



Water Quality and Surface Hydrology of Freshwater Flow Systems in Southwest Alaska

2009 Annual Summary Report

Natural Resource Technical Report NPS/SWAN/NRTR—2010/304



ON THE COVER

Upper Twin Lake in Lake Clark National Park and Preserve.
Photograph by: Jeff Shearer, Southwest Alaska Network

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U.S. Department of the Interior
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Abstract

The Southwest Alaska Inventory and Monitoring Network monitors freshwater systems in five national park units: Alagnak Wild River, Aniakchak National Monument and Preserve, Katmai National Park and Preserve, Kenai Fjords National Park, and Lake Clark National Park and Preserve. To date, most of our efforts have focused on field testing and modifying protocols for water quality and hydrology monitoring on high priority lake systems.

In 2009, lake profiles were measured on Lake Clark, Naknek Lake, and Lake Brooks between the surface and 50 m for water temperature, pH, specific conductivity, dissolved oxygen, and water clarity. Water quality parameters were generally stable between sites throughout each lake except for water clarity. The spring eruptions of Mt. Redoubt and subsequent volcanic ash inputs into the Lake Clark system had a dramatic lake-wide effect on water clarity, greatly decreasing Secchi depth at all sites compared to 2008 observations. Continuous water temperature monitoring in Lake Clark has been ongoing since September 2006 while continuous temperature monitoring on Naknek Lake was initiated in August 2008. Water temperature data from both lakes depict temporary summer stratification followed by abrupt vertical mixing due to a strong wind events in late July.

Water level and discharge measurements were continued on Naknek Lake and Lake Brooks in 2009. Water level measurements were converted into estimated lake discharge based on stage discharge rating curves developed in 2006-07 by the U.S. Geological Survey. Subsequent discharge measurements were used to refine rating curves. Continuous water quality and water level monitoring was conducted on Exit Creek during two-week deployment periods (late spring and mid-summer) to examine natural variation in water quality parameters due to diel glacial melting. Diel patterns were most obvious in water temperature and specific conductivity during low flow (spring / early summer) when ground water contributions to surface flow exceed runoff contributions comprising glacial and snowmelt runoff as well as precipitation events.

Monitoring in 2010 will focus on applying all four aspects of freshwater flow system monitoring (lake profile monitoring, continuous water temperature monitoring, continuous water quality monitoring at select tributaries and outlets, and lake outlet level / discharge monitoring) on all four Tier 1 lake systems as well as incorporating lake profile monitoring on select Tier 2 lake systems.

Acknowledgements

We express our deep gratitude to Dan Young and Angela Olson, Lake Clark National Park and Preserve; Troy Hamon and Vera Gilliland, Katmai National Park and Preserve; Fritz Klasner and Deb Kurtz, Kenai Fjords National Park; and Chuck Lindsay, Southwest Alaska Network for their continued logistical support and assistance in completing monitoring activities. We are indebted to the professionalism of pilot Allen Gilliland of the National Park Service. Thanks to Bill Thompson, Southwest Alaska Network, for advice on survey design and providing GRTS sample site analysis. Reviews by Michael Shephard and Dan Young greatly improved earlier versions of this document.

Introduction

The Southwest Alaska Inventory and Monitoring Network (SWAN) monitors freshwater systems in five national park units: Alagnak Wild River (ALAG), Aniakchak National Monument and Preserve (ANIA), Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), and Lake Clark National Park and Preserve (LACL) (Figure 1). The goal of SWAN freshwater monitoring is to document the natural variability and to monitor for potential influences of large scale anthropogenic impacts, such as climate change, on large lake systems. SWAN's primary objective is to monitor water quality and hydrologic parameters in large lake systems, including associated tributaries and outlets, in order to describe the current status and trends of limnological conditions. To date, much of SWAN's freshwater monitoring efforts have focused on protocol testing for the freshwater chemistry and surface hydrology vital signs. Specifically, methods were explored to document variability of core water quality parameters (e.g. temperature, pH, dissolved oxygen, and specific conductivity), quantify seasonal hydrograph changes during the ice-free season, and track water temperature patterns in select lakes.

Water quality monitoring efforts have focused on Lake Clark, LACL and Naknek Lake, KATM while hydrologic monitoring has taken place primarily on Naknek and Brooks Lakes, KATM. Additionally, protocol testing for continuous deployment of multi-parameter sondes was conducted in Exit Creek, KEFJ. Although most SWAN freshwater monitoring takes place during the ice-free period (typically May through September), lake water temperature is monitored year-round. Water temperature has been monitored continuously in Lake Clark since September 2006 and was initiated in Naknek Lake in August 2008. This report will discuss the results of the 2009 field sampling efforts as well as summarize water temperature collected between September 2008 and September 2009.

Methods

Study Area

During the SWAN monitoring development process, park resource staff and regional experts suggested developing a tiered system to categorize water bodies for monitoring based on management priorities, access, and system type (e.g., glacial vs. non-glacial, anadromous vs. non-anadromous). Lakes Clark and Kontrashibuna in LACL, Naknek Lake and Lake Brooks in KATM, and Exit Creek in KEFJ were all identified as high priority (Tier 1) water bodies for monitoring. Lake Kontrashibuna was not monitored in 2009 and was reclassified as a medium priority (Tier 2) waterbody in March 2010 (discussed further in Conclusions section). The Chulitna River is a major tributary to Lake Clark where we initiated river gaging and water quality monitoring in 2009.

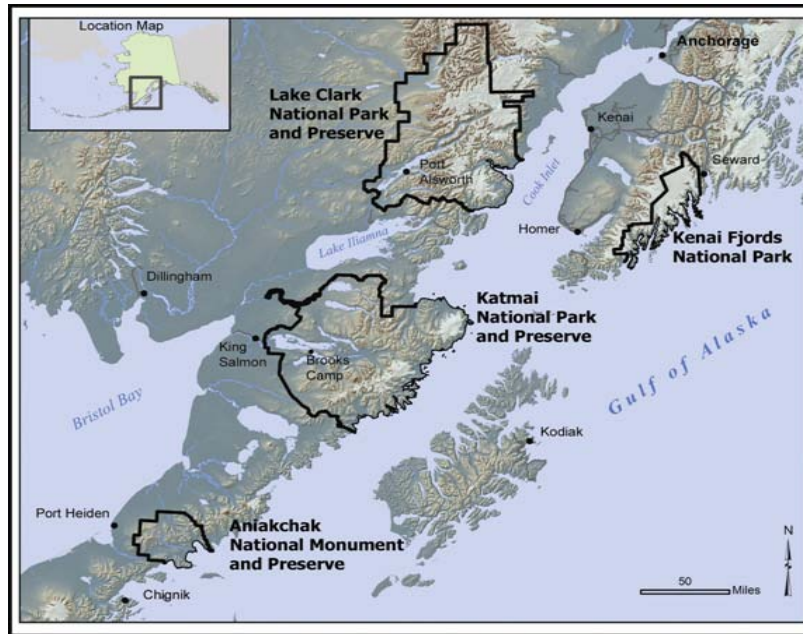


Figure 1. National Park units included in the Southwest Alaska Inventory and Monitoring Network.

Lake Clark (Figure 2) is located within the Kvichak River drainage in southwest Alaska and is the third largest lake (313 km²) in the National Park system (behind Naknek Lake and Yellowstone Lake – Yellowstone National Park). Lake Clark is a glacially-carved oligotrophic lake that is 66 km long and 5–8 km wide; it has an average depth of 103 m, a maximum depth of 280 m, and a drainage area of 7,620 km² (Young and Woody 2007). Six tributaries contribute the majority of runoff into the lake. Three tributaries are glacially fed, two are clear, and one is organically stained (Brabets 2002). Seasonal runoff from glacial tributaries is highest between June and September, which creates a turbidity gradient along the length of the lake from the turbid upstream to the relatively clear (approximately 2 Nephelometric Turbidity Units (NTU)) downstream (Brabets 2002, Wilkens 2002). The Chulitna River (Figure 2) is a low gradient (7% mean slope), organically stained river flowing from the southwest tundra region of the Lake Clark watershed. The Chulitna River has a watershed area of 2,997 km² with no glaciers and approximately 92 km² of lakes (Brabets 2002).

Naknek Lake and Lake Brooks (Figure 3) are located within the Naknek River drainage in southwest Alaska. Naknek Lake is the largest lake (609 km²) in the National Park system and third largest in Alaska (Kozlowski 2007). Naknek Lake is a bathymetrically complex system with multiple basins. The North Arm of Naknek Lake has an average depth of 63 m, maximum depth of 167 m, and receives runoff from snowmelt and wet tundra. The Iliuk Arm of Naknek Lake has an average depth of 96 m, maximum depth of 173 m, and receives water from Grosvenor Lake, glacial inputs from the Savonoski River, and ash flows from the Valley of Ten Thousand Smokes via the Ukak River (Kozlowski 2007). The East (avg. depth 27 m, max. depth 71 m) and West (avg. depth

13 m, max. depth 80 m) Basins of Naknek Lake serve as mixing areas for waters from the North and Iliuk Arms. Lake Brooks is a major lake within the Naknek system, flowing into the East Basin of Naknek Lake via the Brooks River. Lake Brooks has a surface area of 75 km², an average depth of 45 m, a maximum depth of 79 m, and receives much of its runoff from snowmelt and wet tundra (Goldman 1960, Kozlowski 2007).

Exit Creek (Figure 4) flows from Exit Glacier on the northeast end of the Harding Icefield in south central Alaska. Exit Creek flows from the terminus of the glacier for approximately 3.2 km to the confluence with the Resurrection River which enters Resurrection Bay at Seward, AK.

Field Methods

Lake temperature was monitored year-round through the use of automated temperature thermistors attached to a moored array. Thermistors recorded water temperature (°C) hourly at 5 m, 10, and every 10 meter to 100 m using Onset HOBO Water Temp Pro thermistors. During summer months, a surface buoy with a thermistor was attached to the moored array so that surface temperature could be recorded. Data were downloaded once or twice annually during the open water season (between late May and late September) depending on site access logistics and staff availability.

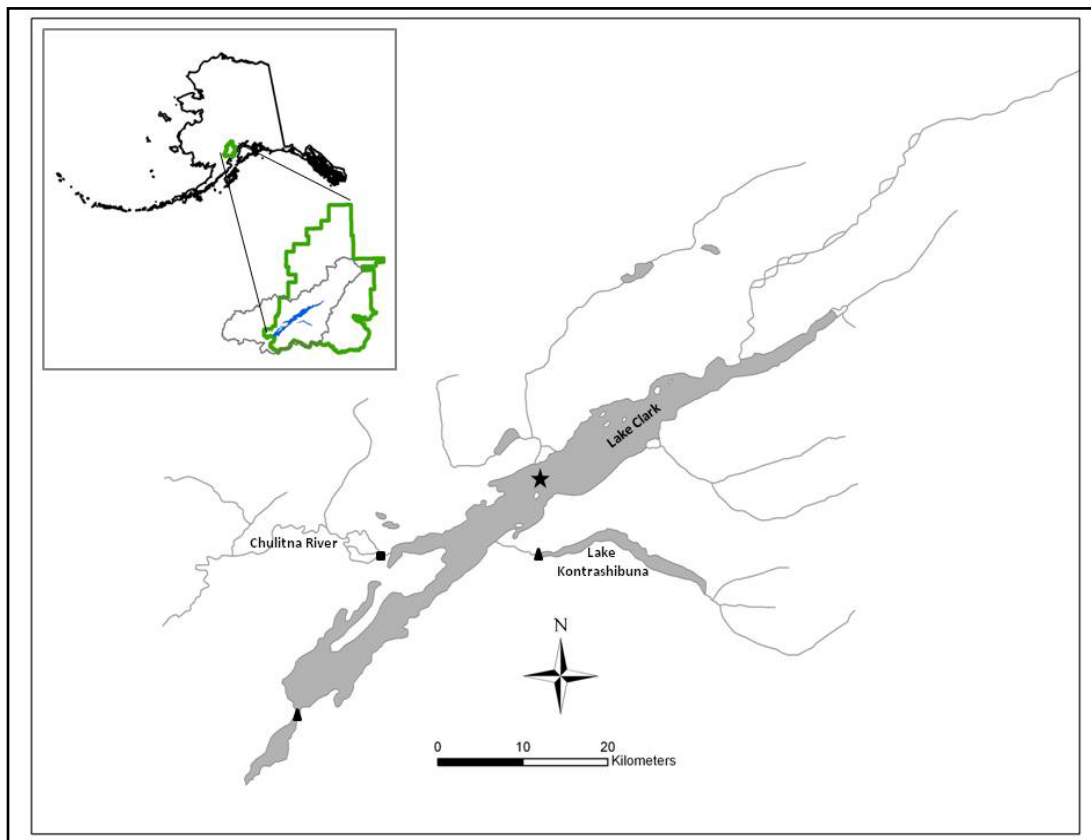


Figure 2. Lakes Clark and Kontrashibuna including major tributaries in LACL. Chulitna River monitoring site (square), temperature array (star), and lake outlets (triangle) are denoted as well.

