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Alaska Shallow Lake Monitoring Program

2009 Annual Report

Natural Resource Data Series NPS/AKRO/NRDS—2010/119

ON THE COVER
View of Tanada Peaks from Shallow Lake WRST-002, Wrangell-St. Elias National Park and Preserve
Photograph by Heidi Kristenson

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The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Abstract

The 2009 field season marked the fourth year of implementation of the Alaska Network's Shallow Lake Monitoring Program. Twenty five lakes were sampled in Wrangell-St. Elias National Park and Preserve and 29 lakes were sampled in Kobuk Valley National Park. Seven lakes were continuously monitored throughout the two networks. Continuous water chemistry monitoring indicated peak temperatures in early July with relatively little seasonal variation in pH and specific conductivity. Results from synoptic sampling efforts indicated that lakes in Wrangell-St. Elias were significantly impacted by the geologic terrain found in the lakeshed while lakes in Kobuk Valley tended to be more varied. Lake sampling in FY2011 will continue in both of these parks.

Acknowledgments

We thank the Central Alaska and Arctic Network Vital Signs Monitoring Programs for funding this project. Thanks also go to Yukon-Charley Rivers National Preserve and Wrangell-St. Elias National Park and Preserve for providing field technicians to support our efforts. Special thanks to Brad Shults, Ken Barnes and Stan Hermens for providing exceptional aviation support to the project. Mark Henspeter, Ben Sedinger and Sara Turner provided invaluable assistance during our field forays. Finally, we'd like to thank the staff at Wrangell-St. Elias and Tara Whitesell with the Arctic Network for providing logistic support to our operations. In addition to logistic support, we received excellent advice and guidance from the park employees and local residents that call these beautiful places home. Their thoughtful input streamlined our efforts and enhanced our productivity.
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Introduction

In 2006 the Central Alaska Network (CAKN) began implementing the Shallow Lake Monitoring Project. The goal of the project is to monitor the physical, chemical and biological properties of standing water. Shallow lakes and ponds were selected as the medium for monitoring standing water for three primary reasons: 1) they are abundant, 2) they provide diverse ecological functions, and 3) they are sensitive to climate warming. In 2009, the Arctic Network (ARCN) adopted the Shallow Lake Monitoring Plan and we began monitoring shallow lakes in ARCN parks as well.

Rationale for Sampling Shallow Lakes

Abundance

Tens of thousands of lakes are distributed throughout the National Parks and Preserves in the subarctic and arctic zones of Alaska. Lake density ranges greatly across the two networks from low density areas in the mountains of Wrangell-St. Elias National Park and Preserve to high densities in Bering Land Bridge National Preserve. This wide distribution across a variety of landscapes allows ample opportunity to access and sample lakes throughout the network parks, and provides an excellent platform for field experiments.

Ecological Diversity

Shallow lakes serve a diverse array of ecological functions. The interactions of physical, biological and chemical components of a shallow lake, such as soils, water, plants and animals, enable the ecosystem to perform vital services including flood abatement, water quality improvement, biodiversity enhancement, carbon management, and aquifer recharge (Mitsch and Gosselink, 1986). In addition, lakes behave as microcosms, or small theatres where the ecological interactions of organisms and their environment can be more easily tracked. Because they have distinct boundaries, they are easier to sample than other wetland ecosystems.

Climate Change Implications

Data collected over the past 5 years shows that shallow lakes are sensitive to climate warming and that these important ecosystems are at risk of disappearing. Research conducted in Alaska (Riordan *et al.*, 2006; Klein *et al.*, 2005; Yoshikawa *et al.*, 2002) and Russia (Smith *et al.*, 2005) indicates that lakes in the Subarctic are decreasing in size and number.

Shallow lakes are sensitive to climate warming because permafrost, common in Alaska, prevents infiltration and impedes drainage of the upper unfrozen soil layers (Ford and Bedford, 1987). Extensive permafrost degradation has been documented in western Canada (Beilman *et al.*, 2001), Russia (Pavlov, 1994), China (Ding, 1998), Mongolia (Sharkuu, 1988) and interior Alaska (Osterkamp *et al.*, 2000).

Several studies in Alaska have linked lake drying with permafrost degradation (Yoshikawa and Hinzman, 2003), (Jorgenson *et al.*, 2001). When permafrost degrades and the thawed ground sinks below the current water level, new wetlands are often formed. On the other hand, if permafrost degradation enhances drainage, as often happens in upland areas, wetlands can be converted into a drier ecosystem. Under either condition, permafrost degradation changes the

hydrologic cycle altering wetland ecosystems. While relatively few studies have focused on the physical and chemical properties of the shallow lakes undergoing these changes, the few that have been conducted demonstrate that these systems are changing both physically and chemically (Schindler *et al.*, 1996).

Shallow Lake Monitoring Objectives

With these important distribution, ecosystem and climate change issues in mind, the monitoring project for the networks has developed four measurable objectives:

1. Detect decadal-scale trends in the area, distribution, and number of shallow lakes and ponds in Central Alaska and Arctic Network Parks.
2. Detect decadal-scale trends in the water quality of shallow lakes and ponds in Central Alaska and Arctic Network Parks.
3. Detect decadal-scale trends in the structure and composition of vegetation in shallow lakes and ponds in Central Alaska and Arctic Network Parks.
4. Detect decadal-scale trends in macroinvertebrate taxa richness in shallow lakes and ponds in Central Alaska and Arctic Network Parks.

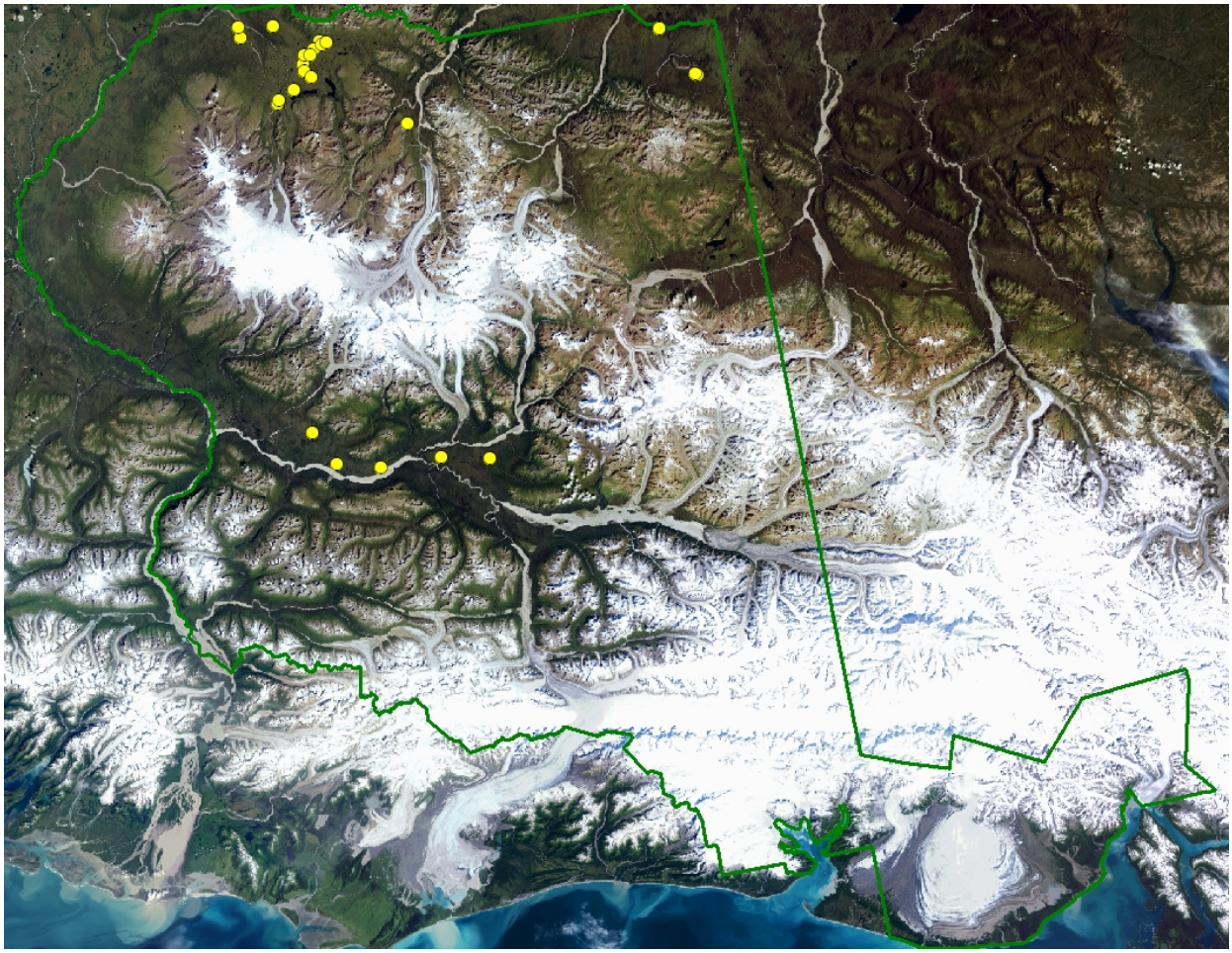

Figure 1. Location of the 25 shallow lakes sampled during the 2009 field season in Wrangell-St. Elias National Park and Preserve

Table 1. Subsection designation for each lake sampled in Wrangell-St. Elias National Park and Preserve in 2009

Subsection	Lakes Sampled	Lithology
Carden Hills	WRST-017, WRST-018	Igneous, mafic, ultramafic, metamorphic mixed
Chitina Valley Moraines and Hills	WRST-021, WRST-022, WRST-023, WRST-024, WRST-025	Quaternary, glacial till
Jack Valley	WRST-004, WRST-015, WRST-016	Quaternary, glacial till
Nabesna	WRST-001	Quaternary, glacial till
Natat Plain	WRST-005	Quaternary, lacustrine and alluvium
Snag Beaver Creek Plain	WRST-019, WRST-020	Quaternary, alluvium
Tanada Moraine	WRST-002, WRST-003, WRST-006, WRST-007, WRST-008, WRST-009, WRST-010, WRST-011, WRST-012, WRST-013, WRST-014	Quaternary, glacial till

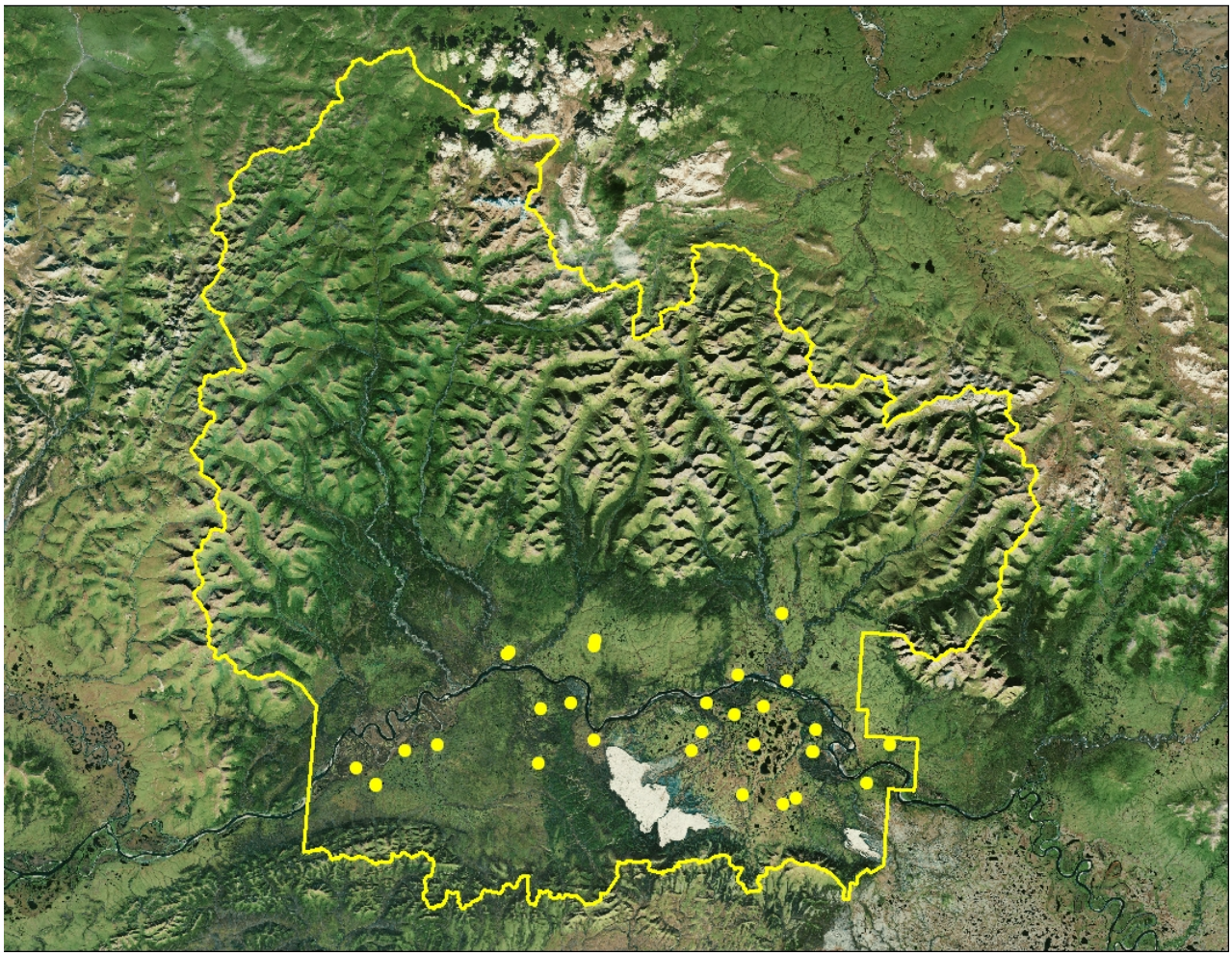

Figure 2. Location of the 29 shallow lakes sampled during the 2009 field season in Kobuk Valley National Park

Table 2. Subsection designation for each lake sampled in Kobuk Valley National Park in 2009

Subsection	Lakes Sampled	Lithology
Ahnewetut Wetlands	KOVA-004, KOVA-006, KOVA-021, KOVA-022, KOVA-023	Quaternary sand, silt and peat
Akillik Plain	KOVA-016, KOVA-017, KOVA_024, KOVA-025, KOVA-027, KOVA-029	Quaternary silt and peat
Salmon-Hunt Terraces and Floodplains	KOVA-011, KOVA-012	Quaternary alluvium
Nigeruk Plain	KOVA-001, KOVA-005, KOVA-007, KOVA-008, KOVA-009, KOVA-013, KOVA-014, KOVA-015, KOVA-018, KOVA-019, KOVA-020, KOVA-030	Quaternary, non-carbonate deposits (eolian)
Kobuk River Floodplain	KOVA-002, KOVA-003, KOVA-010, KOVA-026	Quaternary alluvium

Methods

Synoptic Sampling

Study area

In 2009, synoptic sampling efforts were concentrated in Wrangell-St. Elias National Park and Preserve (WRST) and Kobuk Valley National Park (KOVA). Twenty-five lakes were successfully sampled in WRST (Figure 1) and 29 lakes were successfully sampled in KOVA (Figure 2). Lakes were selected using an un-equal probability sample, with lakes close to roads and navigable waters having a higher probability of being selected. This was achieved by drawing an un-equal probability General Randomized Tessellation Stratified (GRTS) sample. This design insured that lakes selected for sampling were spread out uniformly across the park. Each lake was sampled for the full suite of environmental monitoring variables in accordance with the Shallow Lake Monitoring (SLM) Protocols.

