00	1,103	1,276
K214P	7/25/03 15:00	227	
K214P	11/7/03 16:00	294	
K214P	1/19/04 12:00	526	
K214P	2/23/04 13:00	1,384	1,182
K214P	3/19/04 15:45	2,462	2,085
K214P	5/12/04 8:30	4,073	4,610

Table 36: Alkalinity, turbidity, nitrate and nitrite measured ex-situ at station location at a depth of ½ the free water column under-ice: December 2002 – May 2004.

Lake	Date	Alkalinity, mg/L as CaCO3	Turbidity, NTU	Nitrogen as Nitrite, mg/L	Nitrogen as Nitrate, mg/L
K113C	2/26/03 18:00	194.8	6.26		
K113C	5/14/03 15:00			0.005	0.2
K113C	7/24/03 9:00	54.8	5.98	0.005	0.2
K113C	11/8/03 17:15		0.33		
K113C	1/20/04 0:00	172.4	0.53		
K113C	2/23/04 20:00			0.010	0.2
K113C	3/19/04 13:35	340.0	7.09	0.085	0.3
K113C	5/14/04 20:00	504.0	2.81	0.013	0.1
K203C	2/13/03 13:30				
K203C	2/25/03 12:30	406.5	1.35		
K203C	5/13/03 12:00			0.005	1.0
K203C	8/5/03 21:30				
K203C	11/8/03 15:00		0.32		
K203C	1/16/04 15:45	262.5	0.53		
K203C	2/24/04 12:45			0.009	0.6
K203C	5/12/04 14:00	1081.0	27.10	0.005	0.3
K209P	12/14/02 18:00		4.04		
K209P	2/26/03 12:00	218.5	25.01		
K209P	5/15/03 14:30			0.001	0.0
K209P	7/28/03 14:30				
K209P	8/6/03 0:00				
K209P	11/8/03 11:00		0.54		
K209P	1/19/04 13:30	284.4	0.55		
K209P	2/26/04 16:30	350.0		0.062	0.2
K214P	12/16/02 10:00		0.81		
K214P	2/25/03 15:00	308.3	5.41		
K214P	5/14/03 10:00			0.003	0.1
K214P	7/25/03 15:00	82.8	7.61	0.000	0.2
K214P	11/7/03 16:00		0.40		
K214P	1/19/04 0:00	219.6	0.35		
K214P	2/23/04 13:00			0.003	0.1
K214P	3/19/04 15:45	884.0	2.88	0.013	0.2
K214P	5/12/04 8:30	2147.0	31.40	0.305	2.7

Table 37: The pH measured *in-situ* at station location at a depth of ½ the free water column under-ice: December 2002 – May 2004.

Lake	DateTime (AST)	pH
K113C	2/26/03 18:00	8.67
K113C	5/14/03 15:00	6.47
K113C	7/24/03 9:00	8.04
K113C	2/23/04 20:00	6.16
K113C	3/19/04 13:35	7.64
K113C	5/14/04 20:00	7.21
K203C	2/13/03 13:30	7.60
K203C	2/25/03 12:30	8.28
K203C	5/13/03 12:00	5.47
K203C	8/5/03 21:30	4.96
K203C	1/16/04 15:45	7.15
K203C	2/24/04 12:45	7.37
K203C	5/12/04 14:00	6.95
K209P	12/14/02 18:00	7.85
K209P	2/26/03 12:00	8.10
K209P	5/15/03 14:30	5.05
K209P	7/28/03 14:30	5.35
K209P	8/6/03 0:00	5.24
K209P	2/26/04 16:30	7.45
K214P	12/16/02 10:00	7.96
K214P	2/25/03 15:00	8.02
K214P	5/14/03 10:00	6.44
K214P	7/25/03 15:00	8.27
K214P	2/23/04 13:00	7.41
K214P	3/19/04 15:45	7.45
K214P	5/12/04 8:30	7.44

Table 38: Measured ion and carbon concentrations at lake K113C.