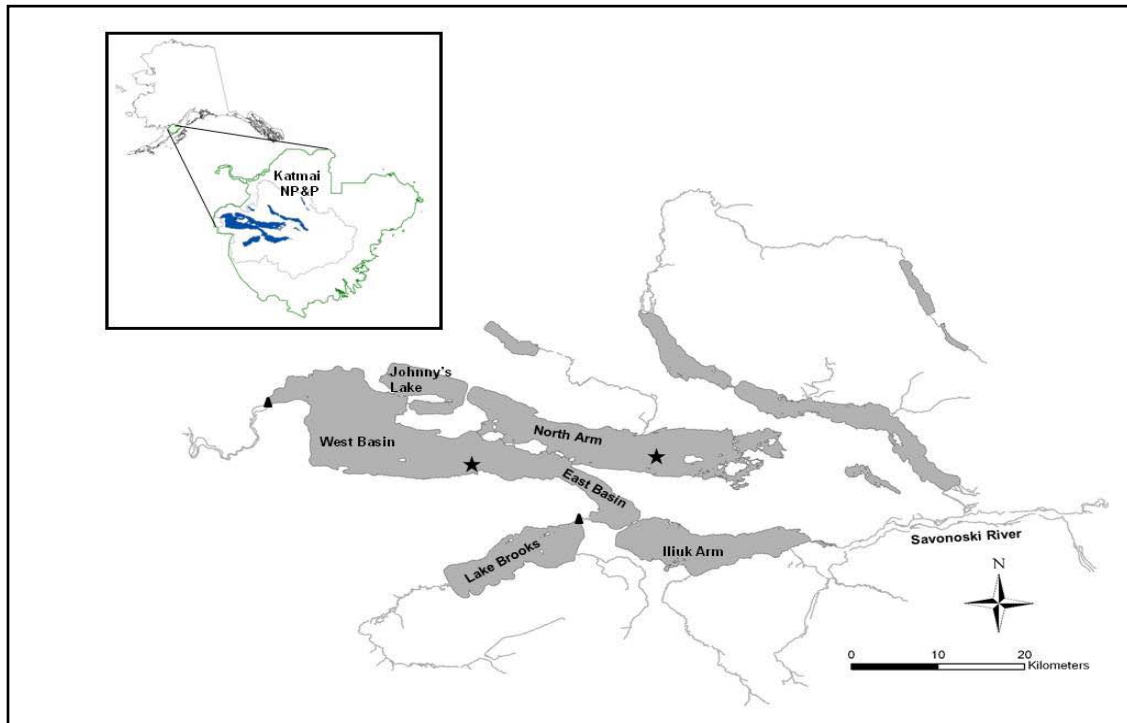


Figure 3. Lake Brooks and major basins of Naknek Lake including major tributaries in KATM. Lake outlets denoted with a triangle, temperature arrays denoted with a star.

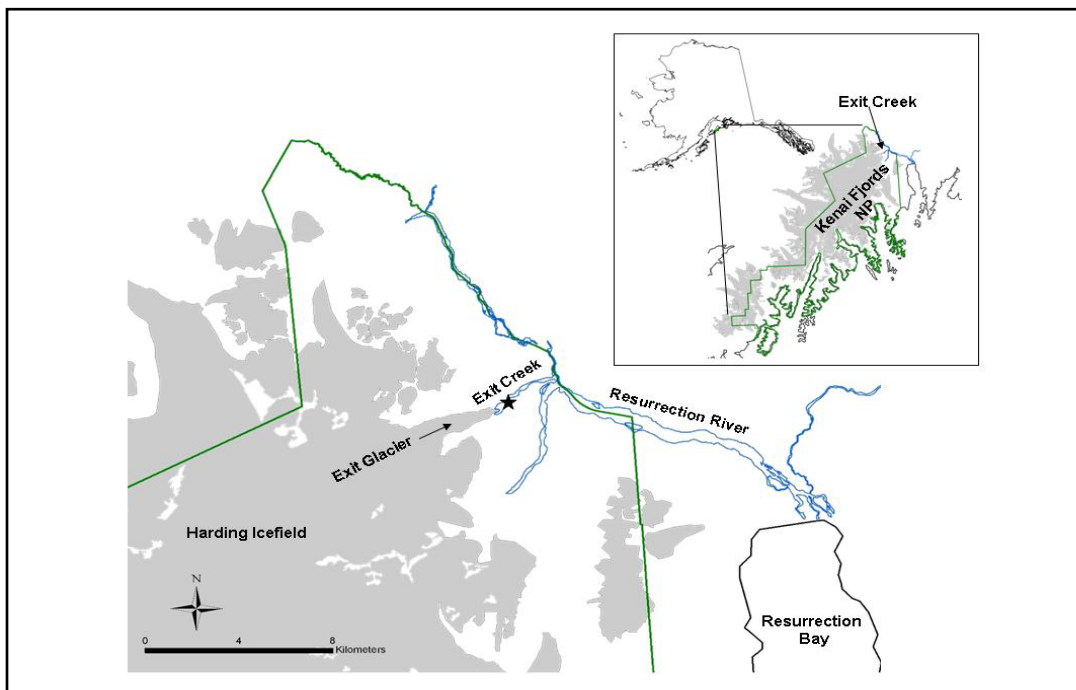


Figure 4. Exit Creek area in KEFJ. Study site is denoted with a star. Gray areas represent glacial ice cover.

Water quality sampling was comprised of recording vertical lake profiles at lake sites and continuous water quality parameters at select tributary sites. Yellow Springs Incorporated (YSI) multiparameter sondes were used for all water quality measurements. A series of calibrations and error checks for temperature, dissolved oxygen, pH, and specific conductivity were performed each day before sondes were used in the field. Additionally, post-trip error checks were conducted at the end of each day during lake profile measurements and at the end of each deployment period for continuous water quality monitoring.

Continuous water level measurements were taken with In-Situ Level Troll pressure transducers on the outlets of Lake Brooks, Naknek Lake, and Lake Clark and on the Chulitna River. Lake Brooks and Naknek Lake are among the sites the U.S. Geological Survey Water Resources Division developed stage / discharge rating curves for SWAN in 2007. Additionally, a Solinst Levellogger pressure transducer was used to record water level at Exit Creek. All pressure transducers were programmed to record water level (feet) hourly. Barometric loggers deployed nearby were used to compensate water level readings for atmospheric pressure.

Vertical lake profiles were measured on Lake Clark, Naknek Lake, and Lake Brooks during the mid-summer index period (late July to late August). The mid-summer index period is defined by the period where the vertical thermal gradient is greatest (based on previous lake temperature monitoring). Sampling was conducted at general random tessellation stratified (GRTS) points on each of the three lake basins (Figures 5 and 6). GRTS points were created by overlaying a 1-km² grid of cells on each lake basin with a point assigned to the center of each cell in a geographic information system. A coordinate list (containing latitude and longitude) for each center point was generated and a GRTS analysis was applied to the coordinate list. The result was a list of randomly selected, spatially balanced sample locations for collecting lake profile information. Lake Clark was divided into three basins (upper, middle and lower) to consider the affects of the turbidity gradient whereas Naknek Lake was divided into five basins (West, East, Iliuk, North Arm, and Johnny's Lake) based on bathymetry and water source (glacial, ash-laden waters of the Iliuk Arm vs. non-glacial, clear waters of the North Arm). We sampled 10 sites in each basin of Lake Clark (Figure 5), 10 sites total in Lake Brooks (Figure 6) and 10 sites each in the West, East and Iliuk Arms of Naknek Lake (Figure 6). The North Arm and Johnny's Lake basins within Naknek Lake were not sampled due to weather conditions. Additionally, one in every 10 sites was randomly selected for repeat sampling to track sample variability.

We used a YSI 600QS multiparameter sonde to collect water temperature (°C), pH (unitless), dissolved oxygen (mg/L and % saturation), and specific conductivity (µS/cm) (collectively referred to as core parameters) between the surface and 50 m depth. Once the multi-parameter sonde was placed in water and readings stabilized, core parameters were recorded on the descent and ascent. Measurements were collected at the surface, 1 m, 2 m, 3 m, 4 m, 5 m, and every 5 meters to 50 m or the bottom, whichever was reached first. A 20-cm black and white Secchi disc was used to record water clarity at each site

as well. The Secchi disc was lowered vertically into the water on the shaded side of the boat, the depth at which the disc disappeared was recorded. The disc was then lowered farther before being slowly raised; the depth at which the disc reappeared was recorded. This process was repeated two more times and Secchi depth was reported as the average of all six readings. Multiparameter sonde and Secchi disc methods were similar to those described in Hoffman et al. (2005) and USGS (2005). Information on recent precipitation, wind conditions, and overall site depth was also collected at each sample site.

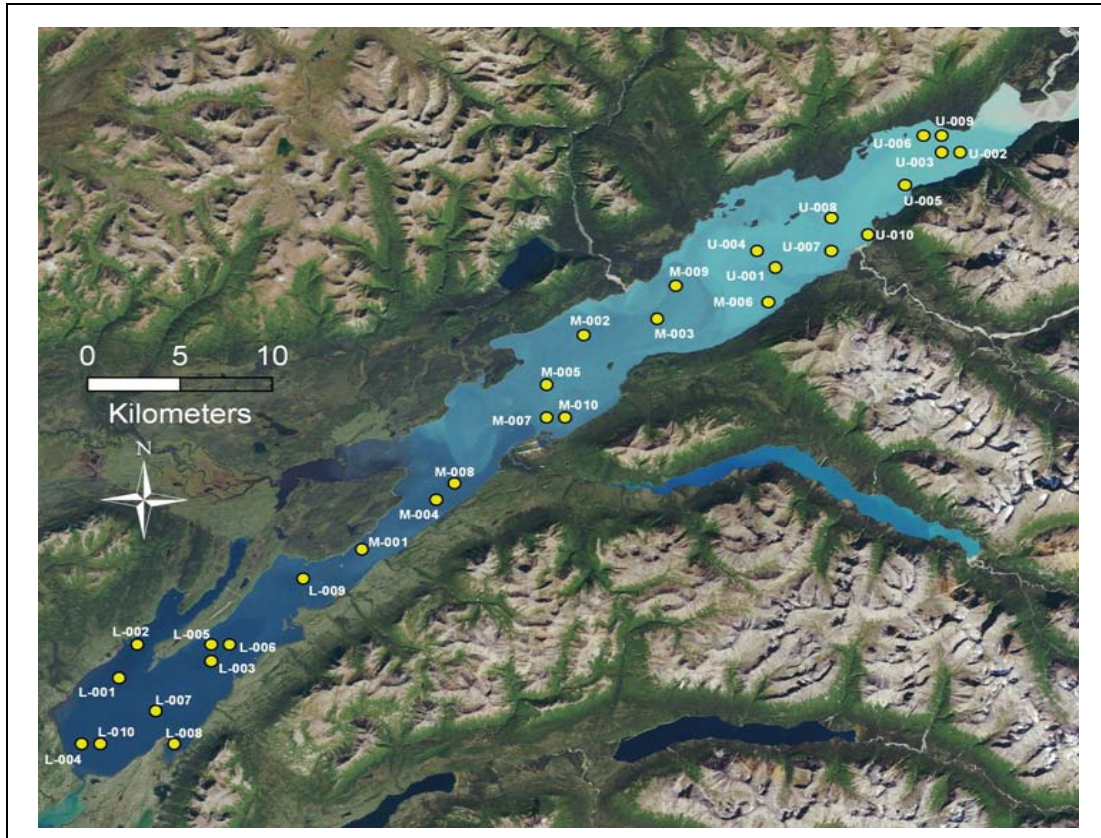


Figure 5. GRTS sample locations on Lake Clark where vertical lake profiles were measured. Note longitudinal turbidity gradient as represented by changing water color from northeast to southwest axis.