Lakes sampled in WRST are located within seven subsections distributed throughout the Park (Table 1). Lakes are distributed across an elevation gradient extending from 380 m above sea level (ASL) to 1022 m ASL. The majority of lakes (n=20) are situated on glacial till, while three lakes are situated on Quaternary alluvium and the remaining two lakes are situated in on a matrix of igneous, mafic, and ultramic rock. Lake bottoms in WRST tend to be dominated by large rocks covered with a thin layer of sediment characteristic of a recently glaciated environment.

Lakes sampled in KOVA are distributed throughout five subsections (Table 2). Lakes span an elevation gradient of 8-70 m ASL. Lakes sampled in KOVA are substantially lower in elevation than the lakes sampled in WRST. Underlying lithology in KOVA differs from WRST in that virtually all of the lakes sampled are in Quaternary deposits of sand, silt and peat, and sedimentation was largely due to alluvial or eolian processes rather than glacial activity. In addition, sediment in the lakes sampled in WRST tends to be composed of larger material, including large cobble and gravel, while lakes sampled in KOVA are underlain by fine material such as sand and silt.

Water sampling

Water samples were collected in triplicate at each lake. Grab samples were collected 50 cm below the surface and processed according to SLM protocols. Unfiltered aliquots of water were frozen for specific conductivity, total nitrogen (TN), total phosphorus (TP) and alkalinity analysis. Aliquots were filtered through a membrane filter, with 250 mL stored frozen and analyzed for nitrate (NO_3), ammonia (NH_3), orthophosphate (PO_4), sulfate (SO_4), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and chloride (Cl), and 125 mL stored refrigerated for analysis of dissolved organic carbon (DOC) and silica (Si).

Lake profiles were collected at three locations within each basin using an YSI QS multi-parameter probe. Measurements were taken for specific conductivity, dissolved oxygen (DO), temperature (°C) and pH every 0.5 m in the water column. Chlorophyll-a (Chl*a*) samples were collected by filtering 600-800 ml of lake water through a Gelman A/E glass fiber filter, then storing the filter frozen and in the dark until extraction.

Lake depth was measured along the two major axes of the lake at a minimum of 20 locations. Depths were measured using a Speedtech 5 and geotagged with spatial data using a Trimble GPS unit.

Vegetation sampling

Percent cover and frequency of plant species were measured along each of three permanent transects near the lake monument according to the SLM protocols. Line intercept techniques were used to estimate percent cover by transect. The beginning and end point was noted for each species encountered along each transect. Percent cover was determined by calculating the total distance for which a species was present along the transect, then dividing that sum by the overall length of the transect. Nested frequency plots were sampled every 4 meters along the permanent transects.

Macroinvertebrate sampling

Three macroinvertebrate samples were collected from each of the lakes. Invertebrate samples were collected along the vegetation sampling transect using the standardized sweep technique (Oswood *et al.*, 2001) in accordance with the SLM protocols. Specimens were sorted and identified by ABR Inc.; when possible, all specimens were identified to genera and enumerated.

Continuous sampling

Study Area

We deployed a total of seven continuous data logger arrays throughout the network. Arrays were located on lakes YUCH-004 and YUCH-005 in Yukon Charley Rivers National Preserve (Figure 3) in the vicinity of Tacoma Bluffs; DENA-023 and DENA-018 (Caribou Lake) were located in Denali National Park and Preserve in the northwestern section of the Preserve near Lake Minchumina (Figure 4); WRST-015 and WRST-016 were located in Wrangell-St. Elias National Park and Preserve along the Nabesna Road just west of Jack Lake (Figure 5) and KOVA-TEMP was located on the south side of the Kobuk River in the Ahnewetut Wetlands (Figure 6).

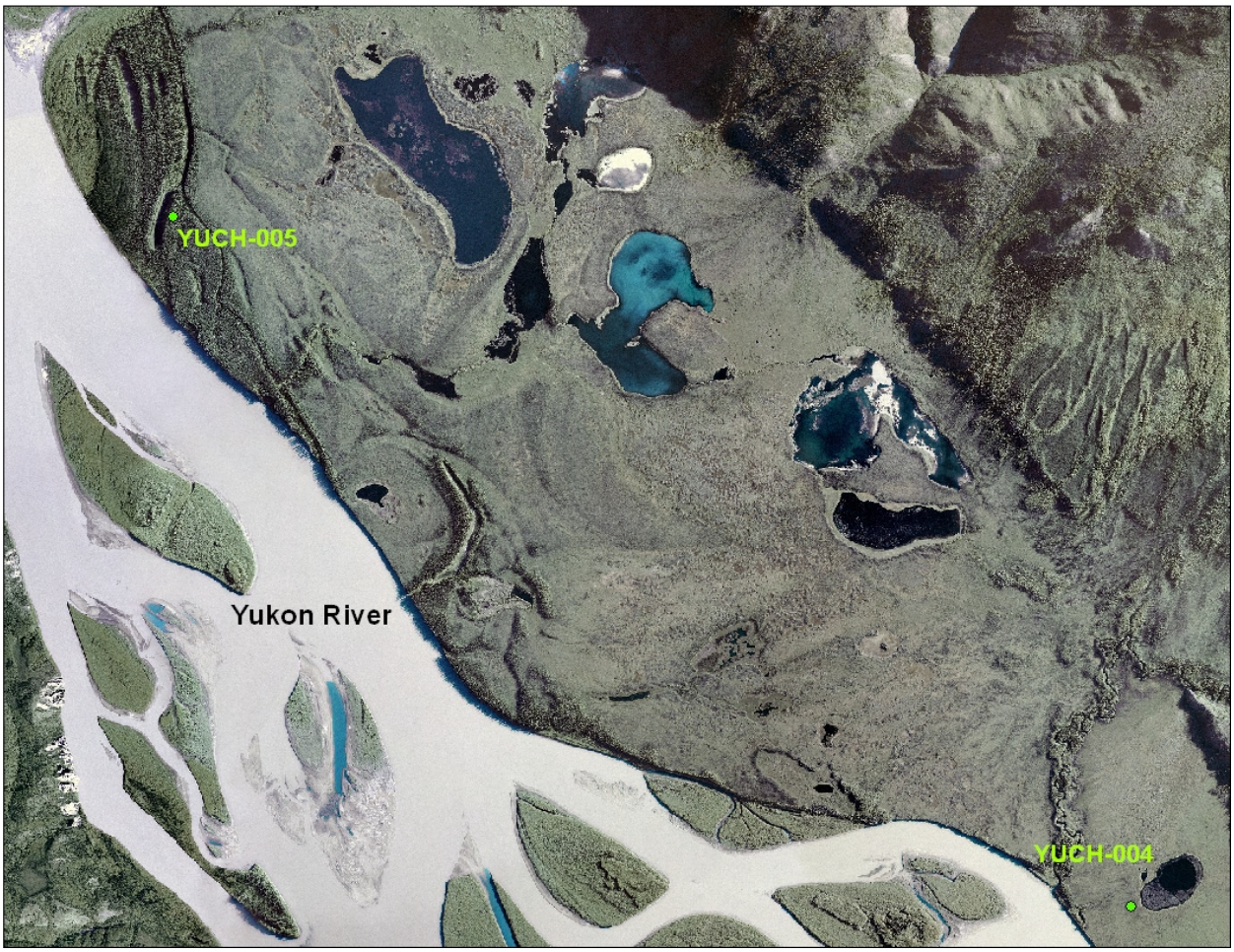

Figure 3. Locations of data logger arrays deployed in Yukon-Charley Rivers National Preserve

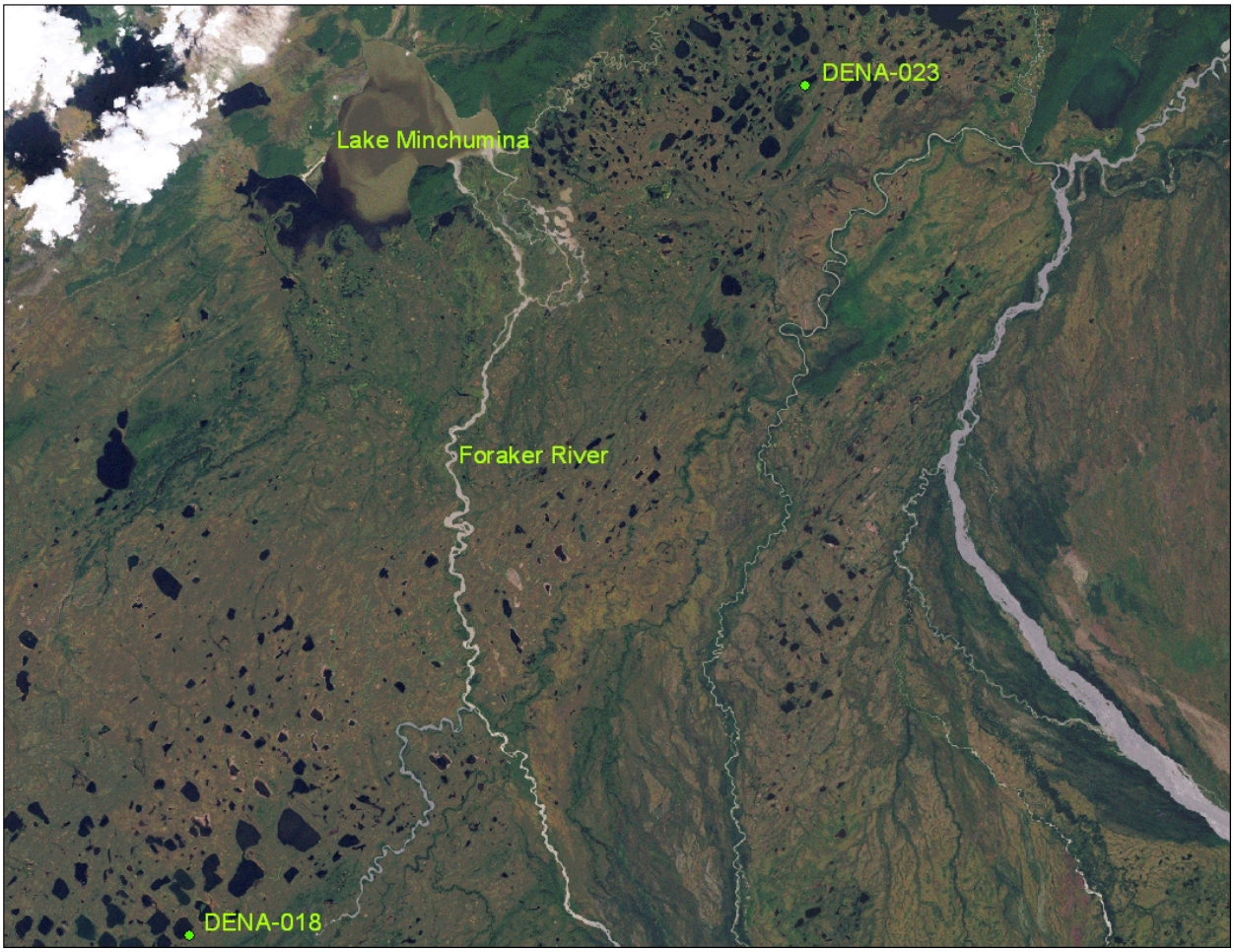

Figure 4. Locations of data logger arrays deployed in Denali National Park and Preserve

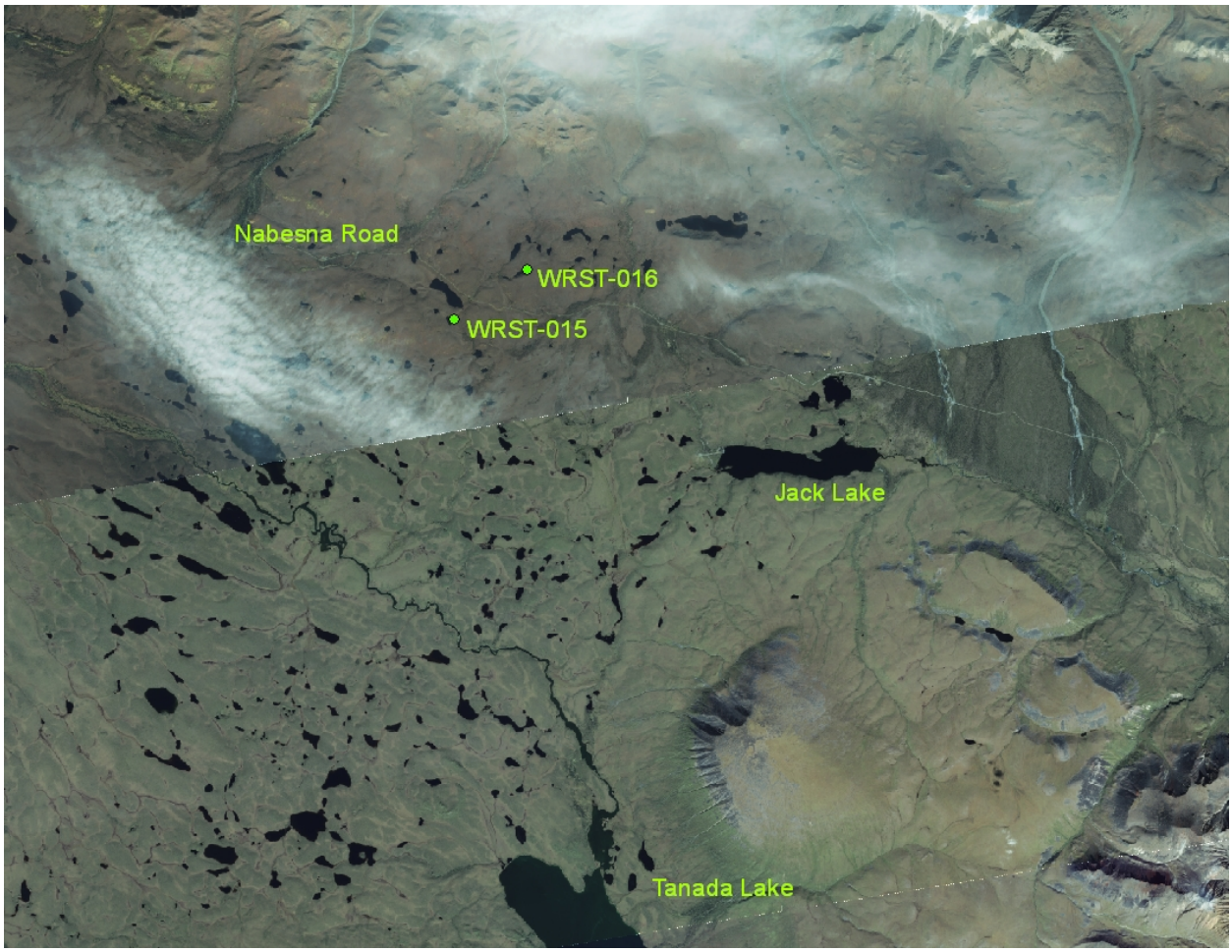

Figure 5. Locations of data logger arrays deployed in Wrangell-St. Elias National Park and Preserve