LAKE K113C										
Date	N as nitrate (ppm)	N as nitrite (ppm)	Na (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Fe (ppm)	TOC (ppm)	DOC (ppm)	Ortho-phosphate (ppm)
2/26/03	3.8	ldl	19.10	88.55	1.60	29.12	ldl	22.6	22.5	ldl
2/26/03	4.2	ldl	15.50	75.38	1.40	25.45	ldl	21.5	21.5	ldl
5/14/03	10.3	ldl	25.40	135.60	2.65	19.30	ldl	19.5	18.4	ldl
5/14/03	8.5	ldl	22.30	114.60	1.90	18.20	ldl	21.0	17.0	ldl
7/23/03	4.3	ldl	8.62	67.58	0.92	20.35	ldl	-	-	ldl
7/23/03	4.1	ldl	7.39	58.88	0.93	20.58	ldl	-	-	ldl
5/14/04	0.009	ldl	43.28	186.44	2.86	19.19	ldl	-	-	ldl
5/14/04	0.004	ldl	43.82	188.41	2.82	19.02	ldl	-	-	ldl
5/14/04	-	-	43.12	185.06	2.70	19.08	ldl	-	-	ldl
5/14/04	-	-	42.71	185.03	2.68	19.02	ldl	-	-	ldl

Table 39: Measured ion and carbon concentrations at lake K203C.

LAKE K203C										
Date	N as nitrate (ppm)	N as nitrite (ppm)	Na (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Fe (ppm)	TOC (ppm)	DOC (ppm)	Ortho-phosphate (ppm)
2/25/03	3.5	ldl	15.50	68.70	1.10	12.60	ldl	14.3	14.4	ldl
2/25/03	3.7	ldl	5.60	65.70	1.10	6.30	ldl	15.2	14.5	ldl
5/13/03	8.4	ldl	16.20	128.30	2.45	18.40	ldl	26.2	21.5	ldl
7/26/03	3.9	ldl	9.65	78.77	1.10	24.32	ldl	-	-	ldl
7/26/03	4.6	ldl	8.18	62.63	0.84	17.73	ldl	-	-	ldl
7/26/03	5.2	ldl	8.01	64.09	0.83	17.63	ldl	-	-	ldl
5/12/04	-	ldl	74.02	349.75	3.68	41.86	ldl	-	-	ldl
5/12/04	-	ldl	76.63	375.74	3.68	42.60	ldl	-	-	ldl
5/12/04	-	-	76.20	377.12	3.60	40.63	ldl	-	-	ldl
5/12/04	-	-	77.14	374.02	3.64	40.81	ldl	-	-	ldl

Table 40: Measured ion and carbon concentrations at lake K209P.

LAKE K209P										
Date	N as nitrate (ppm)	N as nitrite (ppm)	Na (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Fe (ppm)	TOC (ppm)	DOC (ppm)	Ortho-phosphate (ppm)
12/14/2002	3.6	ldl	7.17	68.89	1.04	11.98	ldl	13.1	13.9	ldl
12/14/2002	3.7	ldl	7.30	65.09	1.04	8.19	ldl	13.1	-	ldl
2/26/2003	4.2	ldl	7.10	68.90	1.04	11.98	ldl	12.6	12.7	ldl
2/26/2003	4.1	ldl	7.20	65.10	1.05	8.45	ldl	12.8	12.6	ldl
7/28/2003	4.8	ldl	7.42	60.29	0.82	17.39	ldl	-	-	ldl
7/28/2003	6.0	ldl	6.99	54.10	0.72	16.13	ldl	-	-	ldl
7/28/2003	4.2	ldl	9.46	73.71	1.00	21.97	ldl	-	-	ldl

Table 41: Measured ion and carbon concentrations at lake K214P.

LAKE K214P										
Date	N as nitrate (ppm)	N as nitrite (ppm)	Na (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Fe (ppm)	TOC (ppm)	DOC (ppm)	Ortho-phosphate (ppm)
1/16/03	3.54	ldl	15.49	68.66	1.10	12.57	ldl	8.9	9.2	ldl
1/16/03	3.95	ldl	5.86	65.67	1.10	6.31	ldl	-	-	ldl
2/25/03	4.5	ldl	7.90	52.40	0.70	7.70	ldl	12.1	12.2	ldl
2/25/03	4.3	ldl	14.10	58.60	0.90	6.30	ldl	11.5	11.3	ldl
5/14/03	7.9	ldl	14.80	125.60	3.22	16.50	ldl	24.3	22	ldl
5/14/03	9.2	ldl	22.40	129.60	3.10	17.20	ldl	22.5	18.5	ldl
7/24/03	5.2	ldl	10.56	84.02	1.10	23.53	ldl	-	-	ldl
7/24/03	5.1	ldl	10.07	80.98	1.60	35.72	ldl	-	-	ldl
5/12/04	-	ldl	138.84	886.34	7.80	89.16	ldl	-	-	ldl
5/12/04	-	ldl	136.41	938.90	7.71	83.50	ldl	-	-	ldl
5/12/04	-	-	138.74	956.39	7.71	82.78	ldl	-	-	ldl
5/12/04	-	-	139.59	940.04	7.57	82.96	ldl	-	-	ldl