Continuous monitoring of core parameters was conducted on Exit Creek and the Chulitna River during three 2-week periods from May through September using a YSI 6600V2 multiparameter sonde with optical dissolved oxygen and turbidity sensors. The sonde was placed inside a polyvinyl chloride pipe housing which was then attached to a concrete block (approximate weight 45 kg) and placed in the channel thalweg or attached to a secure steel cable anchored to the river bank. The sonde was programmed to measure core parameters, including turbidity (NTU), on a 1-hour interval. At the end of each two-week deployment, readings were taken with the a freshly calibrated YSI 6600 sonde to correct for sensor drift due to fouling. Additionally, post-deployment error checks were conducted on the continuous deployment sonde to measure sensor

calibration drift (Wagner et al. 2006). Dataset corrections for sensor fouling and drift correction were applied using AQUARIUS Time Series software.

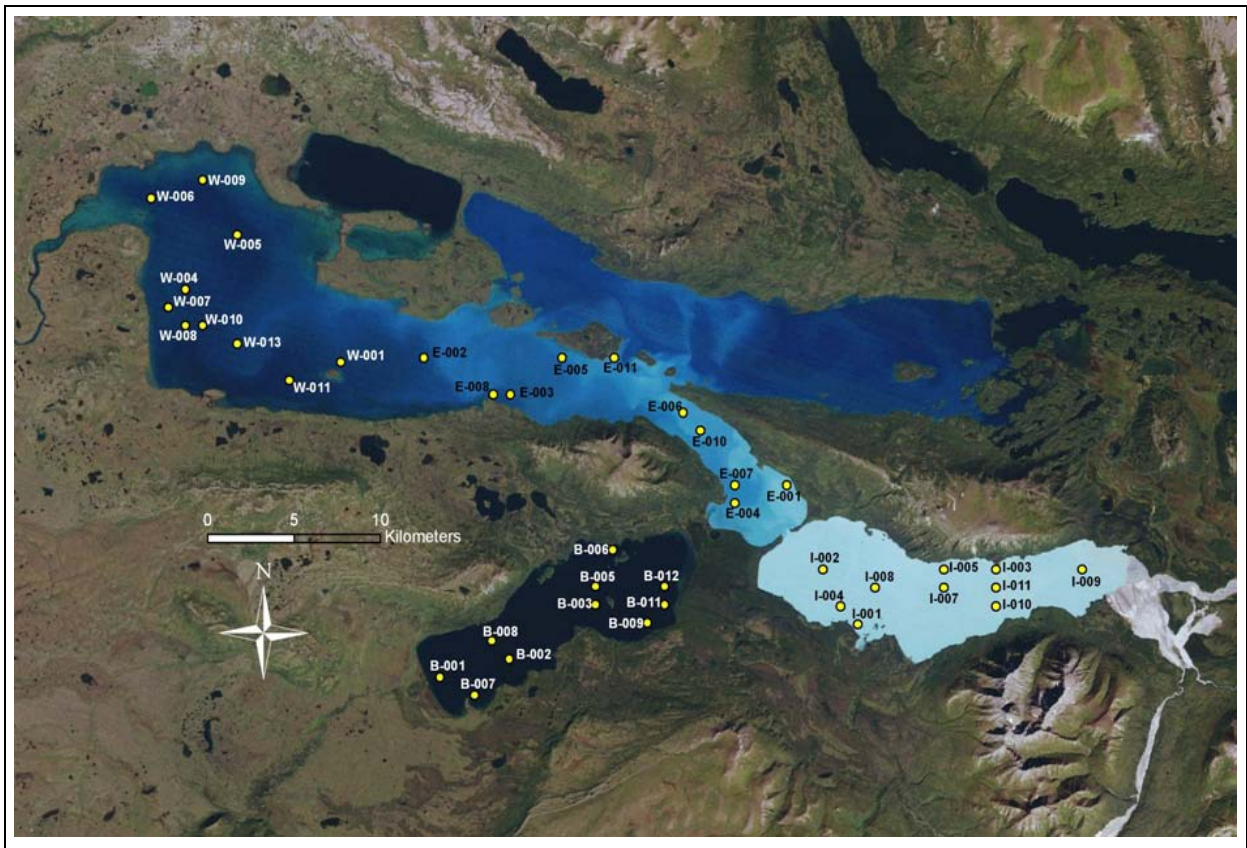


Figure 6. GRTS sample locations on Lake Brooks and Naknek Lake where vertical lake profiles were measured. Note stark contrast in water clarity between lake basins.

Results and Discussion

Lake Clark Water Temperature

Water temperature in Lake Clark has been continuously monitored since September 2006; however, our analysis will focus on comparing 2009 observations with 2007 and 2008 data (Table 1). Generally speaking, monthly maximum and minimum average daily temperatures for January through June 2009 fell between those ranges observed in 2007 and 2008 with a few minor exceptions. Monthly degree days show a relatively warmer January, June and July in 2009 than in 2007 or 2008 but a cooler spring (March – May). As observed in previous years, Lake Clark shows a pattern of summer stratification and inverse winter stratification (Figures 7 and 8). Additionally, two periods of isothermy (uniform temperature throughout the water column) occur from November through early December and in May.

During limnological studies of Lake Clark, Chamberlain (1989) and Wilkens (2002) both reported similar patterns to those described above. Chamberlain (1989) reported a

maximum temperature of 13 °C and a minimum temperature of 0 °C, similar to the 13.7 °C (maximum) and 0.7 °C (minimum) reported by Wilkens (2002). Based on mixing patterns and seasonal presence of ice cover, Lake Clark is best classified as a discontinuous cold polymictic lake. Lewis (1983) defines discontinuous cold polymictic lakes as ice-covered part of the year, ice-free above 4 °C and stratified during the warm season for periods of several days to weeks, but with irregular interruption by mixing. Other large lakes in southwest Alaska share this classification as frequent storms with strong winds result in deep mixing of waters (LaPerriere 1997). Deep vertical mixing of Lake Clark waters was observed following wind events recorded on July 21 and 25, 2009. Maximum hourly wind gust data for July 21 and 25, 2009 for the Coville, Alaska remote automated weather station from the Western Regional Climate Center was 107.6 kph and 113.4 kph, respectively (<http://www.raws.dri.edu/wraws/akF.html>).

Subsequently, wind generated surface disturbance on Lake Clark resulted in warmer surface waters mixing vertically with cooler, deeper waters, dropping near-surface temperatures from 13.8 °C on July 20th to 5.9 °C on July 26th. This disruption of summer stratification explains the lower August maximum and minimum average daily temperature. That is, the wind events acted as a reset mechanism resulting in much cooler near-surface water temperatures during August than would have otherwise likely occurred in the absence of a strong wind event. The warmest 24-hour (July 18th) and 7-day (July 14th -20th) mean water temperatures occurred immediately prior to the first wind event further suggesting that Lake Clark water was still warming and may have continued to warm in the absence of a strong surface disturbance.

Naknek Lake Water Temperature

Water temperature monitoring in Naknek Lake was initiated in August 2008 and thus this discussion will focus on comparing the North Arm and the West Basin of Naknek Lake, rather than inter-annual observations (Table 2). Temperature patterns follow the bathymetric nature of the two basins with the deeper North Arm (mean depth 63 m, volume 63 km³) cooling slower and warming slower compared to the much shallower West Basin (mean depth 13 m, volume 13 km³) as represented by the maximum average daily temperature and monthly degree days for the fall (November and December) and spring (May and June) periods. Mid- to late winter temperatures appear to stabilize similarly between the basins as maximum, minimum, and monthly degree days for February and March temperatures are similar. However, mid-summer temperatures again reflect the volume differences between the two basins. Although maximum average daily temperatures are similar (15.8 °C for the North Arm vs. 16.1 °C for the West Basin), minimum average daily temperatures are much lower in the North Arm (6.8 °C) compared to the West Basin (11.9 °C). By July, waters within the deeper North Arm are still warming and a larger thermal gradient exists (Figure 9) compared to the shallower West Basin where water has warmed throughout the water column and exhibits less thermal stratification (Figure 10).

The warmest day for each basin (as indicated by the highest observed 24-hr mean) was July 15th. This date was immediately preceded by a period where the mean (based on a

Table 1. Summary of water temperature data for Lake Clark between September 1, 2006 and September 1, 2009. Analyses based on near surface temperature data.

Month	Max. Avg. Daily Temp ¹ mean (1 SD ⁴); °C			Min. Avg. Daily Temp ² mean (1 SD ⁴); °C			Monthly Degree Days ³		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
January	0.7 (0.1)	2.7 (0.0)	1.1 (0.0)	< 0.1 (0.0)	0.1 (0.0)	0.3 (0.1)	8	22	27
February	1.9 (0.1)	1.1 (0.1)	1.2 (0.0)	0.7 (0.1)	0.1 (0.0)	0.6 (0.0)	38	14	28
March	2.4 (0.0)	1.5 (0.1)	1.1 (0.0)	1.4 (0.2)	0.6 (0.1)	0.8 (0.0)	65	37	28
April	3.4 (0.5)	2.3 (0.1)	2.0 (0.1)	2.0 (0.1)	1.2 (0.3)	0.8 (0.0)	83	56	34
May	4.3 (0.1)	3.7 (0.1)	3.6 (0.1)	3.0 (0.2)	1.8 (0.3)	2.1 (0.1)	108	92	89
June	9.9 (0.5)	8.4 (0.9)	8.5 (0.7)	4.0 (0.0)	3.6 (0.0)	3.6 (0.0)	204	155	160
July	15.0 (0.9)	11.0 (0.5)	14.1 (0.2)	8.9 (0.3)	7.2 (0.3)	5.9 (0.5)	395	285	321
August	15.9 (0.4)	13.5 (0.5)	12.1 (0.1)	10.3 (1.2)	10.5 (0.3)	8.1 (0.5)	403	378	320
September	13.5 (0.3)	10.2 (0.2)		7.9 (0.5)	6.4 (0.6)		292	236	
October	8.1 (0.1)	7.4 (0.1)		5.5 (0.0)	4.9 (0.0)		204	190	
November	5.6 (0.0)	4.9 (0.0)		4.5 (0.0)	3.2 (0.2)		148	127	
December	4.4 (0.0)	3.6 (0.1)		2.5 (0.1)	0.5 (0.1)		116	76	

Year	Highest Avg. Daily Temp date	Highest Avg. Daily Temp 24-hr mean (1 SD); °C	Highest Avg. 7-Day Temp dates	Highest Avg. 7-Day Temp 7-day mean (1 SD); °C
2007	August 13 th	15.9 (0.4)	Aug. 10 th - 17 th	14.7 (0.8)
2008	August 18 th	13.5 (0.5)	Aug. 22 nd - 29 th	13.0 (0.5)
2009	July 18 th	14.1 (0.4)	July 14 th - July 20 th	13.4 (0.6)