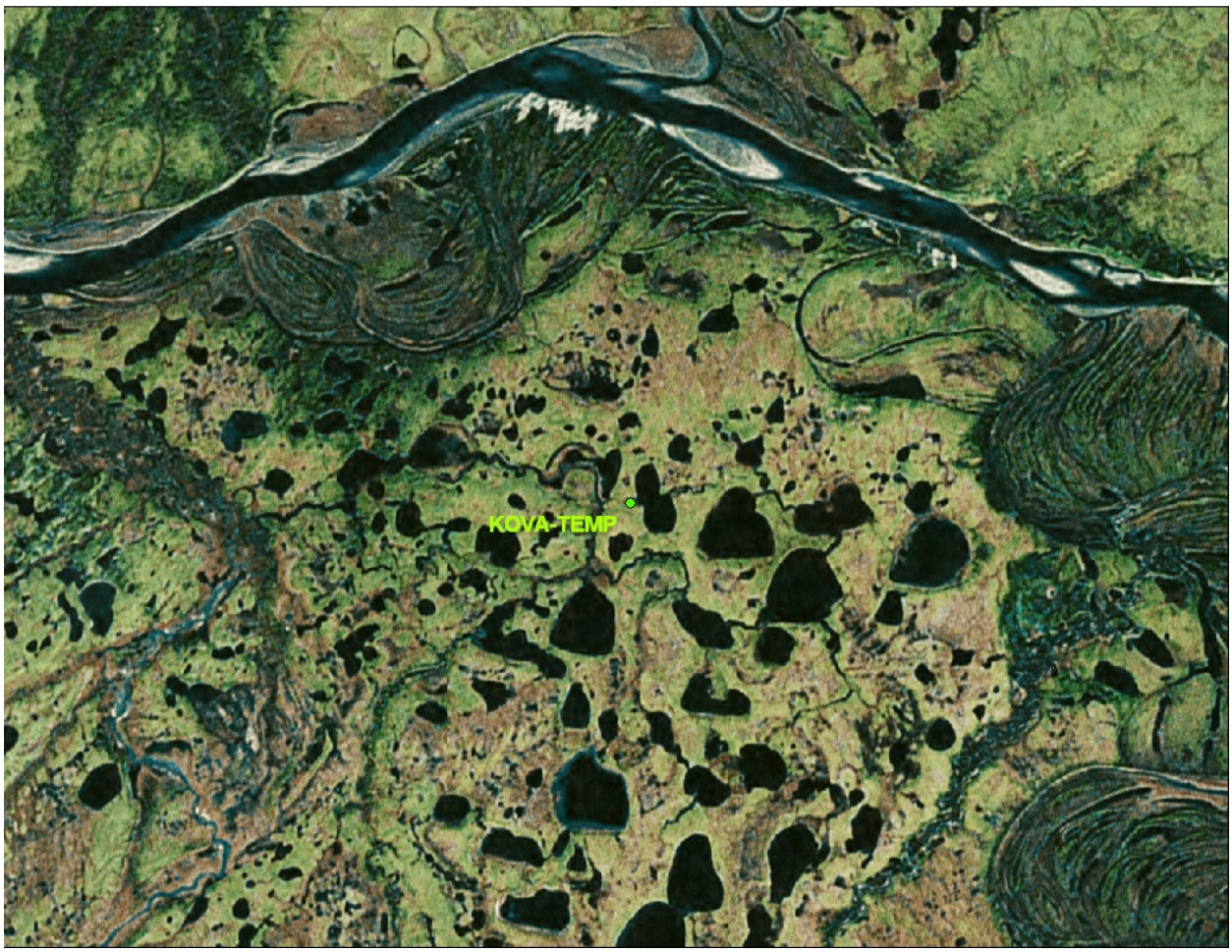

Figure 6. Locations of data logger array deployed in Kobuk Valley National Park

Sensor arrays

Each data logger array consisted of three types of data loggers: a water level/temperature logger, temperature/light loggers, and a multi-parameter probe that recorded dissolved oxygen, temperature, pH, and specific conductivity. Data loggers were attached to a line that stretched from the lake surface to the sediment. The line was anchored in place by a 10 kg kedge anchor and suspended from a number 1 fishing buoy.

The water level logger was situated on the bottom of the lake and recorded pressure every 12 hours. The water temperature/light loggers were located at 0.25, 0.5, 1.0, 1.5 and 3.0 m along the line and recorded measurements hourly. The multi-parameter probe was suspended directly from the surface buoy and recorded measurements hourly.

Logger arrays were placed in an area of the lake where water depth was equal to or greater than 3m. Arrays were installed in the lake shortly after ice-out and retrieved just prior to ice-on (Table 3). During retrieval, the multi-parameter probe and temperature/light loggers were removed, while the water level logger was downloaded and returned to the lake to continue recording during the winter.

Table 3. Multiparameter probe deployment and retrieval dates for each of the probes deployed in CAKN and ARCN

Lake	Deployment Date	Retrieval Date	Condition on Retrieval
DENA-018	May 28, 2009	September 24, 2009	Moved to shoreline
DENA-023	May 28, 2009	September 24, 2009	Moved to Shoreline; No data collected.
WRST-015	June 22, 2009	September 15, 2009	Excellent condition
WRST-016	June 22, 2009	September 15, 2009	Excellent condition
YUCH-004	May 31, 2009	September 21, 2009	Moved to shoreline
YUCH-005	May 31, 2009	September 23, 2009	Excellent condition
KOVA-TEMP	July 15, 2009	September 10, 2009	Excellent condition

Results

Synoptic Sampling

Physical description

Area, Depth, Stratification

Lakes in WRST ranged in size, depth and thermal stratification (Table 4). Lake area ranged from 1 to 316 ha in size, and mean depth ranged from 0.8 to 6.8 m, with a maximum lake depth of 12.3 m measured on WRST-004 in the Jack Valley. Lakes with mean depth greater than two meters were thermally stratified at the time of sampling, but the stability of the stratification is not known, as each lake was only sampled once during the season. The remaining 17 lakes in WRST were mixed throughout the water column.

Lakes in Kobuk Valley (Table 5) tended to be shallower than those in WRST, with the mean depth ranging from 0.4 to 3.5 m, and the maximum depth measured at 7.8 m. The lakes in KOVA were also smaller on average than lakes in WRST, with sizes ranging from 1 to 17.3 ha. Only 6 of the 29 lakes in KOVA were thermally stratified at the time of sampling. Again, the stability of the stratification in these lakes is unclear, as only one measurement was taken. In general, stability of thermal stratification is largely dependent on lake morphometry and prevailing weather conditions (Wetzel, 1983).

Shoreline Development Index

Shoreline length and lake surface area estimates were acquired from the National Hydrography Dataset for Alaska to estimate the Shoreline Development Index (D_L) for each lake sampled (Equation 1). Shoreline development is an important measure because it represents the potential for development of littoral communities (Hutchinson 1957), which frequently represent the most productive region of the lake ecosystem.

Equation 1. Shoreline Development Index (D_L)

$$D_L = \frac{S}{2\sqrt{A\pi}}$$ where S is the shoreline length in meters and A is the area of lake in square meters

A lake with a D_L of 1 is a perfect circle. Only a few lake types typically approach this lower limit for D_L, but these include crater lakes, kettle lakes and thaw lakes (Hutchinson 1957). Because there are numerous kettle lakes and many young thermokarst lakes in Alaska, it is not uncommon to see low D_L values. Long linear lakes or highly convoluted lakes have higher D_L values.

Values for the Shoreline Development Index in WRST ranged from 1.2 to 1.9, suggesting that all of the lakes sampled are subcircular/elliptical ($1.15<D_L<2.0$). Most of the lakes we sampled in WRST appeared to be kettle-hole lakes. This is consistent with the geologic history of the region, in which glacial retreats occurring approximately 12,000 years ago left large chunks of ice that have since melted to form kettle lakes.

In KOVA, the D_L values ranged from 1.04 to 2.76. Thirteen of the lakes sampled are circular (D_L<1.15), and likely formed due to thermokarst. This region was not glaciated recently, and the lakes are characteristic of thaw lakes. The remaining lakes in KOVA are subcircular/elliptical, with the exception of KOVA-002, which is a long thin oxbow lake with a D_L of 2.76.

Light Penetration

Secchi depth, an estimate of light penetration, varied from 1.10 to 5.7 m in WRST (Table 4). Light penetrated to the bottom of the lake in nine of the shallow lakes sampled in WRST. Secchi depths in the lakes sampled in KOVA ranged from 0.3 to 5.1 m (Table 5), with light penetrating to the bottom of 18 of these lakes. Light transmission is a function of the amount of particulate inorganic and organic material in the water column, and indicates what portion of the water column is available for photosynthetic activity (Wetzel, 1983).

Table 4, Morphometric and mixing characteristics of lakes sampled in Wrangell-St. Elias National Park and Preserve

Lake	Lake area (ha)	D_L	Secchi depth	Mean depth	Maximum Depth	Thermal Stratification
WRST-001	11.4	1.5	2.50	5.3	9.3	Stratified
WRST-002	4.0	1.2	3.75	3.7	6.6	Mixed
WRST-003	3.5	1.2	1.30	1.4	2.0	Mixed
WRST-004	2.8	1.3	3.25	6.8	12.3	Stratified
WRST-005	5.3	1.5	1.10	0.9	2.1	Mixed
WRST-006	13.6	1.3	2.30	5.1	12.1	Mixed
WRST-007	18.5	1.9	2.70	1.6	2.7	Mixed
WRST-008	7.2	1.8	1.70	1.3	2.0	Mixed
WRST-009	1.3	1.2	2.10	2.3	5.8	Stratified
WRST-010	5.8	1.2	2.00	1.3	2.1	Mixed
WRST-011	NA	NA	2.40	3.0	6.3	Stratified
WRST-012	16.7	1.3	1.00	0.9	1.1	Mixed
WRST-013	13.9	1.3	2.00	1.2	2.3	Mixed
WRST-014	4.2	1.3	1.40	1.1	1.4	Mixed
WRST-015	1.0	1.3	1.60	2.0	4.0	Stratified
WRST-016	1.5	1.2	1.80	3.1	5.4	Stratified
WRST-017	9.9	1.5	1.20	0.7	1.9	Mixed
WRST-018	316	1.5	1.40	1.4	4.1	Mixed
WRST-019	37.2	1.4	1.50	2.8	8.1	Stratified
WRST-020	1.5	1.6	1.20	1.3	2.2	Mixed
WRST-021	1.1	1.1	2.50	1.2	2.5	Mixed
WRST-022	3.1	1.1	1.70	0.8	1.7	Mixed
WRST-023	17.4	1.6	2.30	1.6	2.5	Mixed
WRST-024	43.7	1.7	1.90	1.6	2.5	Mixed
WRST-025	73.3	1.3	5.70	6.2	10.9	Mixed

Table 5. Morphometric and mixing characteristics of lakes sampled in Kobuk Valley National Park

Lake	Lake area (ha)	D_L	Secchi depth	Mean depth	Maximum Depth	Thermal Stratification
KOVA-001	2.7	1.18	1.80	1.3	1.6	Mixed
KOVA-002	9.2	2.76	1.80	1.7	4.2	Mixed
KOVA-003	1.9	1.41	1.50	0.8	1.5	Mixed
KOVA-004	17.3	1.11	1.40	1.2	1.6	Mixed
KOVA-005	2.2	1.42	3.90	4.3	7.8	Stratified
KOVA-006	17.3	1.10	3.50	3.4	5.8	Mixed
KOVA-007	1.5	1.38	0.90	1.0	1.7	Mixed
KOVA-008	2.4	1.20	1.90	0.9	2.0	Mixed
KOVA-009	1.5	1.12	1.50	0.7	1.5	Mixed
KOVA-010	1.0	1.77		0.6	1.2	Mixed
KOVA-011	1.8	1.07	2.00	1.3	2	Mixed
KOVA-012	8.0	1.72	1.00	0.7	1.3	Mixed
KOVA-013	1.2	1.11	2.10	2.1	5.1	Stratified
KOVA-014	1.5	1.15	1.50	1.5	3.6	Stratified
KOVA-015	2.1	1.73	3.60	2.2	4.7	Stratified
KOVA-016	1.2	1.11	0.30	0.4	0.9	Mixed
KOVA-017	3.2	1.11	1.00	0.8	1.4	Mixed
KOVA-018	1.3	1.14	2.05	3.5	7.5	Stratified
KOVA-019	1.9	1.09	0.70	0.6	0.8	Mixed
KOVA-020	7.5	1.60	5.10	1.6	5.3	Mixed
KOVA-021	2.6	1.07	2.20	1.4	2.7	Mixed
KOVA-022	5.6	1.10	2.30	1.4	2.3	Mixed
KOVA-023	5.2	1.10	1.30	1.0	1.4	Mixed
KOVA-024	13.8	1.77	2.15	2.0	3.4	Mixed
KOVA-025	2.7	1.04	2.20	1.4	2.2	Mixed
KOVA-026	4.1	1.23	1.80	1.5	2.3	Mixed
KOVA-027	5.6	1.15	0.60	0.7	0.9	Mixed
KOVA-029	1.0	1.24	2.40	1.3	3.0	Stratifed
KOVA-030	1.0	1.15	1.10	0.9	1.6	Mixed

Water chemistry

pH

Measurements of pH ranged from 5.8 to 8.9 in the lakes sampled in WRST (Table 6). This high degree of variation is not surprising, given the differences in geology across the park. The lakes in the northern section of the Park, in the vicinity of the Nabesna Road, had relatively low pH values (5.8-6.9). These lakes are largely underlain by quaternary glacial till borne from the surrounding mountains, which are composed of igneous rocks of andesite and basalt. While the lakes in the Chitina River Valley are also underlain by glacial till, the surrounding mountains are composed of sedimentary and mafic rocks, and these lakes had much higher pH measurements (8.1-8.9). Lakes in the Carden Hills, surrounded by mountains of igneous, mafic, ultramafic and metamorphic rock, had circumneutral pH values (7.3-7.6). Pearson correlation calculations for

this area showed that pH is highly correlated with specific conductivity, alkalinity, and each of the base cations (Table 8).

Measurements of pH in KOVA ranged from 5.7 to 8.8 (Table 7), and no clear pattern was evident across the park. This mosaic is likely due to the fact that the majority of lakes lie in areas of alluvial and eolian deposits of sand and silt. The watersheds in the northern section of the park are largely underlain by metamorphic schist while watersheds in the southern section are underlain by non-carboniferous sedimentary rock. Small areas of carboniferous rock reside in the northern and eastern sections. Pearson correlation calculations for this area showed that pH is highly correlated with silica, specific conductivity, alkalinity, calcium and magnesium (Table 9).

Alkalinity

Alkalinity (HCO_3^-) ranged between 1.9 and 28.6 mg/L HCO_3^- in the lakes sampled in WRST, indicating a wide range in their buffering capacity (Table 6). Alkalinity (HCO_3^-) was highest in the Chitina River Valley, due to carboniferous rocks, and lowest in the lowland areas near the Nabesna Road, where the underlying substrate is composed of igneous rock. In general, the buffering capacity of lakes in the Chitinia River Valley is considerably higher than lakes in the northwestern section of the park.