¹ Based on highest 24-hour average

² Based on lowest 24-hour average

³ Difference between daily mean temperature and 0 °C summed for each month

⁴ Standard deviations < 0.05 are reported as 0.0

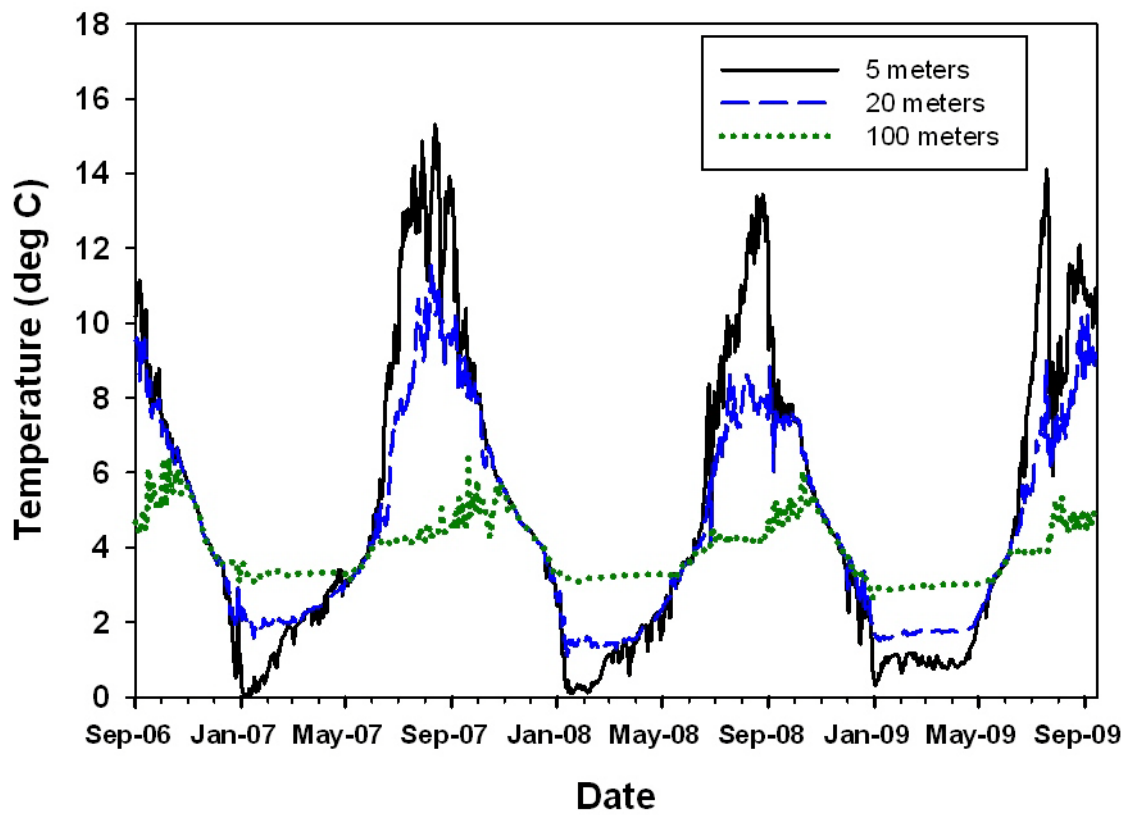


Figure 7. Water temperature data for Lake Clark between January 1, 2007 and September 1, 2009. Data from 5 m (solid black), 20 m (dashed blue), and 100 m (dotted green) depth intervals.

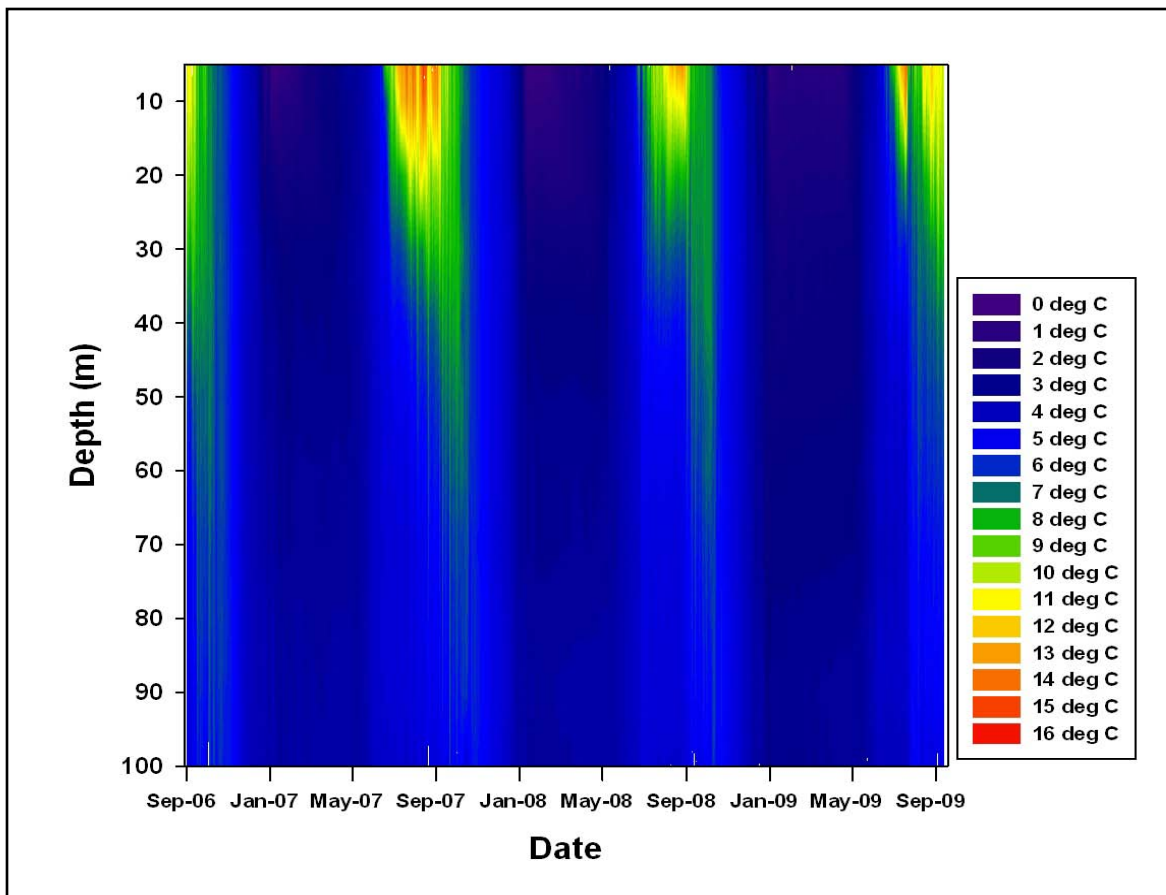


Figure 8. Lake Clark isotherm displaying patterns of summer stratification.

Table 2. Summary of water temperature data for the North Arm and West Basin of Naknek Lake between September 1, 2008 and August 31, 2009. Analyses based on near surface temperature data.

Month	Max. Avg. Daily Temp ¹ mean (1 SD ⁴); °C		Min. Avg. Daily Temp ² mean (1 SD ⁴); °C		Monthly Degree Days ³	
	North Arm	West Basin	North Arm	West Basin	North Arm	West Basin
September 2008	12.0 (0.1)	12.6 (0.1)	7.3 (0.1)	9.7 (0.0)	304	328
October 2008	9.6 (0.0)	9.8 (0.0)	6.2 (0.0)	4.1 (0.4)	239	216
November 2008	6.2 (0.0)	4.6 (0.4)	4.1 (0.0)	0.6 (0.1)	158	67
December 2008	4.1 (0.1)	1.4 (0.0)	0.9 (0.1)	0.4 (0.0)	98	31
January 2009	1.2 (0.1)	0.7 (0.0)	0.7 (0.0)	0.2 (0.0)	26	14
February 2009	1.0 (0.0)	1.1 (0.0)	0.7 (0.0)	0.6 (0.0)	21	23
March 2009	1.3 (0.0)	1.4 (0.0)	1.0 (0.0)	1.0 (0.0)	37	41
April 2009	2.0 (0.1)	2.3 (0.2)	1.4 (0.0)	1.5 (0.0)	46	50
May 2009	3.8 (0.0)	6.8 (0.1)	2.1 (0.1)	2.3 (0.1)	93	118
June 2009	9.4 (0.2)	12.1 (0.2)	3.9 (1.0)	6.1 (0.2)	191	275
July 2009	15.8 (0.25)	16.1 (0.1)	6.8 (0.2)	11.9 (0.1)	365	439
August 2009	12.2 (0.1)	13.4 (0.1)	8.2 (0.3)	11.7 (0.2)	344	387
Year	Highest Avg. Daily Temp date	Highest Avg. Daily Temp 24-hr mean (1 SD); °C	Highest Avg. 7-Day Temp dates	Highest Avg. 7-Day Temp 7-day mean (1 SD); °C		
North Arm – 2009	July 15 th	15.8 (0.2)	July 14 th – July 20 th	15.4 (0.5)		
West Basin – 2009	July 15 th	16.1 (0.1)	July 14 th – July 20 th	15.9 (0.2)		

¹ Based on highest 24-hour average

² Based on lowest 24-hour average

³ Difference between daily mean temperature and 0 °C summed for each month

⁴ Standard deviations < 0.05 are reported as 0.0

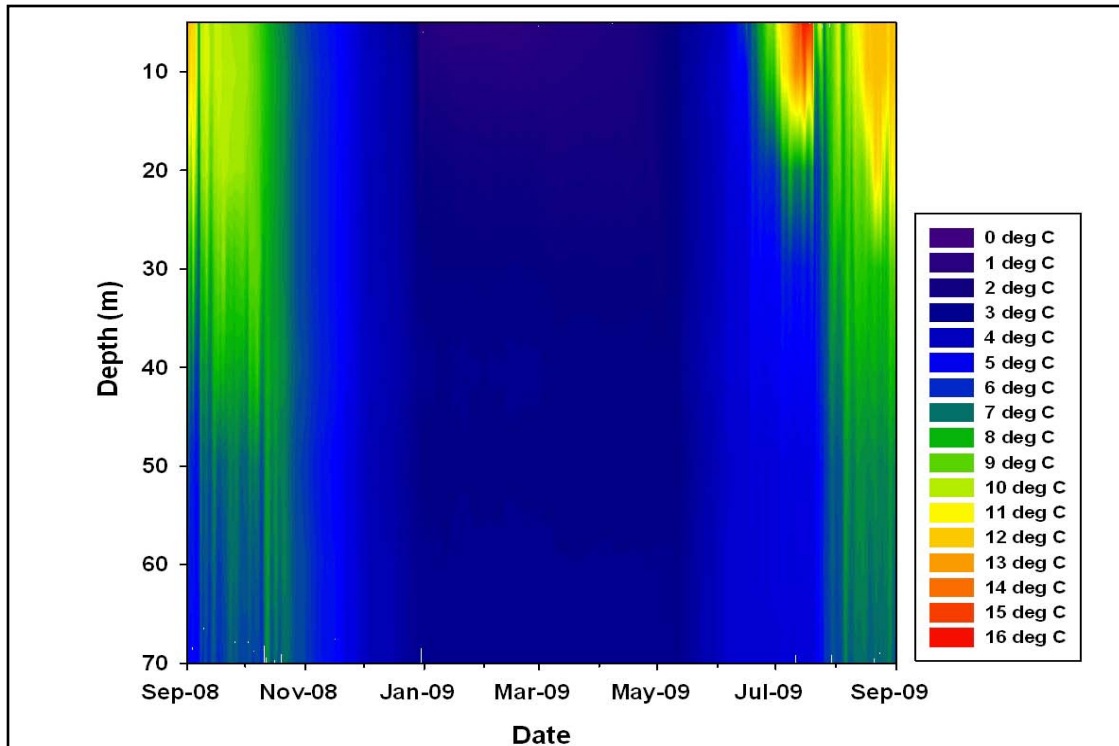


Figure 9. Isotherm for North Arm of Naknek Lake displaying patterns of summer stratification.

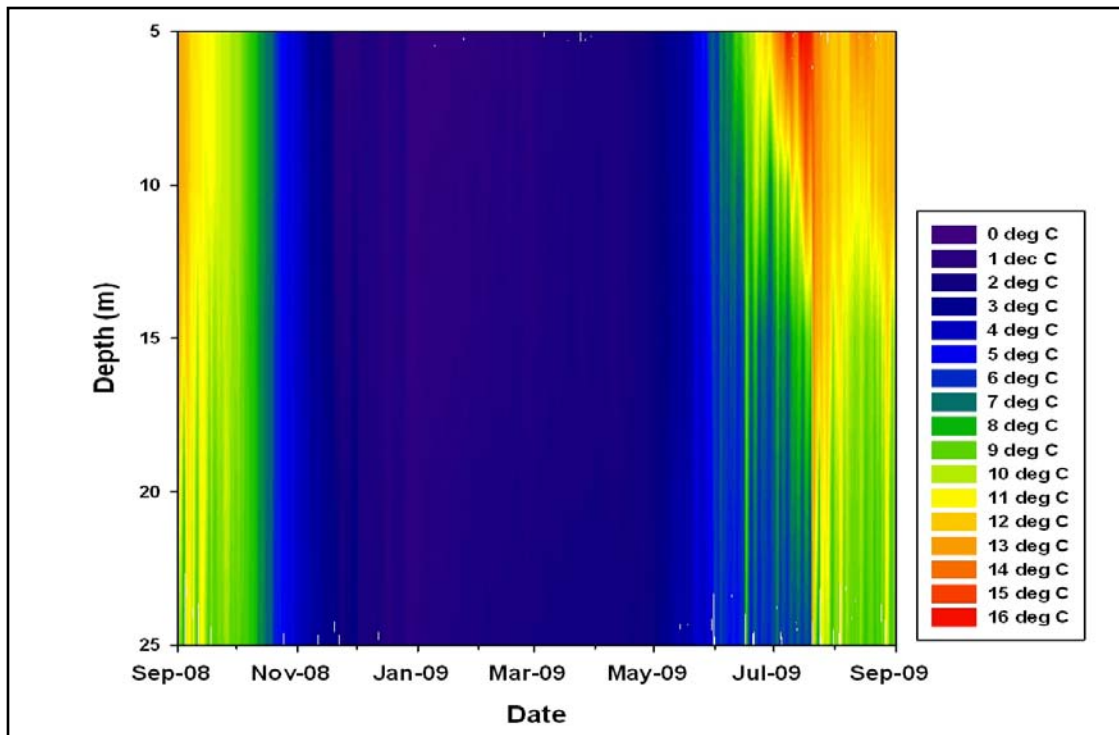


Figure 10. Isotherm for West Basin of Naknek Lake displaying patterns of summer stratification.

5-day running average) air temperature (16.84 °C) was the highest and mean wind speed (10.1 kph) was the lowest observed for June or July 2009 at the Coville, Alaska remote automated weather station (<http://www.raws.dri.edu/wraws/akF.html>). Thus, conditions were fairly stable for thermal warming near the surface of Naknek Lake. The late July wind events previously described for Lake Clark also served to vertically mix water within Naknek Lake as well. Isotherms for both basins within Naknek Lake (Figures 9 and 10) reveal relatively uniform temperatures throughout the water column following these winds, illustrating Naknek Lake's polymictic (e.g. frequent mixing) nature. As with Lake Clark, the warmest 7-day mean for each basin in Naknek Lake occurred between July 14th and 20th, suggesting that Naknek Lake water may have continued to increase in temperature in the absence of a large-scale wind event.

Lake Brooks and Naknek Lake Discharge

Lake discharge was estimated for Lake Brooks and Naknek Lake based on stage / discharge rating curves developed by the U.S. Geological Survey Water Resources Division (Table 3).

Lake Brooks water levels increased quickly during the spring 2009 due to above average air temperatures in May and June that resulted in rapid snow melt (National Weather Service – King Salmon Station). However, after this initial rise, water levels quickly dropped in June to the point that the water level pressure transducer was out of water by early July. Without accurate water level data we are unable to compare discharge estimates from July through September to previous years. In 2010 we will relocate the pressure transducer to accommodate lower water levels.

Naknek Lake discharge followed a similar pattern in 2009 compared to previous years with two exceptions: May discharge was higher and the summer peak, and subsequent decline in lake discharge, occurred earlier (Figure 11, Table 3). The elevated discharge out of Naknek Lake during May was likely a result of above average air temperatures throughout the region which resulted in rapid snow melting (National Weather Service – King Salmon Station). With Lake Brooks as a major contributing basin to the Naknek Lake system, elevated discharge from Lake Brooks will serve to increase lake levels, and in turn discharge, from Naknek Lake. The 2009 peak estimated discharge for Naknek Lake occurred on August 4th compared to October 4, 2007 and September 20, 2008 in previous years. Additionally, the peak 7-day average (based on a moving average) occurred from August 3-9, 2009 versus October 6-12, 2007 and September 16-22, 2008 (Table 3). The relatively rapid rise of the Naknek Lake discharge in early summer followed by a period of gradually increasing discharge (Figure 11) is a reflection of spring snowmelt coupled with summer precipitation that resulted in peak lake levels, and subsequently discharge, into late summer. Naknek Lake receives both glacial meltwater and non-glacial surface runoff (Kozlowski 2007). Glacial melt increases throughout the summer months with increasing solar radiation, resulting in stage peaks that occur later in summer than systems driven exclusively by snowmelt and precipitation. The relatively early peaking of water levels in Naknek Lake may be a result of decreased precipitation and/or reduced glacial melting within the Savanoski River drainage, the largest tributary

Table 3. Summary of estimated lake discharge (Q) data for Naknek and Brooks Lakes during ice-free period for 2007 - 2009.

Month	Avg. Monthly Q mean (1 SD); cfs ¹			Max. Monthly Q cfs			Min. Monthly Q cfs		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Brooks Lake									
May	343 (21)		440 (47)	398		523	321		363
June	414 (57)	610 (43)	317 (37)	525	671	376	363	518	266
July	445 (52)	500 (36)		512	588		348	434	
August	343 (25)	350 (55)		387	469		278	290	
September	456 (40)	351 (29)		551	402		373	322	
Naknek Lake									
May	4,671 (542)		6,328 (329)	5,753		6,996	3,948		5,758
June	6,817 (749)	7,912 (1,052)	7,882 (376)	8,142	9,831	8,334	5,610	6,163	7,061
July	8,923 (327)	11,320 (770)	8,804 (619)	9,395	12,313	10,010	8,226	9,822	8,116
August	9,924 (302)	11,797 (273)	7,948 (262)	10,505	12,235	10,284	9,424	11,301	9,351
September	10,438 (166)	11,870 (267)	9,042 (289)	10,752	12,361	9,424	10,191	11,305	8,424
October	10,650 (325)	10,730 (521)		11,072	11,560		9,722	9,718	
Year	Peak Q date	Peak Q cfs		Peak 7-day Avg. Q dates			Peak 7-day Avg. Q mean (1 SD); cfs		
Brooks Lake									
2007	September 20 th	551		June 26 th – July 2 nd			517 (8)		
2008	June 20 th	671		June 17 th – June 23 rd			660 (9)		
2009	May 9 th	523		May 9 th – May 15 th			493 (19)		
Naknek Lake									
2007	October 4 th	11,072		October 6 th – October 12 th			10,982 (47)		
2008	September 20 th	12,361		September 16 th – September 22 nd			12,204 (123)		
2009	August 4 th	10,284		August 3 rd – August 9 th			10,174 (65)		

¹ cfs = cubic feet per second

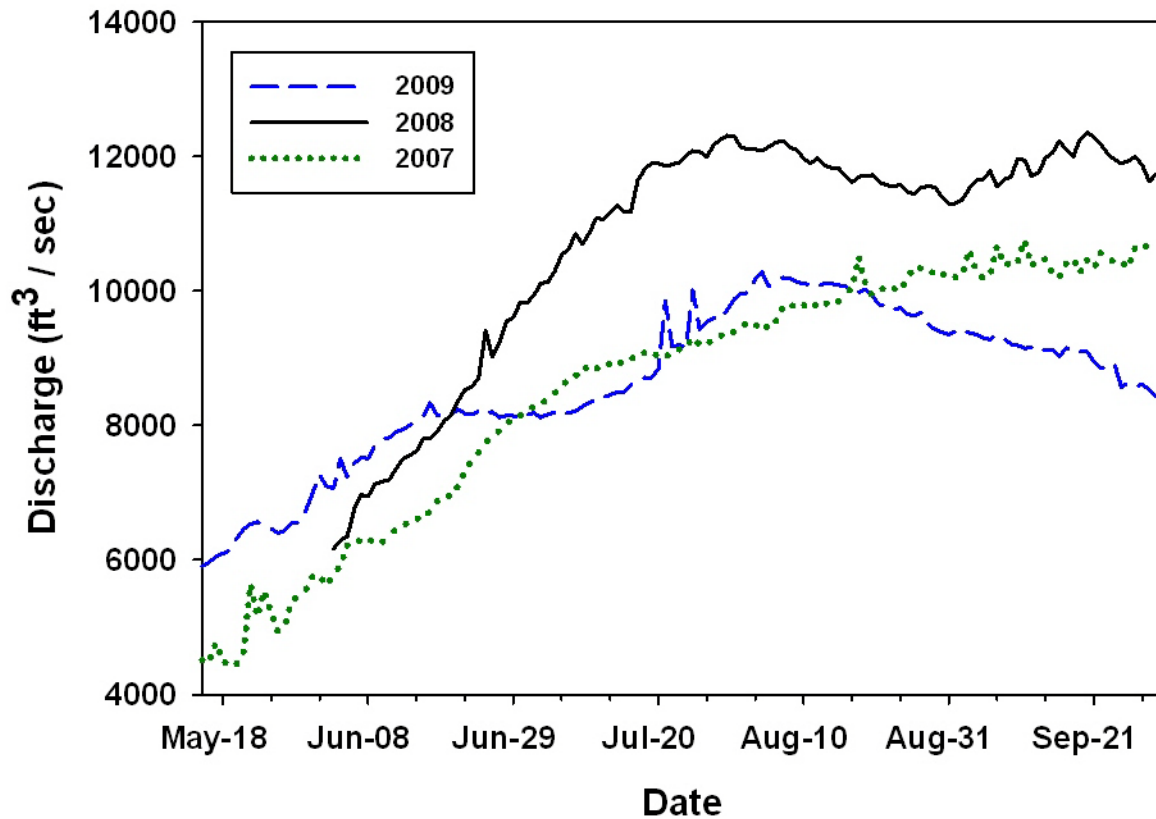


Figure 11. Estimated discharge for Naknek Lake for 2007 (dotted green), 2008 (solid black), and 2009 (dashed blue).

flowing into Naknek Lake (Kozlowski 2007). However, a more in-depth analysis of weather data would be needed to verify possible causes.

Vertical Lake Profiles

Table 4 provides a statistical summary of core parameters averaged across sites within each basin of Lake Clark, Naknek Lake, and Lake Brooks. Summary results for each parameter are discussed individually for each lake.

Water Temperature

Water temperature displayed the opposite pattern from what we would anticipate for Lake Clark. The upper basin of Lake Clark receives all the glacial meltwater inflow whereas the lower basin has no large tributary (glacial or non-glacial). Brabets (2002) reported water temperatures ranging from 4.5 – 7.5 °C for August in the three main glacial tributaries, Tlikakila River, Chocotonk River, and Currant Creek, to Lake Clark. The main non-glacial tributaries, Kijik River, Tanalian River, and Chulitna River, which flow into the middle basin had August water temperatures ranging from 9.5 – 13.5 °C while Lake Clark outlet temperatures ranged from 7.6 – 11.0 °C (Brabets 2002). Based on tributary influences alone, we might expect the upper basin of Lake Clark to have the lowest temperatures. Yet, mean water temperatures were lowest in the lower basin and

Table 4. Summary data for core parameters collected at vertical lake profile sites on Lake Clark, Naknek Lake, and Lake Brooks during summer 2009. Values represent the median between all depth intervals at a site averaged across all sites within the lake basin.