In KOVA, alkalinity measurements ranged from 0.70 to 37.63 (Table 7). Alkalinity was highest in lakes in the southern section of the park and lowest in the Akillik Plain and the Salmon-Hunt Fork terraces. This is not surprising given the dominance of metamorphic schist in the northern reaches of the park, as opposed to more sedimentary rock to the south.

Specific Conductivity

Specific conductivity of lake water sampled in both parks was relatively low, ranging from 17.0 to 193.0 µS/cm in WRST (Table 6) and 11.2 to 203.9 µS/cm in KOVA (Table 7). Specific conductivity varied greatly among lakes within WRST, but the lakes with the highest specific conductivity tended to be in the Chitina River Valley, where more easily weathered carbonate rocks predominate (Figure 7). Specific conductivity was also high in WRST-004, which is a small lake situated adjacent to the Nabesna Road; this lake is likely receiving calcium from the road by way of dust particles, which could contribute to higher specific conductivity. WRST-001 also had high specific conductivity, which may be due to sedimentary rock in the upper portions of the watershed, in addition to the highest measured concentrations of Si, Na, and Cl.

Specific conductivity measurements from WRST were highly correlated with the base ions, particularly with cations (Table 10). Ion concentrations were generally lowest in the Natat Plain, Snag Beaver Creek Plain and the Tanada Moraine (Table 11, Figure 9). The Chitina River Valley had high concentrations of Ca, Mg and K, likely due to the carboniferous rocks in the region.

Specific conductivity was highly correlated with base cations and anions in KOVA. Lakes that were sampled north of the Kobuk River tended to have lower specific conductivity than those sampled in the Kobuk River floodplain, Ahnewetut wetlands or on the Nigeruk Plain (Figure 8). Base cations (Ca, Mg, K) and anions (Cl and SO_4) followed this pattern as well (Table 12, Figure 10). Silica concentrations tended to be highest in the Ahnewetut wetlands, adjacent to the sand

dunes, and in the Kobuk River floodplain. The Great and Little Kobuk Sand Dunes, along with large deposits of sand along the Kobuk River, are likely the primary source of SiO_2 in this region. In the southern section of the park, the eolian and alluvial deposits, which are rich in carboniferous sediment, likely serve as the primary source of ions.

KOVA-018 had extremely high concentrations of all base cations and anions as well as high specific conductivity (Table 12, Table 7), which may be due to fine silt being deposited into the water column by the large thermokarst slump on the eastern lake shore. Cation concentrations in lakes with retrogressive thaw slumps are significantly higher than in adjacent undisturbed lakes (Kokelj *et al.*, 2005) in Northwest Territories, Canada.

Table 6. Mean pH, Alkalinity and specific conductivity in lakes in Wrangell-St. Elias National Park and Preserve

Lake	pH	Alkalinity (HCO_3^-)	Specific Conductivity (µS/cm)
WRST-001	6.3	11.1	101.7
WRST-002	6.9	7.2	57.3
WRST-003	5.8	3.2	31.4
WRST-004	7.0	13.2	136.43
WRST-005	6.1	2.5	40.7
WRST-006	6.4	4.0	36.5
WRST-007	6.2	3.1	28.0
WRST-008	6.6	4.3	36.3
WRST-009	6.3	2.8	28.1
WRST-010	6.2	2.9	27.1
WRST-011	6.1	2.8	26.3
WRST-012	6.1	1.9	18.9
WRST-013	6.2	2.6	25.6
WRST-014	6.3	1.9	17.0
WRST-015	6.7	4.9	43.9
WRST-016	6.7	6.9	59.9
WRST-017	7.8	6.7	55.0
WRST-018	7.9	7.1	59.1
WRST-019	7.3	4.7	47.2
WRST-020	6.5	2.2	23.2
WRST-021	8.1	15.6	119.3
WRST-022	8.5	23.4	173.4
WRST-023	8.8	28.6	193.0
WRST-024	8.9	10.4	83.4
WRST-025	8.7	24.6	166.1

Table 7. Mean pH, Alkalinity and specific conductivity in lakes in Kobuk Valley National Park

Lake	pH	Alkalinity (HCO_3^-)	Specific Conductivity (µS/cm)
KOVA-001	8.60	14.17	84.7
KOVA-002	8.35	14.86	93.3
KOVA-003	7.33	3.56	29.2
KOVA-004	8.17	8.30	62.5
KOVA-005	8.53	9.71	69.7
KOVA-006	8.27	21.30	119.3
KOVA-007	7.30	2.90	26.6
KOVA-008	7.60	4.21	37.1
KOVA-009	6.77	2.01	22.1
KOVA-010	7.80	6.83	60.3
KOVA-011	7.20	2.19	18.7
KOVA-012	6.50	1.02	11.2
KOVA-013	7.30	2.56	23.2
KOVA-014	8.03	11.29	91.8
KOVA-015	7.10	2.41	22.9
KOVA-016	5.73	1.06	17.3
KOVA-017	5.73	0.70	10.5
KOVA-018	8.50	37.63	203.9
KOVA-019	7.87	3.21	28.4
KOVA-020	8.67	8.52	49.7
KOVA-021	6.70	1.12	10.3
KOVA-022	6.67	1.31	15.0
KOVA-023	8.67	6.91	53.2
KOVA-024	7.73	4.30	36.7
KOVA-025	7.23	2.05	17.9
KOVA-026	6.67	1.29	14.1
KOVA-027	5.70	0.81	13.4
KOVA-029	8.77	4.23	33.8
KOVA-030	8.83	6.83	52.0

Table 8. Pearson values for the correlation of pH with specific conductivity, alkalinity, and base cations in lakes in Wrangell-St. Elias National Park and Preserve.

Ion	Pearson r	p
Na^+	0.457	<0.001
K^+	0.409	<0.001
Ca^{2+}	0.696	<0.001
Mg^{2+}	0.668	<0.001
Sp. Cond	0.725	<0.001
Alkalinity	0.702	<0.001

Table 9. Pearson values for the correlation of pH with silica, specific conductivity, alkalinity, and base ions in lakes in Wrangell-St. Elias National Park and Preserve.

Ion	Pearson r	p
SiO_2	0.417	<0.001
Ca^{2+}	0.654	<0.001
Mg^{2+}	0.410	<0.001
Sp. Cond	0.602	<0.001
Alkalinity	0.588	<0.001

Table 10. Pearson values for the correlation of specific conductivity with base ions in lakes in Wrangell-St. Elias National Park and Preserve.

Ion	Pearson r	p
Na^+	0.711	<0.001
K^+	0.800	<0.001
Ca^{2+}	0.980	<0.001
Mg^{2+}	0.964	<0.001
SO_4^{2-}	0.357	<0.001
Cl^-	0.429	<0.001

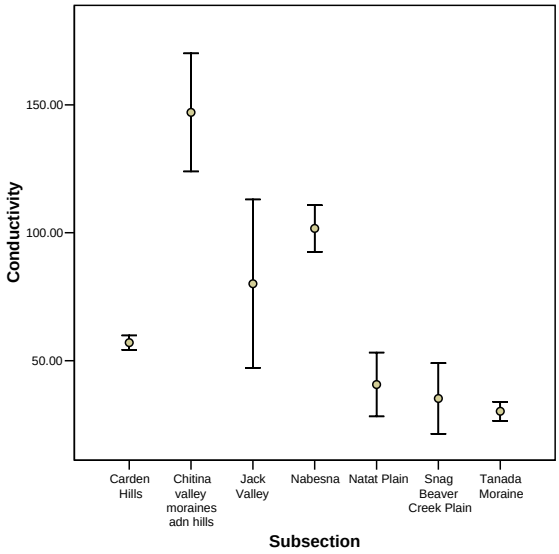

Figure 7. Mean (+/-SE) specific conductivity (µS/cm) in the seven subsections of Wrangell-St. Elias National Park and Preserve

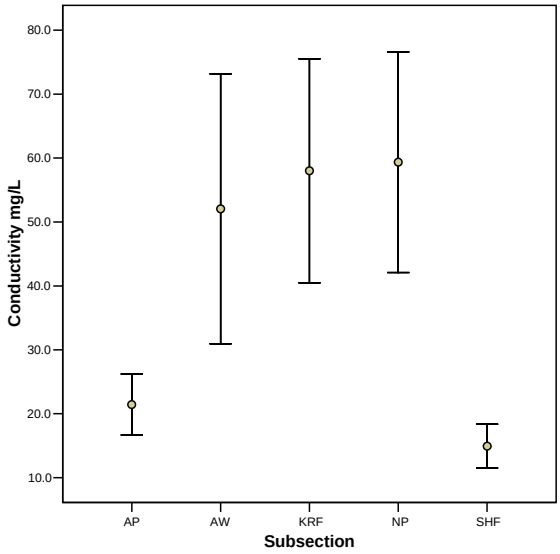

Figure 8. Mean (+/-SE) specific conductivity (µS/cm) in the seven subsections of Kobuk Valley National Park

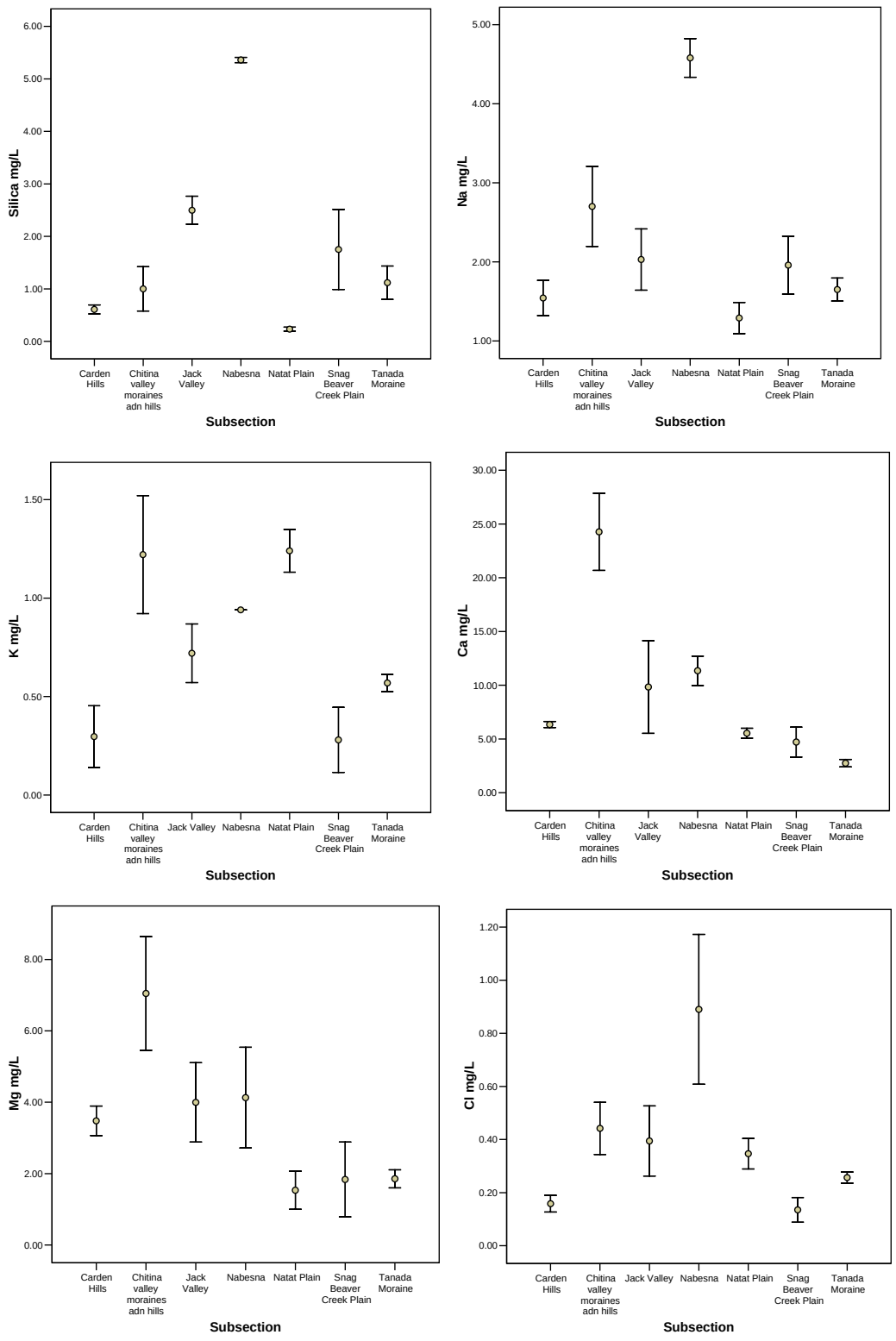

Figure 9. Mean (+/-SE) cation concentrations (mg/L) in the seven subsections of Wrangell-St. Elias National Park and Preserve

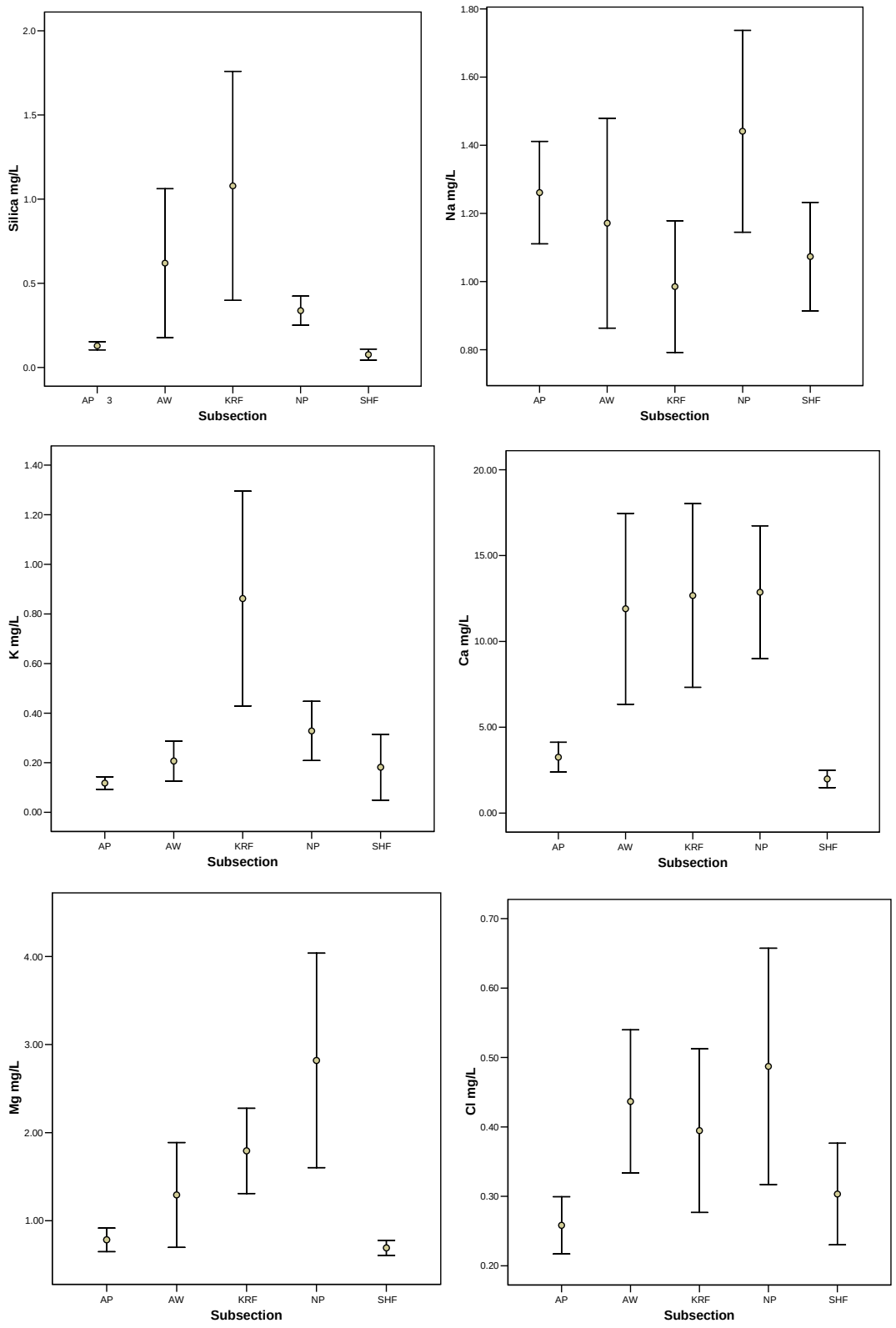

Figure 10. Mean (+/-SE) cation concentrations (mg/L) in the seven subsections of Kobuk Valley National Park