Parameter	Lake Clark			Naknek Lake			Lake Brooks
Statistic	Upper Basin	Middle Basin	Lower Basin	East Basin	West Basin	Iliuk Arm	
Water Temperature (°C)							
Mean	11.29	9.88	8.93	11.79	13.60	8.63	10.88
Standard Deviation	0.51	1.55	1.02	1.23	0.52	0.79	0.99
Maximum	12.59	11.98	10.77	13.17	14.82	10.28	11.66
Minimum	10.76	7.05	7.30	9.74	13.01	7.53	9.18
pH (standard units)							
Mean	7.36	7.38	7.26	7.56	7.86	7.46	7.53
Standard Deviation	0.06	0.07	0.06	0.20	0.05	0.11	0.07
Maximum	7.45	7.49	7.39	7.73	7.97	7.59	7.61
Minimum	7.29	7.26	7.16	7.00	7.81	7.16	7.39
Specific Conductivity (µS/cm)							
Mean	62	62	63	140	139	147	77
Standard Deviation	0.5	0.2	1.3	0.7	0.5	0.7	0.0
Maximum	63	63	66	141	139	148	77
Minimum	61	62	62	139	138	146	77
Dissolved Oxygen (mg/L)							
Mean	12.11	11.60	12.10	11.28	10.72	12.04	11.54
Standard Deviation	0.80	0.39	0.24	0.30	0.18	0.17	0.23
Maximum	13.22	12.33	12.47	11.65	10.95	12.29	11.93
Minimum	11.28	11.11	11.70	10.83	10.29	11.68	11.36
Dissolved Oxygen (% Sat)							
Mean	110.7	102.4	104.5	104.4	103.1	103.3	104.3
Standard Deviation	7.9	0.4	0.6	1.2	0.6	1.2	0.5
Maximum	120.2	103.0	105.6	105.8	104.0	106.8	105.0
Minimum	102.4	101.7	103.5	101.4	101.7	102.5	103.6
Secchi Depth (m)							
Mean	0.86	1.06	1.35	4.21	4.36	0.68	10.37
Standard Deviation	0.21	0.24	0.15	1.25	0.58	0.27	0.81
Maximum	1.16	1.37	1.62	5.85	4.90	1.08	11.43
Minimum	0.58	0.67	1.18	2.31	3.48	0.25	8.85

highest in the upper basin (Table 4). In their analysis of thermal regimes for 60 subarctic, Alaskan lakes, Edmundson and Mazumder (2002) indicate that water temperature should remain relatively uniform as relative depth changes for glacial lakes in comparison to clear lakes that should display a more distinct separation of epilimnion, metalimnion, and hypolimnion layers over a range of relative depth. They reason that the high surface reflectance of glacial silt in conjunction with cold, turbid meltwater entering the basin at depth counteracts heat accumulation. We did not observe this pattern in 2008 (Shearer and Moore 2009) or 2009. Temperature profiles in all three basins showed relatively the same pattern with lower basin profiles being slightly more uniform than upper or middle basin profiles (Figure 12). We suggest that mid- to late summer lake warming may be more influenced by wind-generated mixing and internal circulation, especially in light of the dramatic effect the late July wind events had on near surface temperatures over a relatively short time. It is also important to note that our basin boundaries in Lake Clark are arbitrarily defined and are delimited primarily as a coarse-scale distinction between glacial and non-glacial inputs into the lake. However, there are no major bathymetric features of Lake Clark that prevent the movement and mixing of water between basins.

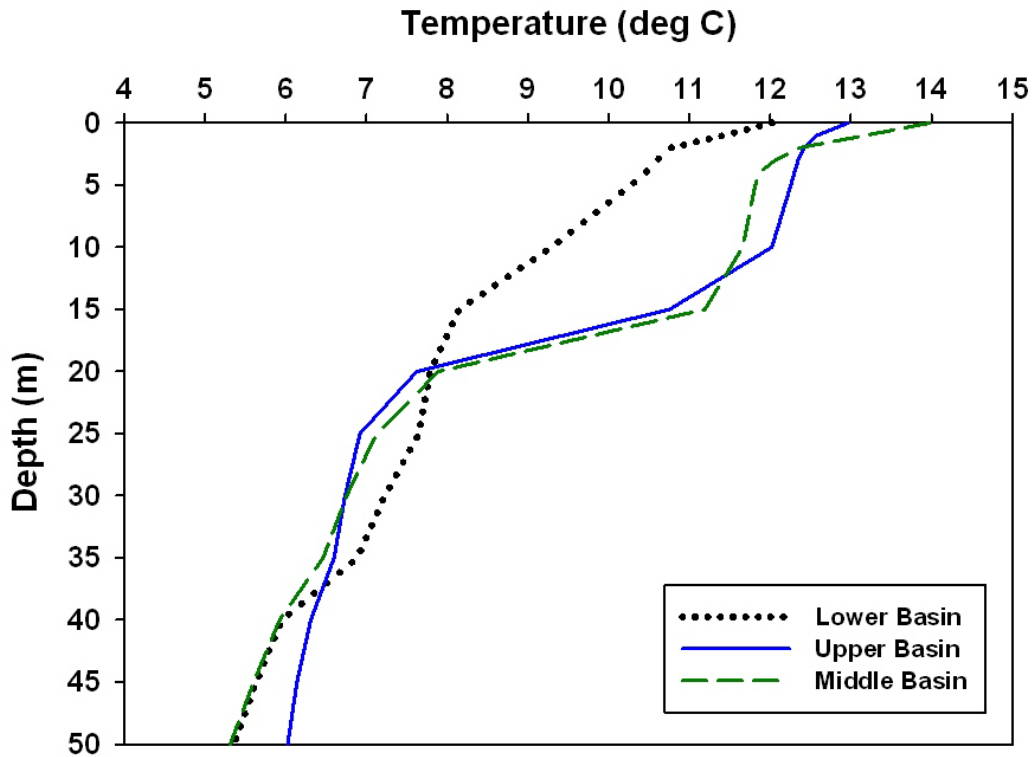


Figure 12. Temperature profiles for select sites that were representative of each basin in Lake Clark during August sampling.

Water temperatures within Naknek Lake ranged between 7.53 °C in the Iliuk Arm to 14.58 °C in the West Basin while Lake Brooks temperatures ranged between 9.18 °C and 11.66 °C (Table 4). Vertically, temperature profiles among basins in Naknek Lake were similar, although the shallow nature of the West Basin prohibits comparison to the deeper depths of the Iliuk Arm and East Basin (Figure 13). Lake Brooks vertical temperatures

remain higher to a greater depth before declining (Figure 13), perhaps as a result of considerably higher water clarity in Lake Brooks compared to Naknek Lake (see Water Clarity section) and thus, increased sunlight penetration. The Iliuk Arm of Naknek Lake receives glacial runoff and ash-laden runoff from the nearby Valley of Ten Thousand Smokes (Kozlowski 2007), creating extremely turbid conditions within this basin. High surface reflectance of glacially turbid waters in the Iliuk Arm (Edmundson and Mazumder 2002) may be responsible for water temperatures declining more quickly immediately below the water surface compared to the less turbid East and West Basins (Figure 13).

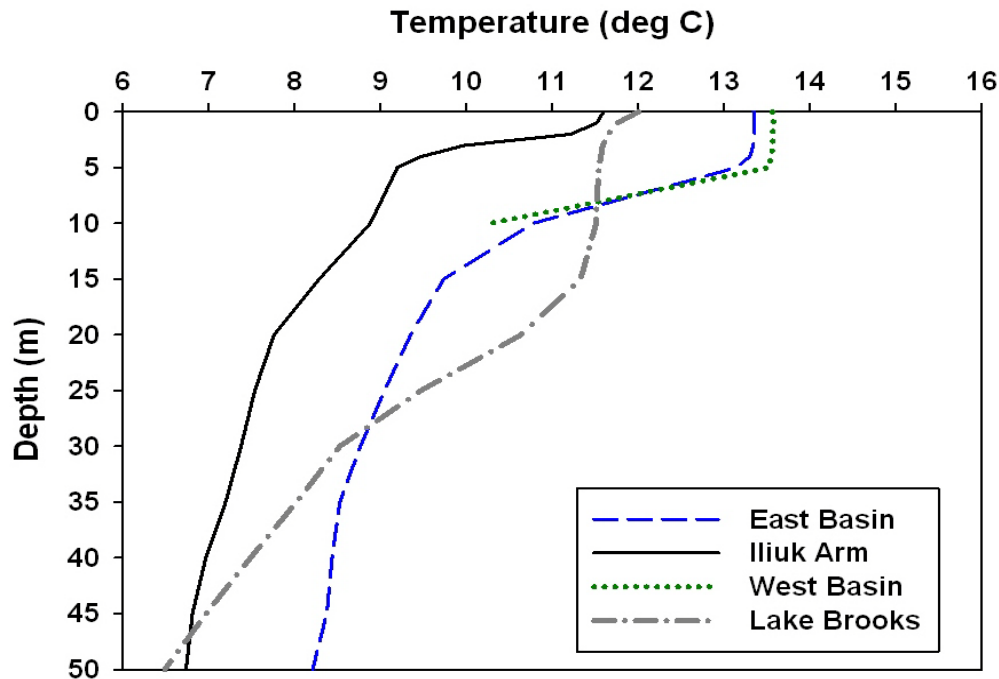


Figure 13. Temperature profiles of select sites within Naknek Lake and Lake Brooks.

pH

pH was relatively stable between basins in Lake Clark ranging between a minimum of 7.16 in the lower basin to a maximum of 7.49 in the middle basin (Table 4). The greatest vertical range in pH was observed in August in the middle basin at site M-006 with a value of 7.57 at the surface and 7.35 at 50 m. All sites displayed a slight decrease in pH with depth. This pattern is likely explained by the photosynthetic depletion of dissolved carbon dioxide in the euphotic zone where phytoplankton production is highest, thus slightly reducing the amount of carbonic acid in water (Wetzel 2001). Wilkens (2002) made the same conclusion based on similar observations.

Naknek Lake pH ranged between 7.00 in the East Basin and 7.97 in the West Basin with Lake Brooks pH falling between this range (Table 4). These values are similar to those reported by LaPerriere (1997). Naknek Lake and Lake Brooks exhibited a decrease in pH with depth (Figure 14). Differences in the euphotic zone and wind mixing among basins likely explain why some pH declines were greater (e.g. Lake Brooks) than others (e.g. Iliuk Arm). Goldman (1960) reported the euphotic zone of Lake Brooks to average

46 m whereas Naknek Lake averaged 16 m with considerable variation as sites within the East Basin and Iliuk Arm were combined.

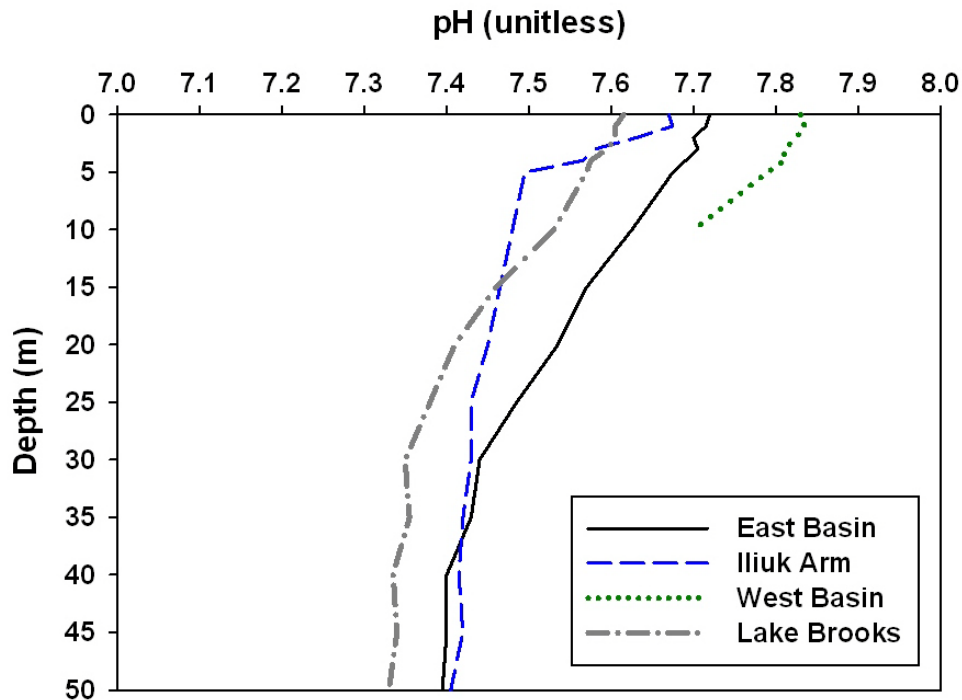


Figure 14. pH profiles for select sites within Naknek Lake and Lake Brooks.

Specific Conductivity

Similar to pH, specific conductivity remained stable between basins in Lake Clark (Table 4). Even along depth gradients, specific conductivity only deviated by 1 or 2 $\mu\text{S}/\text{cm}$ from the basin average for most sites. An exception to this observation was for several sites in the upper basin in August where there appeared to be a lens of water with lower conductance between 10 and 30 m (see Figure 13 as an example). Glacial meltwater entering the upper basin from the nearby Tlikakila River is the most likely explanation for this observation. Brabets (2002) reported specific conductance and water temperature values for the Tlikakila River of 32 $\mu\text{S}/\text{cm}$ and 7.0 $^{\circ}\text{C}$ for August 1999 and 44 $\mu\text{S}/\text{cm}$ and 5.0 $^{\circ}\text{C}$ for August 2000. The higher density of the colder water from the glacial Tlikakila River would sink below the warmer surface waters of Lake Clark as meltwater enters the basin (Figure 15), creating a lens of water with slightly lower conductance that underlies higher conductance surface waters. This same pattern was observed at Lake Clark in 2008 (Shearer and Moore 2009).

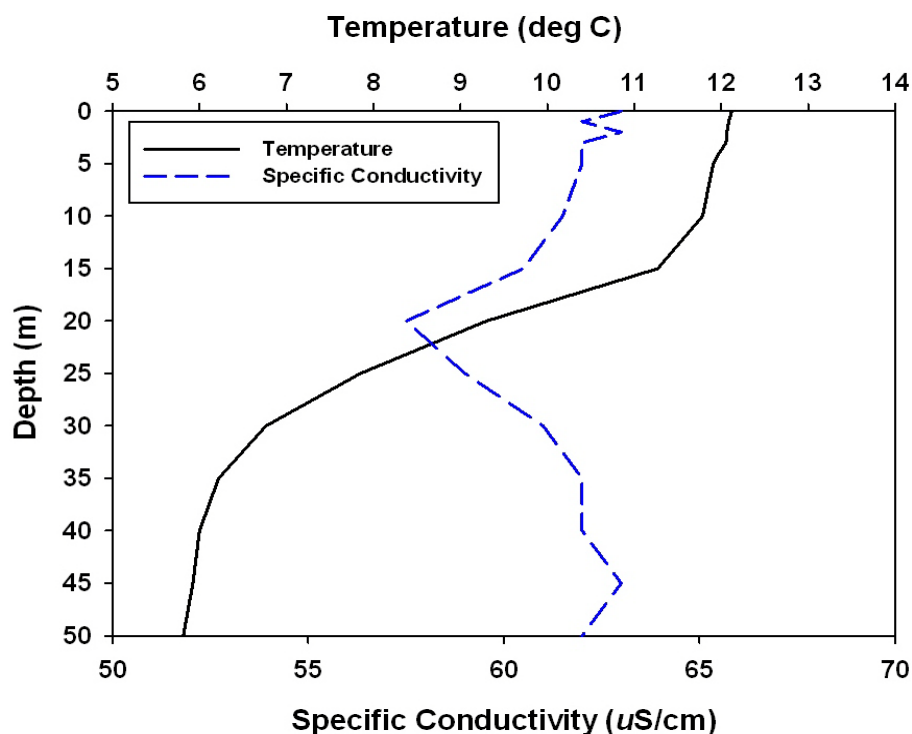


Figure 15. Water temperature and specific conductivity profile for U-009 in Lake Clark.

Specific conductivity was stable among basins in Naknek Lake and Lake Brooks (Table 4). Even with depth, specific conductivity fluctuated by $\leq 1 \mu\text{S}/\text{cm}$ at almost all sites. One exception was site E-004 in the East Basin of Naknek Lake (Figure 16) where specific conductivity values ranged from $136 \mu\text{S}/\text{cm}$ at the surface to $146 \mu\text{S}/\text{cm}$ at the bottom (site depth 12 m). This particular site is located near the inflow of water from the Iliuk Arm and Lake Brooks (Figure 6). It is likely the colder, more conductive water of the Iliuk Arm is underlying the warmer, less conductive water flowing out of Lake Brooks, thus creating a conductivity gradient.

Dissolved Oxygen

Dissolved oxygen concentrations and percent saturation were high and above saturation levels throughout Lake Clark (Table 4). Generally speaking, dissolved oxygen profiles were orthograde, common among oligotrophic lakes (Wetzel 2001), where oxygen concentrations increased as water temperature decreased with depth (Figure 17). These observations are similar to profiles measured by Wilkens (2002), who reported areas of super-saturation (percent saturation approaching 125%) at great depths (up to 110 m). Interestingly, we observed the same pattern for several upper basin profiles in August with dissolved oxygen saturation reaching 121.7% at site U-005. Additionally, we observed super-saturation of dissolved oxygen at middle basin sites during this same day (August 25th) whereas saturation levels were slightly above 100% on August 20th during middle basin profile sampling. Wilkens (2002) did not have a plausible explanation for this occurrence. We are certain instrument error did not play a factor as daily calibrations and error-checks were performed on all dissolved oxygen sensors. While photosynthetic production may partially explain high percent saturation levels near the surface, this

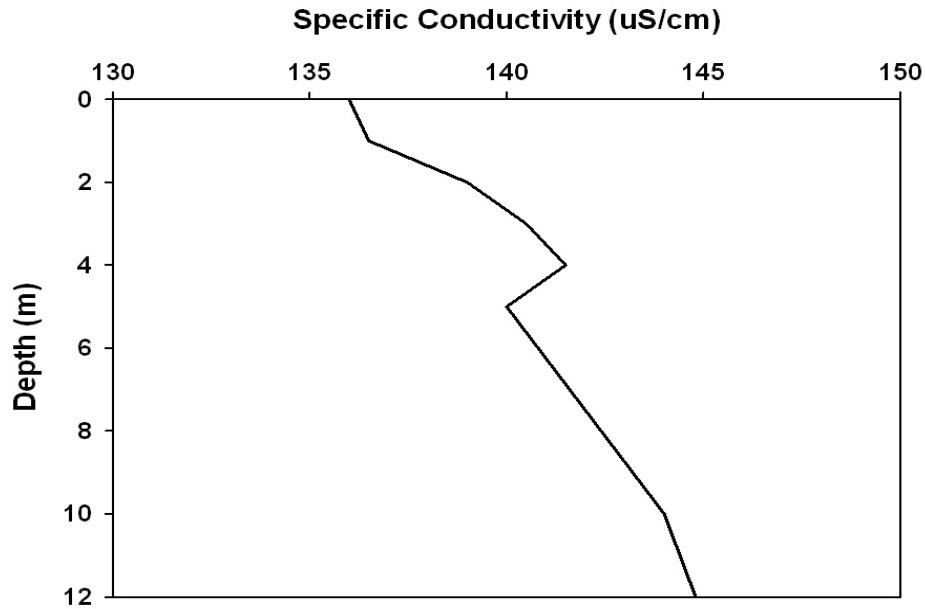


Figure 16. Specific conductivity profile for site E-004 in the East Basin of Naknek Lake.

occurrence at 50 m and deeper remains uncertain. In large, deep lakes, such as Lake Clark, bacterial respiration of organic matter of phytoplanktonic origin is usually dominant over benthic decomposition (Wetzel 2001). It is possible that bacterial depletion of oxygen is minor compared to the replenishing of oxygen supplies by internal lake circulation due to strong wind events, perhaps partially explaining the observations of oxygen super-saturation at greater depths. The large change we observed at middle basin sites with slight above saturation levels on August 20th compared to super

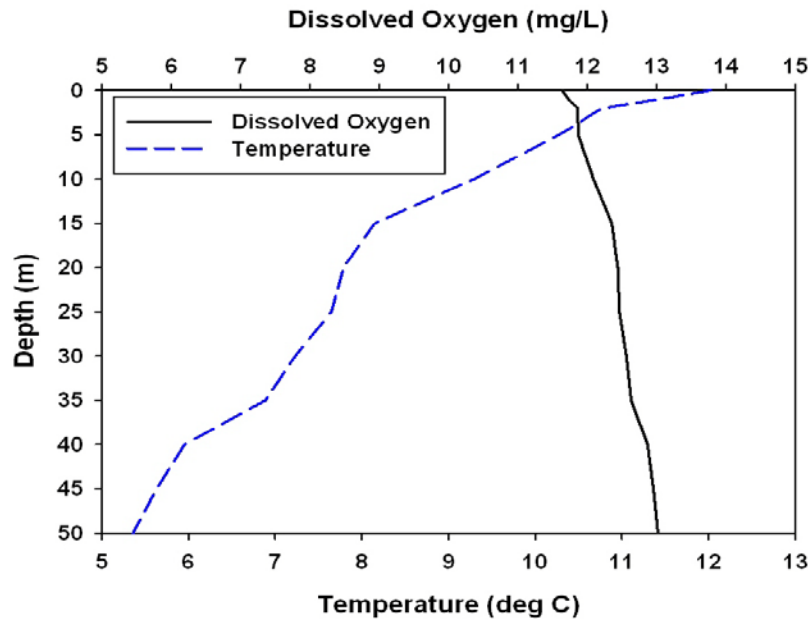


Figure 17. Dissolved oxygen and temperature profile at site L-009 displaying characteristic orthograde nature of dissolved oxygen gradients in Lake Clark.

saturation levels on August 25th suggests that changing atmospheric conditions, such as barometric pressure, may be a contributing factor. We will continue to examine local weather data to explore this occurrence further. Similar to Lake Clark, Naknek Lake and Lake Brooks dissolved oxygen levels were high and at or above saturation levels in all basins (Table 4), displaying an orthograde pattern at all sites.

Water Clarity

Typically, water clarity in Lake Clark typically increases along a gradient from the glacially turbid upper basin to the clear lower basin. This turbidity plume starts in the upper lake in late spring and advances towards the lower lake throughout the summer. This pattern has been reported by Chamberlain (1989), Wilkens (2002), Shearer and Moore (2009), and others. Snow pack in the upper watershed and summer temperatures, which greatly influence glacial melting, dictate the amount of inflow into the upper basin of Lake Clark (Brabets 2002), ultimately determining the extent to which the turbidity plume extends into the lower basin of the lake each year. In the spring of 2009, volcanic eruptions of Mt. Redoubt (located approximately 56 km southeast of Lake Clark) resulted in a broad deposition of ash in many portions of the Lake Clark watershed (Figure 18). Subsequently, volcanic ash was flushed into Lake Clark during spring snow melt and runoff along with the loading of glacial silt, which ‘homogenized’ turbidity conditions lake-wide (Figure 19).



Figure 18. Gray volcanic ash blankets the landscape as steam arises from Mt. Redoubt in LACL (photo credit: J. Shearer; photo date: June 9, 2009).