Table 11. Mean cation and anion concentration (mg/L) by lake in Wrangell St.-Elias National Park and Preserve

Lake	Major Cations				Major Anions		
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	NO_3^{-}	Cl^{-}
WRST-001	11.3	4.1	4.6	0.94	1.91	0.001	0.89
WRST-002	4.6	3.6	2.5	0.88	0.14	0.002	0.36
WRST-003	2.9	2.3	1.8	0.63	0.13	0.000	0.30
WRST-004	17.2	5.9	2.7	0.97	4.61	0.002	0.62
WRST-005	5.5	1.5	1.3	1.24	2.50	0.000	0.35
WRST-006	3.5	2.5	2.2	0.61	0.25	0.000	0.29
WRST-007	2.7	1.6	1.5	0.51	0.09	0.000	0.25
WRST-008	4.1	1.9	1.7	0.63	0.11	0.000	0.31
WRST-009	2.4	1.9	1.7	0.61	0.18	0.000	0.28
WRST-010	2.5	1.8	1.7	0.49	0.12	0.000	0.21
WRST-011	2.2	1.6	1.4	0.45	0.13	0.000	0.25
WRST-012	1.3	1.1	1.2	0.38	0.12	0.000	0.19
WRST-013	2.6	1.4	1.2	0.59	0.07	0.000	0.18
WRST-014	1.3	0.9	1.3	0.52	0.10	0.000	0.20
WRST-015	5.0	2.8	1.6	0.54	0.28	0.000	0.26
WRST-016	7.3	3.3	1.9	0.65	0.21	0.003	0.30
WRST-017	6.2	3.2	1.5	0.17	0.25	0.001	0.15
WRST-018	6.5	3.7	1.6	0.42	0.26	0.000	0.17
WRST-019	5.9	2.7	1.7	0.42	0.93	0.000	0.17
WRST-020	3.5	0.9	2.3	0.14	0.33	0.009	0.10
WRST-021	21.0	4.7	2.0	0.53	0.13	0.003	0.24
WRST-022	29.5	7.8	2.3	1.53	0.04	0.002	0.61
WRST-023	29.5	10.9	3.8	1.88	0.32	0.002	0.63
WRST-024	13.6	3.2	1.7	0.69	0.26	0.001	0.24
WRST-025	27.8	8.6	3.6	1.48	1.69	0.002	0.49

Table 12. Mean cation and anion concentration (mg/L) by lake in Kobuk Valley National Park.

Lake	Major Cations				Major Anions		
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	NO_3^{-}	Cl^{-}
KOVA-001	20.6	4.4	0.8	0.4	0.02	0.002	0.27
KOVA-002	24.7	2.7	0.8	0.7	0.03	0.001	0.36
KOVA-003	4.1	1.0	1.0	0.1	0.14	0.000	0.14
KOVA-004	14.9	0.9	0.6	0.1	0.02	0.001	0.39
KOVA-005	19.4	2.1	0.6	0.3	0.05	0.000	0.34
KOVA-006	29.8	3.3	2.0	0.4	0.06	0.008	0.74
KOVA-007	4.3	1.4	1.8	0.1	0.34	0.001	0.35
KOVA-008	4.9	1.9	1.6	0.2	0.08	0.004	0.45
KOVA-009	3.8	1.0	1.2	0.1	0.10	0.000	0.28
KOVA-010	8.1	2.1	1.3	2.3	0.08	0.000	0.77
KOVA-011	2.6	0.8	1.2	0.3	0.11	0.002	0.35
KOVA-012	1.4	0.6	1.0	0.1	0.09	0.001	0.25
KOVA-013	4.1	1.0	1.1	0.2	0.09	0.000	0.28
KOVA-014	15.8	2.9	1.5	0.2	0.08	0.000	0.20
KOVA-015	4.0	0.9	1.0	0.4	0.10	0.000	0.46
KOVA-016	2.3	0.8	1.7	0.1	0.11	0.000	0.30
KOVA-017	1.2	0.4	1.3	0.1	0.14	0.000	0.26
KOVA-018	44.3	14.3	4.1	1.4	0.56	0.080	2.09
KOVA-019	4.9	0.5	1.0	0.2	0.08	0.001	0.55
KOVA-020	17.5	1.7	1.5	0.2	0.08	0.002	0.42
KOVA-021	1.8	0.4	0.8	0.1	0.06	0.000	0.19
KOVA-022	2.1	0.4	1.0	0.2	0.09	0.000	0.39
KOVA-023	11.0	1.4	1.5	0.2	0.09	0.001	0.48
KOVA-024	5.6	1.2	1.2	0.2	0.12	0.000	0.29
KOVA-025	3.4	0.6	1.0	0.1	0.07	0.000	0.20
KOVA-026	1.9	0.5	1.0	0.5	0.06	0.000	0.35
KOVA-027	1.5	0.6	1.3	0.1	0.12	0.000	0.36
KOVA-029	5.6	1.1	0.9	0.1	0.05	0.001	0.14
KOVA-030	10.8	1.8	1.1	0.2	0.07	0.000	0.15

Nutrients

Concentrations of the major nutrients ranged from 0.320 to 1.670 mg/L TN and 0.008 to 0.029 mg/L TP in WRST (Table 13), while in KOVA the values ranged from 0.230 to 2.070 mg/L TN and 0.006 to 0.044 mg/L TP (Table 14). The range of TN in KOVA is misleading, however, as only KOVA-018 had a TN concentration measurement greater than 1.000. The extremely high concentration of TN measured in KOVA-018 may be due to the presence of a large retrogressive thaw slump along the eastern edge of the lake that contributed large quantities of mineral sediment to the lake.

Pearson Correlation calculations show that TN is highly correlated with DOC in WRST ($r = 0.839$, $p < 0.001$), but is not well correlated in KOVA ($r = 0.240$, $p < 0.05$). This correlation suggests that, in WRST, the majority of TN found in the lakes comes in via allochthonous inputs, the primary source of DOC in forested wetlands. These organic components are also likely high in dissolved organic nitrogen, which is not measured in the Shallow Lakes Monitoring protocol.

Total nitrogen, total phosphorus and Chlorophyll-*a* are commonly used to determine the trophic state of shallow lakes, but in Alaska TN can be dominated by organic forms of nitrogen that are not readily available for photosynthetic activity. As such, TN will not be used as a metric of trophic state for the lakes in this study; only TP and Chl*a* measurements will be used for the determination of trophic state.

In WRST, the TP concentrations indicate that 76% of the lakes sampled are mesotrophic and 24% are oligotrophic. Chl*a* concentrations suggest the majority of the lakes sampled are oligotrophic (92%) compared to 8% being classified as mesotrophic. Additional seasonal measurements are necessary to accurately determine the trophic state of these lakes. In KOVA, the TP concentrations indicate that 48% of the lakes sampled are mesotrophic, 45% are oligotrophic, and 7% are eutrophic. Chl*a* concentrations suggest that all of the lakes sampled are oligotrophic.

The ratio of nitrogen to phosphorus (N:P) has historically been used to identify the primary nutrient limiting phytoplankton productivity. Nitrogen to phosphorus ratios in excess of 20 indicate P limitation (Smith, 1984). In WRST, N:P ratios varied between 19-128 and in KOVA the ratios ranged from 15-152. These data suggest that all of the lakes sampled, with the exception of WRST-001 and KOVA-007, are limited by phosphorus. Lake WRST-001 had N:P values close to 20, suggesting that WRST-001 is potentially limited by both N and P (Smith, 1979).

In WRST, phosphorus limitation is supported by the positive relationship observed between TP and Chl*a*. Multiple regression analysis indicates algal biomass in WRST, as measured by Chl*a*, is significantly related to TP ($r^2 = 0.315$, $p < 0.001$, $f = 18.137$ $df_{2,72}$). In KOVA, however, variation in Chl*a* is better explained by TN ($r^2 = 0.526$, $p < 0.001$ $df_{1, 88}$) than TP ($r^2 = 0.333$, $p < 0.001$, $df_{1, 88}$), indicating a potential nitrogen limitation in spite of the N:P ratio.

DOC concentrations ranged from 6.08 to 29.37 mg/L in WRST (Table 15) and from 4.70 to 53.34 mg/L in KOVA (Table 16). DOC values in WRST tended to be highest in low elevation lakes near McCarthy, while DOC was relatively low in lakes near the Nabesna Road, which are

surrounded by rocky terrain with little peat. In KOVA, DOC tended to be higher in lakes in the Nigeruk and Aikillik Plains, probably due to thicker peat deposits in these two areas. Lakes in the Ahnewetut Wetlands had low DOC, likely due to groundwater inputs to lakes in this region and thin peat layers in the surrounding upland habitat.

Table 13. Mean total nitrogen (TN), total phosphorus (TP), Chlorophyll-a and secchi depth in lakes of Wrangell-St. Elias National Park and Preserve

Lake	TN (mg/L)	TP (mg/L)	Chl-*a* (mg/L)	N:P	Secchi Depth
WRST-001	0.333	0.018*	2.30	19	2.5
WRST-002	0.447*	0.009	1.20	50	3.7
WRST-003	0.693**	0.016*	0.54	43	1.3
WRST-004	0.320	0.010	0.80	32	3.3
WRST-005	0.720**	0.015*	1.46	48	1.1
WRST-006	0.513*	0.010	0.93	51	2.3
WRST-007	0.517*	0.011*	0.89	47	2.7
WRST-008	0.597*	0.009	1.13	66	1.7
WRST-009	0.587*	0.013*	0.58	45	2.1
WRST-010	0.477*	0.012*	0.89	40	2.0
WRST-011	0.477*	0.012*	0.10	40	2.4
WRST-012	0.497*	0.013*	1.75	38	1.0
WRST-013	0.623*	0.012*	1.47	52	2.0
WRST-014	0.463*	0.008	0.82	58	1.4
WRST-015	0.637*	0.014*	0.78	46	1.6
WRST-016	0.583*	0.014*	1.39	42	1.8
WRST-017	0.817**	0.029*	1.91	28	1.2
WRST-018	0.787**	0.017*	3.20	46	1.4
WRST-019	0.717**	0.012*	3.06	60	1.5
WRST-020	0.763**	0.025*	7.97*	31	1.2
WRST-021	0.767**	0.013*	1.26	59	2.5
WRST-022	1.670***	0.013*	1.78	128	1.7
WRST-023	1.233***	0.015*	2.65	82	2.3
WRST-024	0.987**	0.018*	5.97*	55	1.9
WRST-025	0.333	0.009	1.60	37	5.7

*mesotrophic lakes

**Eutrophic lakes

***Hypereutrophic lakes

Table 14. Mean total nitrogen (TN), total phosphorus (TP), Chlorophyll-a and secchi depth in lakes of Kobuk Valley National Park and Preserve

Lake	TN (mg/L)	TP (mg/L)	Chl-*a* (mg/L)	N:P	Secchi Depth
KOVA-001	0.403*	0.009	0.83	46	1.8
KOVA-002	0.332	0.010	0.65	33	2.7
KOVA-003	0.580*	0.018*	0.83	32	1.5
KOVA-004	0.323	0.008	0.61	43	1.4
KOVA-005	0.280	0.007	0.58	42	3.9
KOVA-006	0.417*	0.009	1.25	45	3.5
KOVA-007	0.423*	0.029*	1.85	15	0.9
KOVA-008	0.510*	0.018*	1.00	29	1.9
KOVA-009	0.547*	0.012*	0.88	46	1.5
KOVA-010	0.743**	0.015*	1.11	49	M
KOVA-011	0.333	0.008	1.04	41	2.0
KOVA-012	0.403*	0.013*	1.19	30	1.0
KOVA-013	0.423*	0.008	0.90	54	2.1
KOVA-014	0.863**	0.026*	0.89	33	1.5
KOVA-015	0.433*	0.008	0.58	52	3.6
KOVA-016	0.933**	0.033**	3.32	28	0.3
KOVA-017	0.467*	0.017*	1.15	27	1.0
KOVA-018	2.000***	0.013*	3.49	152	2.1
KOVA-019	0.557*	0.013*	1.75	44	0.7
KOVA-020	0.317	0.007	0.76	50	5.1
KOVA-021	0.383*	0.009	1.17	41	2.2
KOVA-022	0.620*	0.013*	1.39	48	2.3
KOVA-023	0.593*	0.013*	2.77	45	1.3
KOVA-024	0.417*	0.011*	1.19	39	2.2
KOVA-025	0.323	0.006	1.25	51	2.2
KOVA-026	0.517*	0.009	1.28	54	1.8
KOVA-027	0.883**	0.042**	2.89	21	0.6
KOVA-029	0.423*	0.013*	1.16	32	2.4
KOVA-030	0.403*	0.007	0.94	54	1.1

*mesotrophic lakes

**Eutrophic lakes

***Hypereutrophic lakes

Table 15. Mean DOC (mg/L) concentration by lake in Wrangell St.-Elias National Park and Preserve

Lake	DOC
WRST-001	7.92
WRST-002	7.06
WRST-003	17.61
WRST-004	7.90
WRST-005	16.04
WRST-006	16.23
WRST-007	13.58
WRST-008	15.44
WRST-009	16.61
WRST-010	14.28
WRST-011	13.86
WRST-012	13.24
WRST-013	17.47
WRST-014	8.21
WRST-015	20.17
WRST-016	16.50
WRST-017	13.17
WRST-018	13.25
WRST-019	18.06
WRST-020	16.66
WRST-021	16.11
WRST-022	29.37
WRST-023	23.28
WRST-024	18.20
WRST-025	6.08

Table 16. Mean DOC (mg/L) concentration by lake in Kobuk Valley National Park

Lake	DOC
KOVA-001	7.29
KOVA-002	10.68
KOVA-003	13.52
KOVA-004	5.21
KOVA-005	7.09
KOVA-006	5.11
KOVA-007	53.34
KOVA-008	18.13
KOVA-009	21.69
KOVA-010	16.06
KOVA-011	6.70
KOVA-012	10.08
KOVA-013	14.25
KOVA-014	18.34
KOVA-015	14.51
KOVA-016	24.70
KOVA-017	24.70
KOVA-018	20.42
KOVA-019	11.45
KOVA-020	4.70
KOVA-021	8.91
KOVA-022	14.17
KOVA-023	7.92
KOVA-024	8.63
KOVA-025	8.60
KOVA-026	11.61
KOVA-027	24.78
KOVA-029	10.42
KOVA-030	8.35

Continuous Sampling

Before analyzing Continuous Monitoring data from any of the dataloggers, the dataset from each logger was limited to include only the data collected while the sensors were actually in the lake. These limits were set using StreamlineENV software, and the clipped datasets were then used to calculate mean daily, weekly, monthly and annual estimates for temperature, dissolved oxygen, pH and specific conductivity.

Once data were plotted we evaluated each set of values by lake. This QA/QC analysis revealed a series of issues with the probes. When we retrieved the datalogger arrays from DENA-018 and YUCH-004, the YSI Sondes were on the lake shoreline and the sensors were embedded in the lake sediment. This had a significant impact on DO, pH and specific conductivity, and was visible in the dataset downloaded from these dataloggers. During review of the data we were able to discern that the DENA-018 probes had drifted to shore on June 24, however we were not able to discern when the YUCH-004 had been relocated. All DENA-018 data collected after June 24 were flagged as unusable in the data file. YUCH-004 data closely paralleled patterns in YUCH-005 so the data will be retained. We have included all the data in this report to illustrate the problems with sensors/probes but flagged data will not be used in future trend analysis.

We also experienced extensive problems with collecting DO data. All probes outfitted with rapid pulse sensors failed, including those deployed at DENA-018, WRST-016, WRST-015, and YUCH-005. We are evaluating the sensors to determine the cause of the failure and will begin to phase out the use of rapid pulse sensors. The two probes outfitted with optical DO sensors performed significantly better than the rapid pulse sensors. We acquired what appears to be a good set of data from the optical DO sensor deployed in YUCH-004, at least until the sonde came loose from the array. The optical DO sensor on KOVA-TEMP also collected a full set of data, but shows evidence of instrument drift, which will require correction.

Temperature

Epilimnetic temperature differed among lakes, with mean summer temperatures ranging from 12.9 to 16.5°C (Figure 11). Lakes in YUCH were the warmest and lakes in WRST the coolest. Patterns in temporal variation over the course of the season were consistent among lakes, with epilimnetic waters warming in all lakes from the time of deployment in late May through mid-June. Above average temperatures in May resulted in mean daily (Figure 12) and weekly (Figure 13) epilimnetic temperatures nearing summer maximums very early in the season, yet mean monthly temperature calculations illustrate that, overall, temperatures warmed from May to July, then cooled fairly steadily until the sensors were removed at the end of the season (Figure 14).

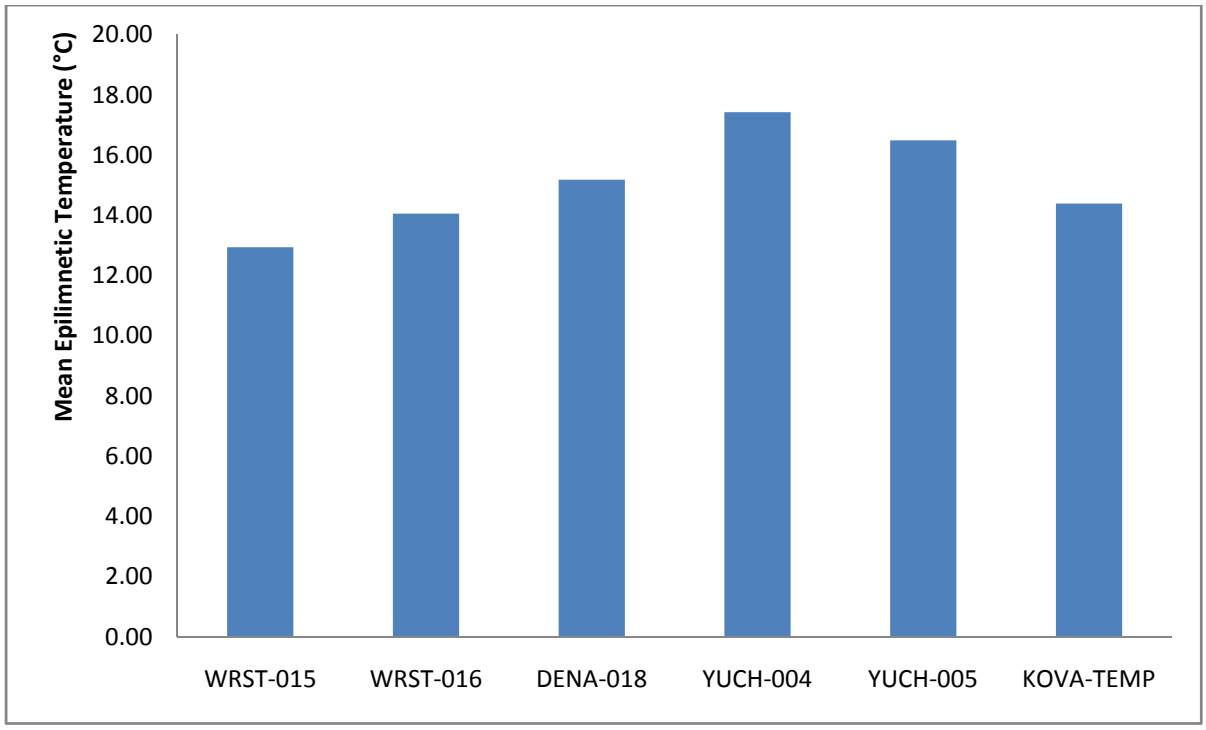

Figure 11. Mean summer epilimnetic temperature in each lake monitored with a sonde in CAKN and ARCN

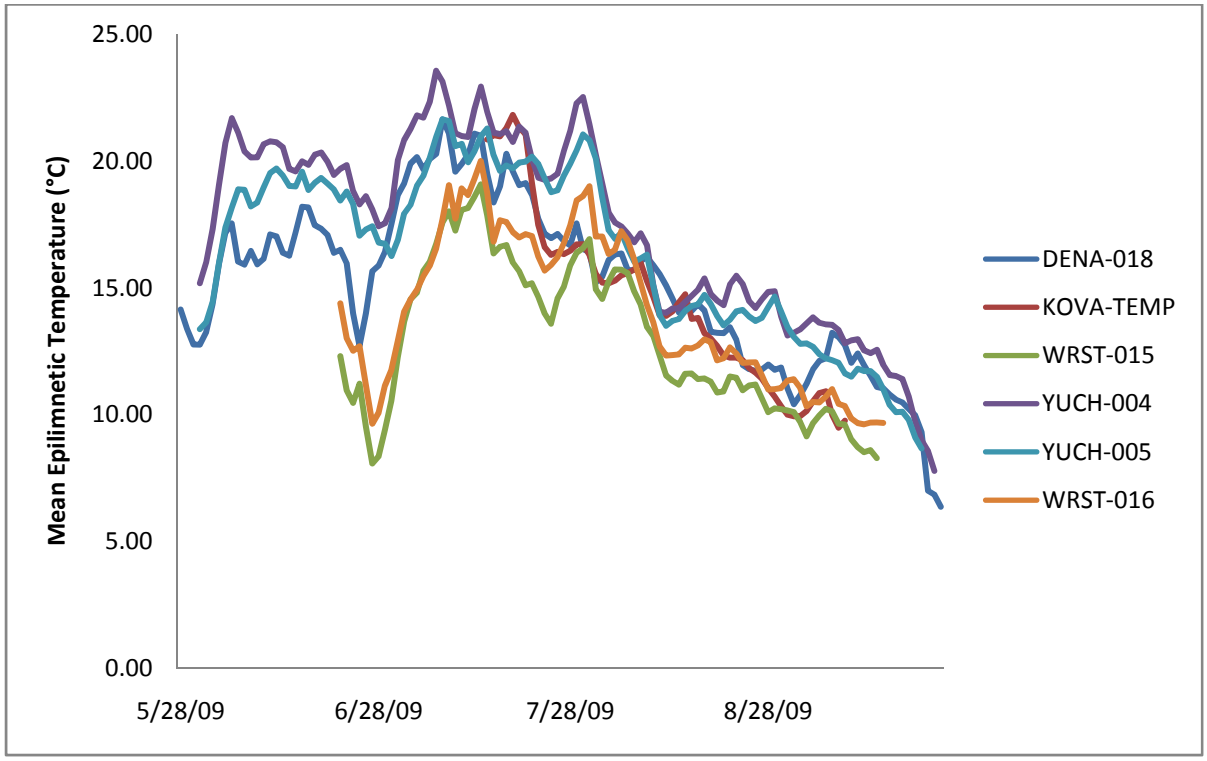

Figure 12. Mean daily epilimnetic temperature in each continuously monitored lake in CAKN and ARCN

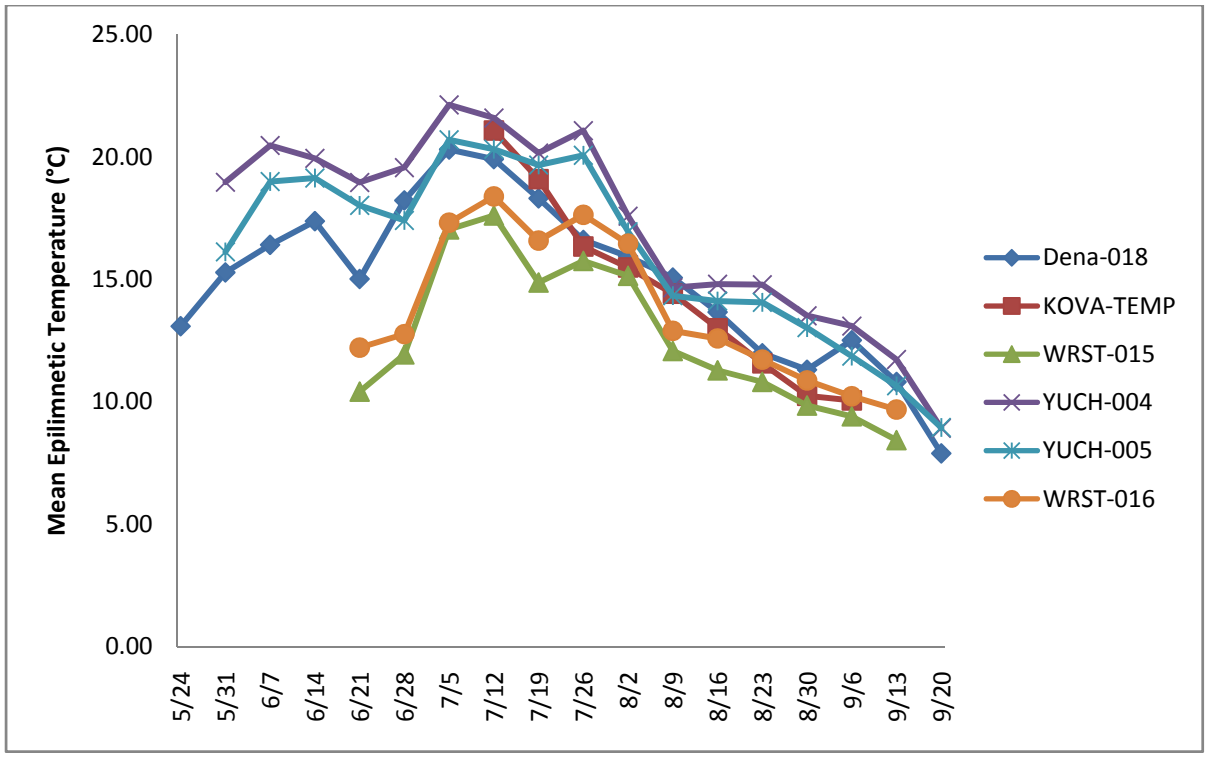

Figure 13. Weekly mean temperature for each sonde deployed in CAKN and ARCN

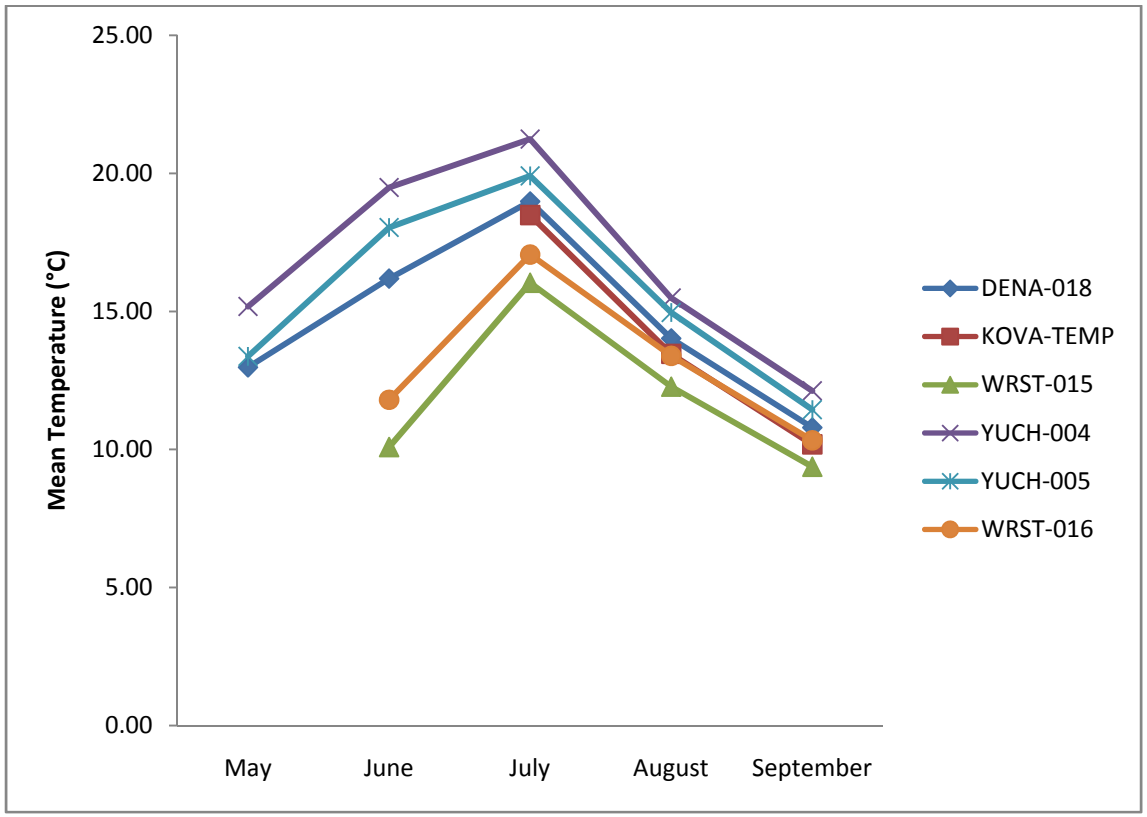

Figure 14. Monthly mean temperature for each sonde deployed in CAKN and ARCN

Specific conductivity

Both WRST and KOVA lakes were very dilute and had extremely stable specific conductivity throughout the entire open water season (Figure 16). Mean summer specific conductivity varied between 0.038 and 0.185 mS/cm among lakes (Figure 15). YUCH-005 had the highest specific conductivity. Daily (Figure 16) and weekly (Figure 17) variation in specific conductivity was very low (<10%) in WRST-015, WRST-016, KOVA-TEMP and moderate (<25%) in YUCH-004. Specific conductivity was stable in DENA-018 until the sonde moved in late June (data for this sonde will not be used in future trend analysis but is presented here for demonstration purposes).

Specific conductivity in YUCH-005 varied 43% over the deployment period ranging between 0.145 and 0.252 mS/cm. The cause of variation in this lake is not well understood but may correspond to fluctuating water levels on the Yukon River. The lake appears to be isolated from surface water inputs, but the variation may be due to groundwater or hyporheic flow from the Yukon River.

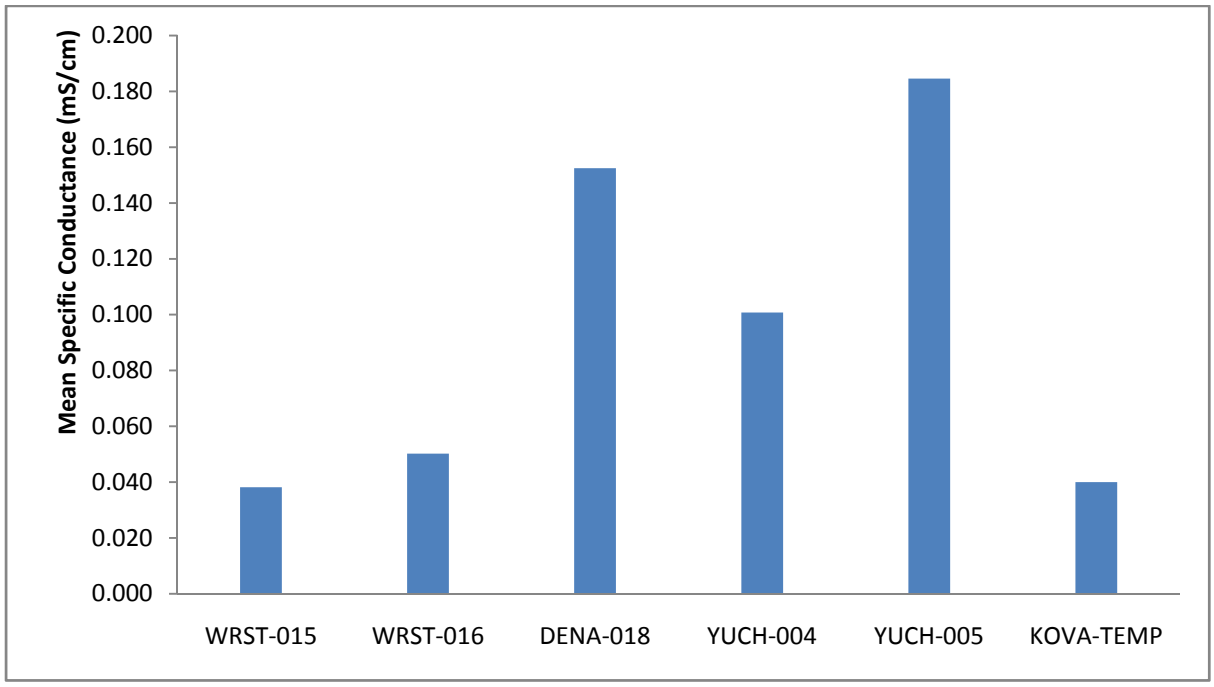

Figure 15. Mean summer specific conductivity in each continuously monitored lake in CAKN and ARCN

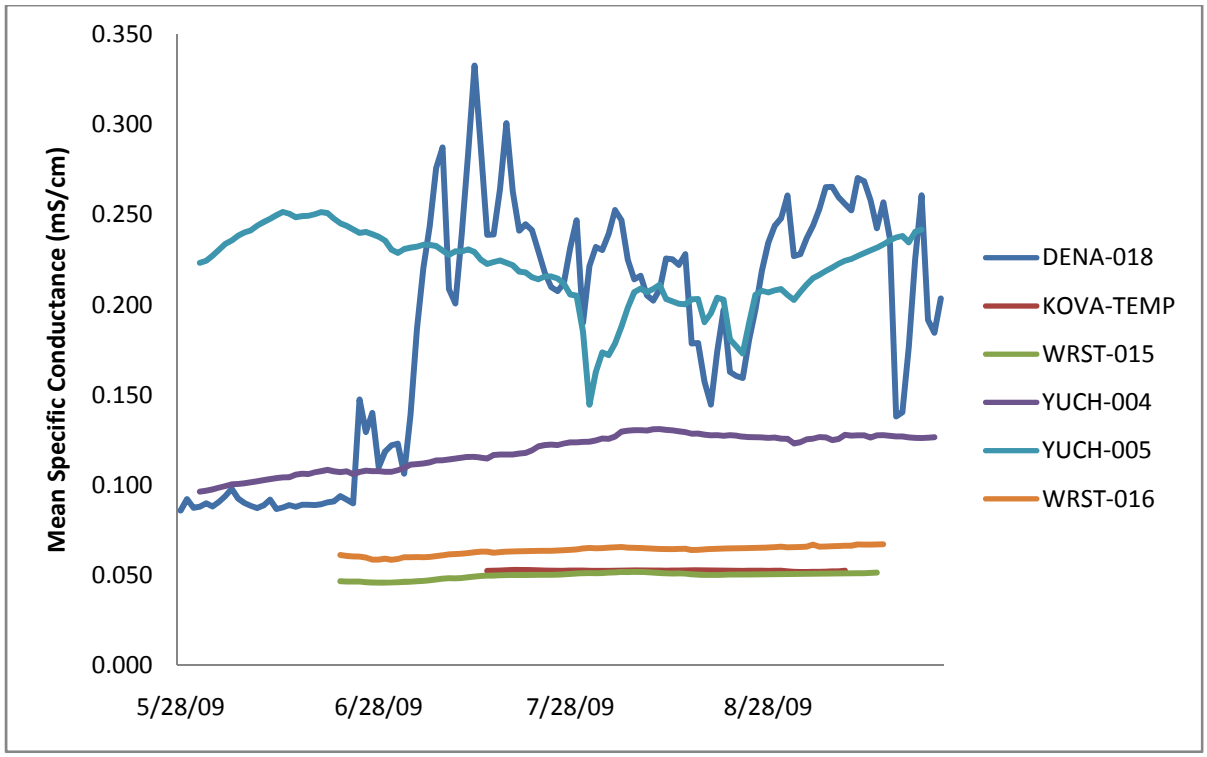

Figure 16. Mean daily specific conductivity in each continuously monitored lake in CAKN and ARCN

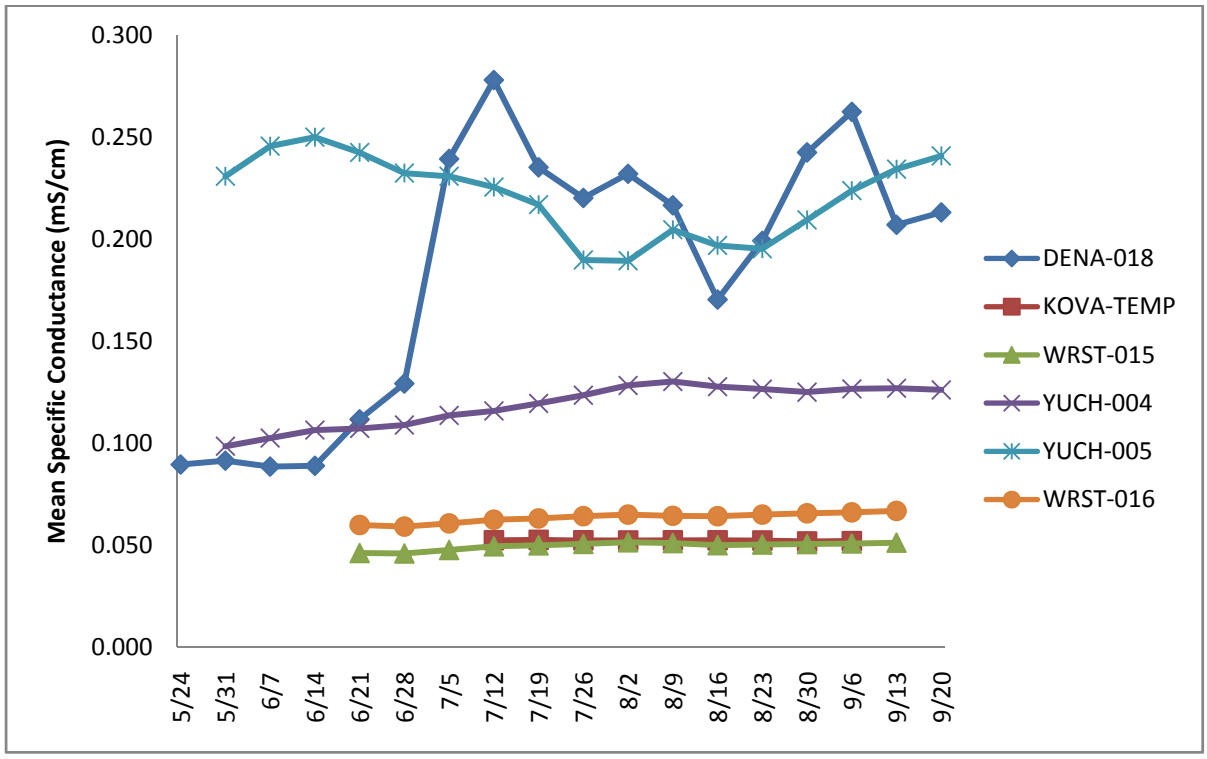

Figure 17. Weekly mean specific conductivity for each sonde deployed in CAKN and ARCN

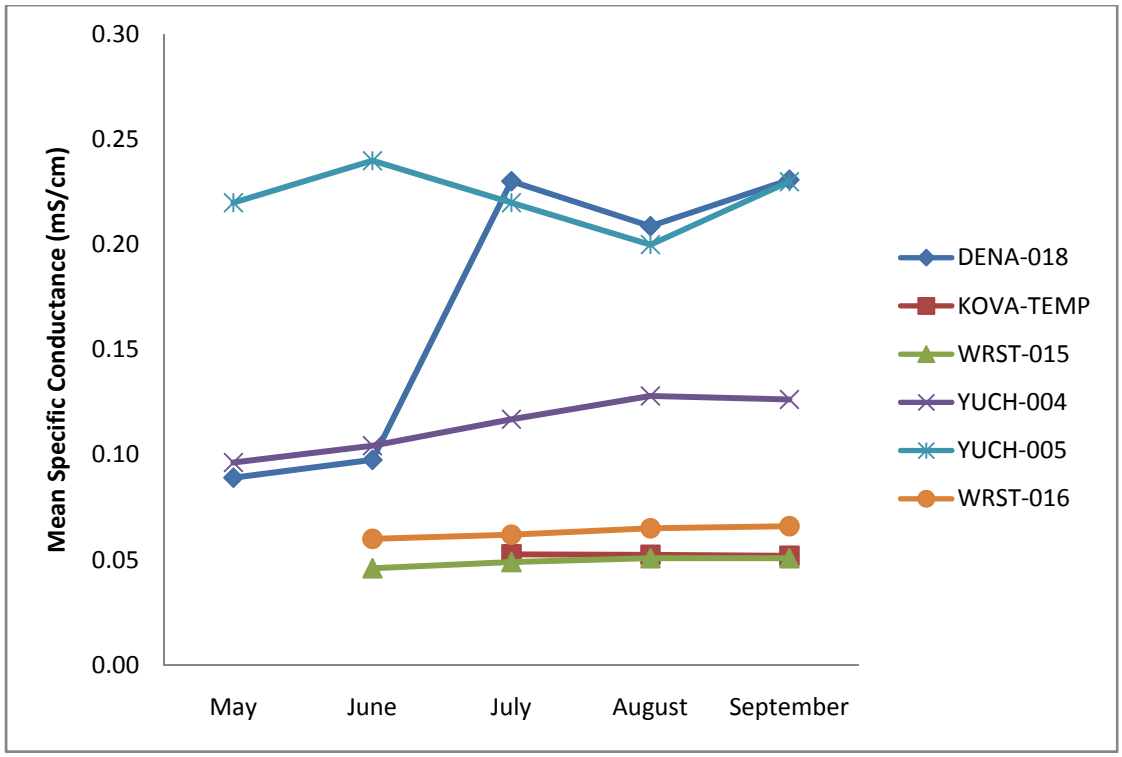

Figure 18. Monthly mean specific conductivity for each sonde deployed in CAKN and ARCN

pH

Mean annual pH varied among lakes from 7.01 to 8.10 (Figure 19). pH fluctuated daily (Figure 20) and seasonally (Figure 21). Daily and seasonal fluctutions were greatest in YUCH-005 and ranged from 7.27 to 8.68. Lakes WRST-015, WRST-016, KOVA-TEMP and YUCH-004 varied little during the course of summer, varying less than 0.6 units. The data suggest that pH may peak in July (Figure 22), but no clear trend is evident. Based on the data collected from the DENA-018 the sonde that had detached from the sensor array and drifted to shore, pH is considerably lower near the wetland margin near the substrate (Figure 20).

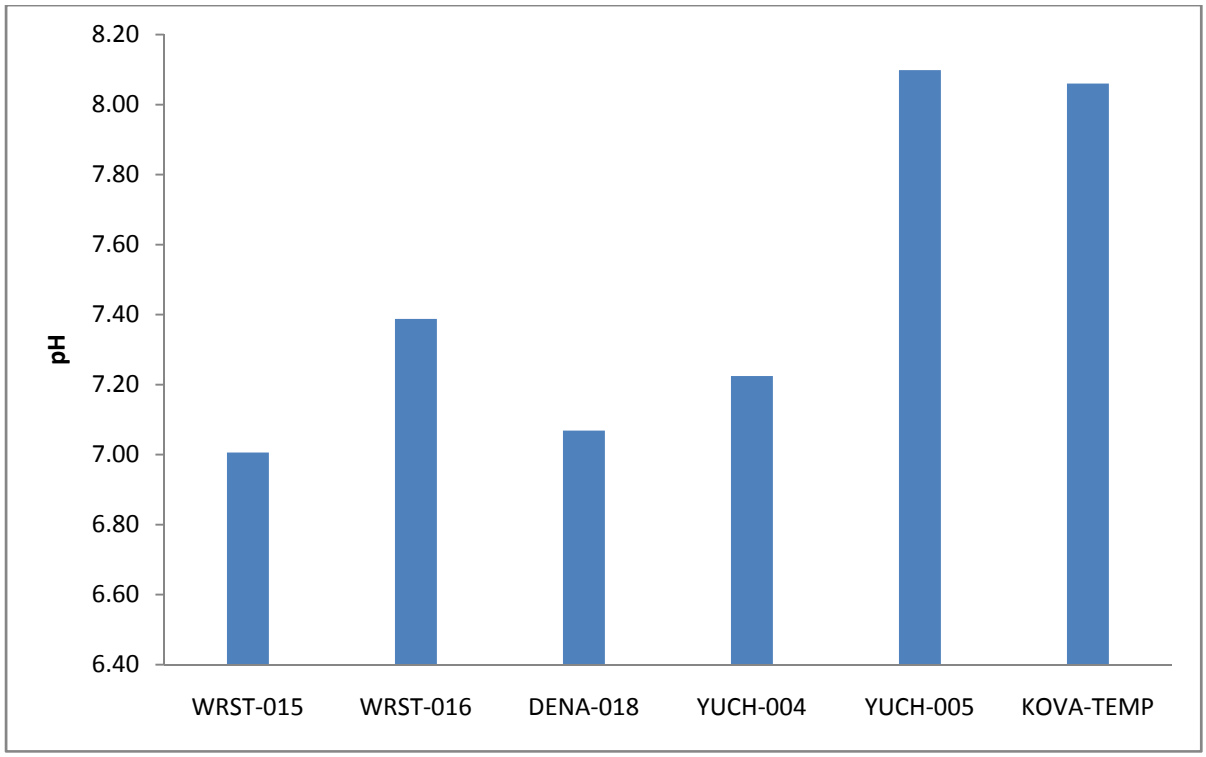

Figure 19. Mean summer pH in each continuously monitored lake in CAKN and ARCN

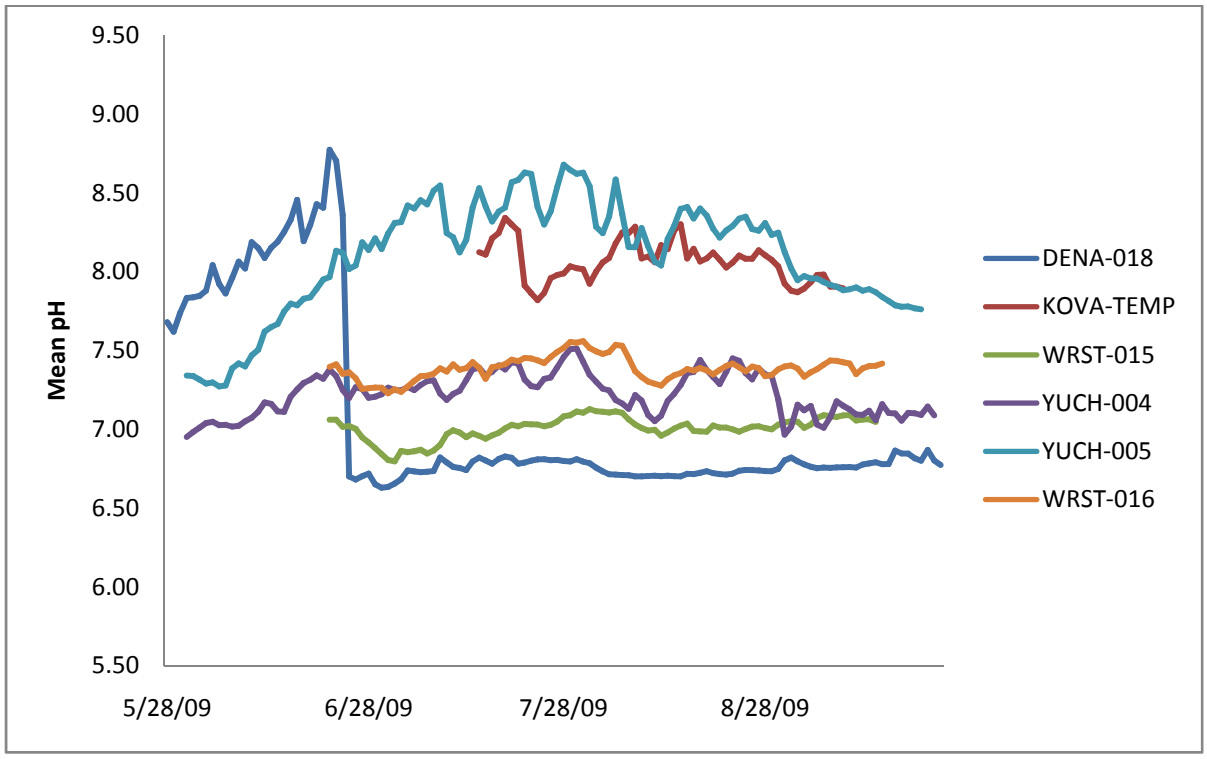

Figure 20. Mean daily pH in each continuously monitored lake in CAKN and ARCN

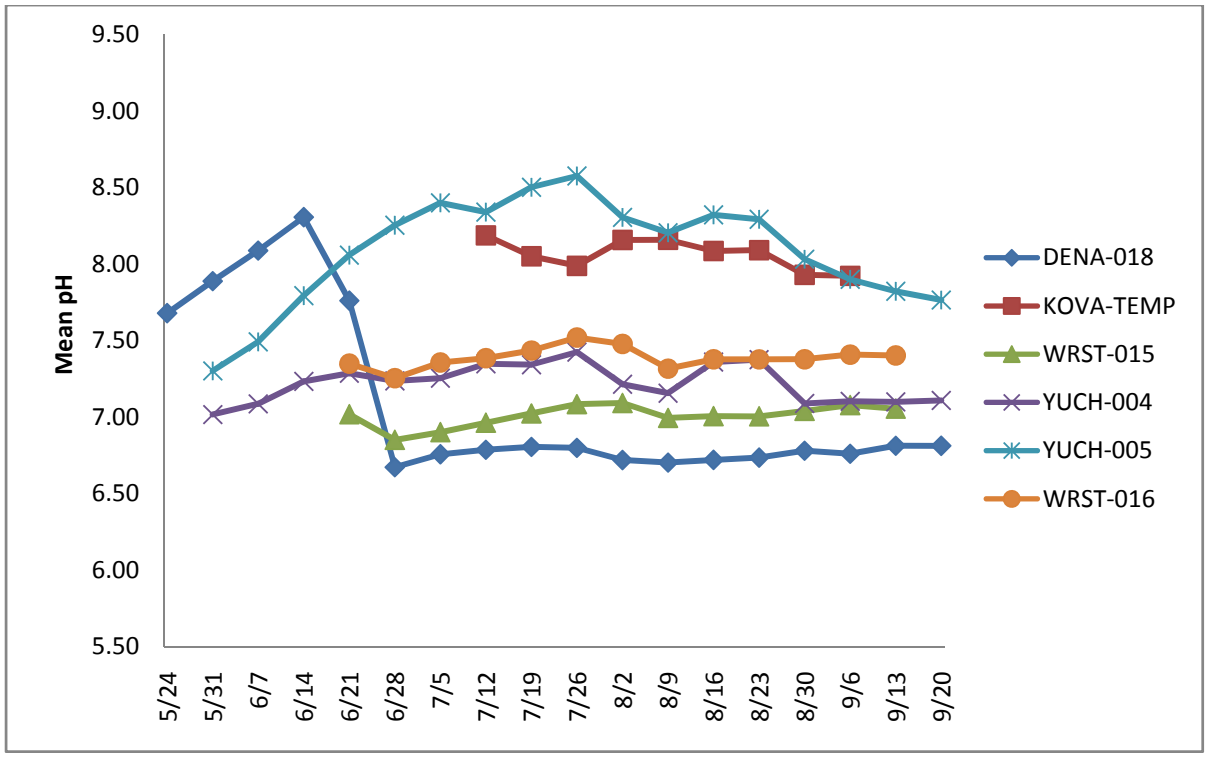

Figure 21. Weekly mean pH for each sonde deployed in CAKN and ARCN

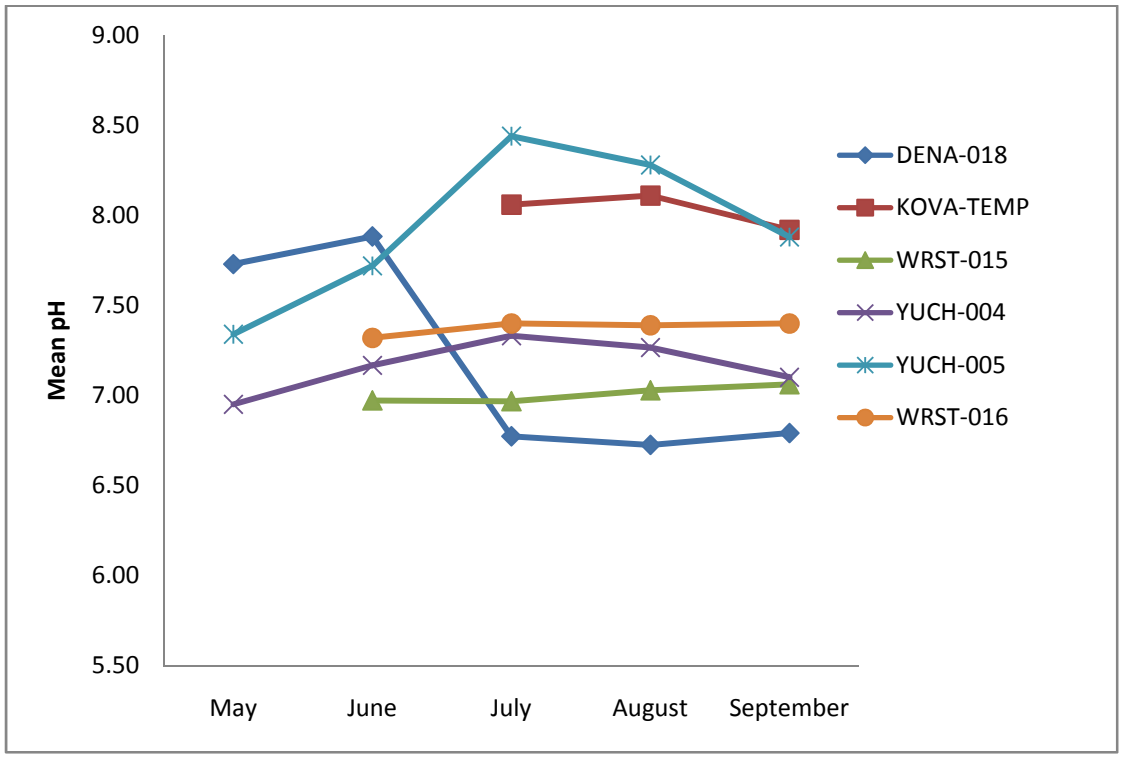

Figure 22. Monthly mean pH for each sonde deployed in CAKN and ARCN

Dissolved Oxygen

Monitoring dissolved oxygen concentration was fraught with problems in 2009. Sensor failure occurred in 3 rapid pulse DO sensors (YUCH-005, WRST-016 and WRST-015), and the data for the DO sensor deployed in KOVA (KOVA-TEMP) indicates significant sensor drift (Figure 23). In addition, the sensor deployed at DENA-018 became detached from the array and drifted to shore, where it became wedged in the sediment and ceased collecting relevant DO data . Of all the DO sensors deployed, it appears that only one good dataset was collected (YUCH-004); that sensor also became detached and drifted to shore, but not until near the end of the season.

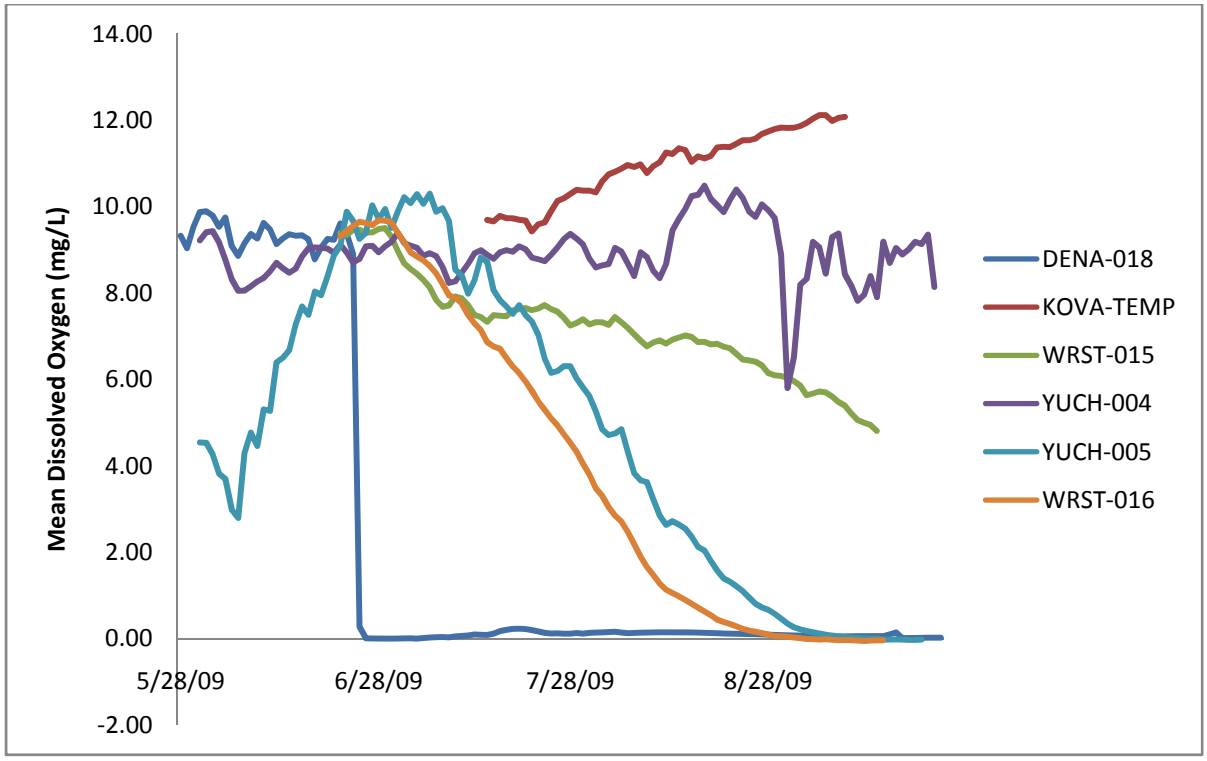

Figure 23. Mean daily dissolved oxygen concentration in each continuously monitored lake in CAKN and ARCN

Discussion

Shallow lake sampling in WRST and KOVA revealed large physical and chemical differences among lakes. Much of the variation across the parks can be explained by differences in geology. Some of the drainages in WRST have lakes with high specific conductivity and high concentrations of cations associated with limestone outcrops, while other drainages have low specific conductivity and low nutrient concentrations, typically associated with volcanic and metamorphic rock. WRST appears to have distinct drainages (lake districts) in which lakes appear to be relatively uniform.

Water chemistry measurements in KOVA also reflected the complex geologic mosaic of the region, but tended to be more heterogeneous than in WRST. Lakes north of the Kobuk River tended to have lower nutrient, conductivity and cation/anion concentrations. The region south of the Kobuk River is largely composed of areas of eolian and alluvial deposits, and lakes adjacent to one another may have completely different substrates. Many lakes are underlain by sand while others are primarily underlain by silt. This area had a much greater degree of variability in water chemistry measurements among lakes, even lakes that were fairly close together; there were no clear “lake districts” indicated by analysis. This variation is likely due to the complex and variable pattern in which sand and silt were deposited in the area.

The data collected in 2009 provides the CAKN and ARCN networks with valuable baseline data and some information to begin understanding lake variation. Additional sampling in these two parks in 2011 will provide us with increased sample sizes, which will help us to better identify and understand the variation among lakes.

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