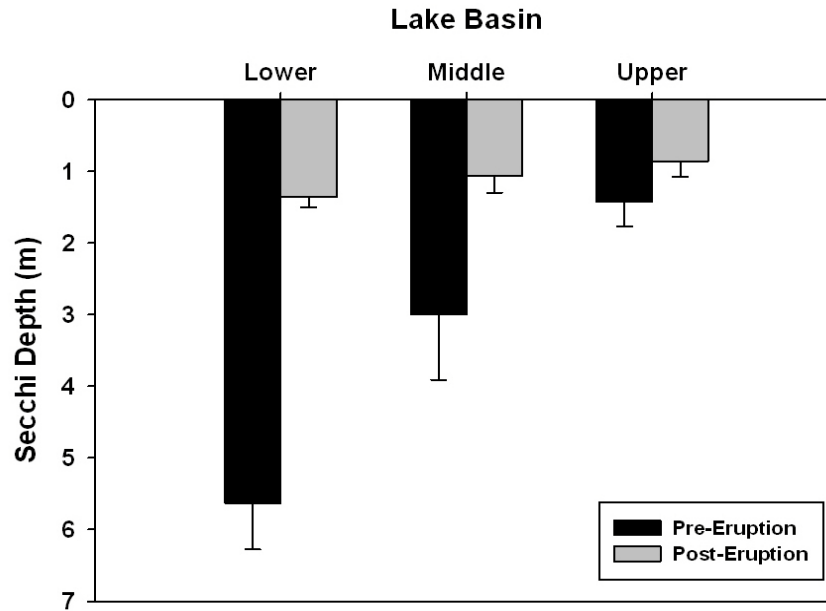


Figure 19. Secchi depths for Lake Clark comparing pre-eruption (2008) and post-eruption (2009) water clarity.

Water clarity varies widely within Naknek Lake due to differences in surface and subsurface runoff. As such, turbidity can vary greatly among basins (Figure 6; Kozlowski 2007). Within Naknek Lake we observed Secchi depths ranging from 0.25 m in the Iliuk Arm to 5.85 m in the East Basin, whereas Lake Brooks had Secchi depths ranging from 8.85 m to 11.43 m (Table 4, Figure 20). The range of Secchi depths for the West Basin of Naknek Lake is based on values recorded at five sites as wind conditions prevented measurements at all sites. These values are similar to those reported by LaPerriere and Edmundson (2000) who provided a Secchi depth range of 3.2 m to 6.5 m

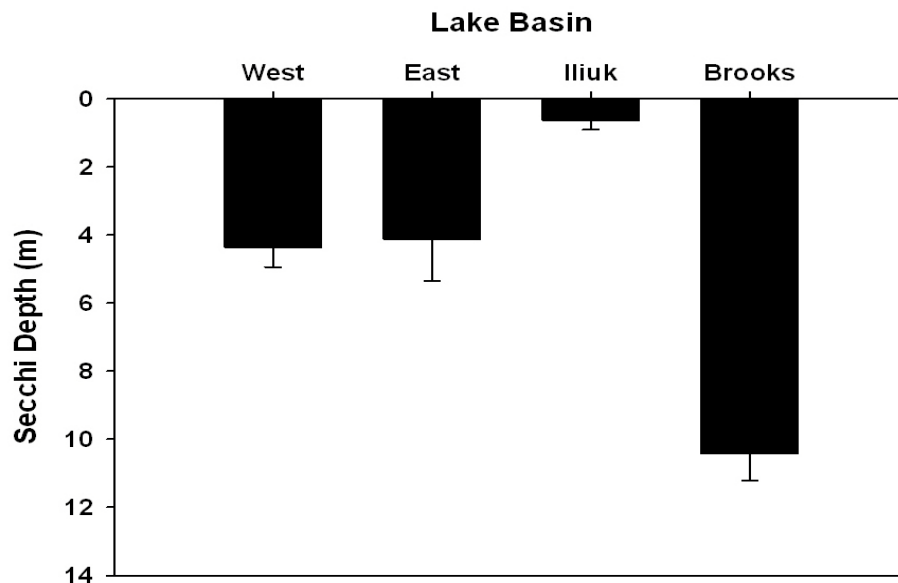


Figure 20. Secchi depths for three basins in Naknek Lake and in Lake Brooks.

for Naknek Lake and 9.6 m to 9.8 m for Lake Brooks between 1990 and 1992. However, LaPerriere and Edmundson (2000) only reported Secchi depth values from one site on Naknek Lake, located between the East Basin and North Arm (a large, clear water basin on the north side of Naknek Lake), whereas Secchi depth measurements taken within the Iliuk Arm would have likely resulted in a greater range of values being reported.

Chulitna River Continuous Water Quality Monitoring

Mean core parameter values for the Chulitna River were relatively stable between early, mid-, and late summer sampling periods (Table 5). However, it is important to note that water conditions at the Chulitna River monitoring site were directly influenced by water levels in Lake Clark (Figure 21). Therefore, it is possible core parameter values are a reflection of lake conditions and not river conditions although flowing water was observed during all site visits (J. Shearer *personal observation*). Specific conductivity displayed the only distinguishable trend (Figure 22) during summer months. This pattern is likely a reflection of relative contributions of groundwater to flow within the Chulitna River throughout the summer where groundwater contributes less to total flow within the river in late spring / early summer during peak snow melt and more to total flow during mid-late summer after most snow has melted within the basin. Although many factors determine specific conductivity concentrations in water, groundwater tends to have higher specific conductivity concentrations than surface runoff due to increased contact time of water with parent material (Wetzel 2001).

Exit Creek Continuous Water Quality Monitoring

The objective of monitoring water quality parameters in Exit Creek was to compare variation between three phases of the hydrograph: rising flows in late spring, peak flows in mid-summer, and descending flows in late summer / early fall. Failure to retrieve the water quality sonde following the early fall deployment period restricted us to only comparing water quality between rising and peak flows although water level was recorded from mid-May through late September (Table 6). Specific conductivity displayed the largest difference between late spring ($95 \pm 7 \mu\text{S/cm}$) and mid-summer ($31 \pm 1 \mu\text{S/cm}$) deployment periods. Late spring monitoring started just after the onset of glacial melting, thus groundwater likely contributed a larger portion of the flow to Exit Creek at this time of year compared to the mid-summer monitoring period when glacial melting was peaking. Additionally, the mid-summer monitoring period overlapped with a large precipitation event that caused Exit Creek flows to quickly rise (Figure 23). The large contribution of recent precipitation combined with glacial meltwater likely explains why specific conductivity values were considerably lower during this time compared to late spring. The wider daily fluctuation in water temperature during late spring (Figure 23) may be a result of solar radiation having a more pronounced effect on warming surface water when flow velocity and volume are relatively low. As flow velocity and volume increase with increased glacial melting the proportion of water warmed by solar radiation is reduced, thus leading to less diel temperature fluctuation and lower mean daily temperatures.

Table 5. Summary data for core parameters for the Chulitna River.

Parameter	Early Summer ¹	Mid-Summer ²	Late Summer ³
Statistic			
Water Temperature (°C)			
Mean	13.57	13.71	11.75
Standard Deviation	1.29	1.73	1.11
Maximum	16.30	17.92	14.10
Minimum	11.38	10.88	9.06
pH (standard units)			
Mean	7.50	7.83	7.68
Standard Deviation	0.10	0.12	0.10
Maximum	7.75	8.19	7.98
Minimum	7.34	7.59	7.48
Specific Conductivity (µS/cm)			
Mean	70	87	85
Standard Deviation	2	2	2
Maximum	73	90	89
Minimum	66	81	81
Dissolved Oxygen (mg/L)			
Mean	10.73	10.94	10.73
Standard Deviation	0.43	0.67	0.42
Maximum	11.49	12.33	11.90
Minimum	9.77	9.53	9.09
Stage (ft) ⁴			
Mean		1.59	
Standard Deviation		0.81	
Maximum		2.86	
Minimum		0.15	
Parameter	Greatest Diel Fluctuation*		
	Date		Range
Water Temperature (°C)	June 15 th		2.84
pH (standard units)	July 17 th		0.40
Specific Conductivity (µS/cm)	July 29 th , Aug 23 rd , Sept 3 rd , Sept 9 th		3
Dissolved Oxygen (mg/L)	Sept 14 th		2.15
Stage (ft)	August 28 th		0.23

¹ Deployment period: June 10th – 17th

² Deployment period: July 17th – 26th

³ Deployment period: August 19th – September 17th

⁴ Stage measured continuously from June 13th – September 15th

* Based on hourly measurements over a 24-hour period.

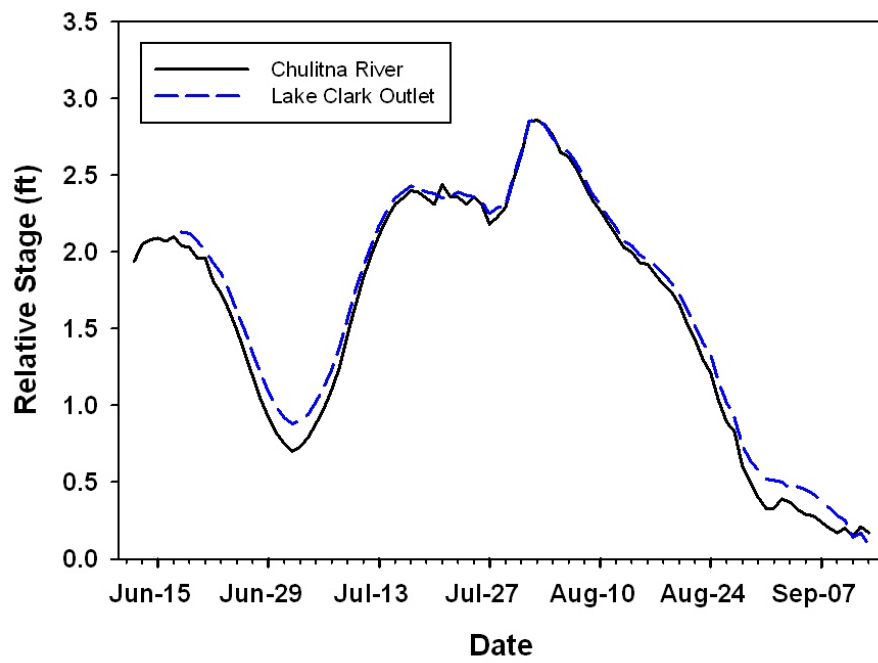


Figure 21. Relative stage for Chulitna River monitoring site and Lake Clark outlet.

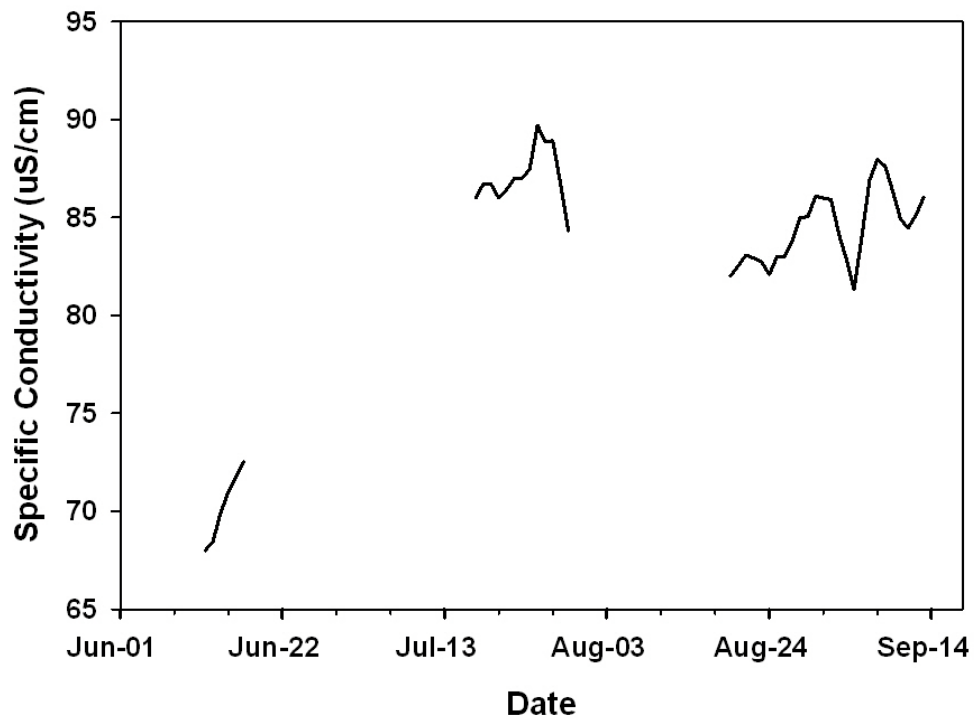


Figure 22. Specific conductivity trend for Chulitna River monitoring site.

Table 6. Summary data for core parameters for Exit Creek.

Parameter Statistic	Late Spring ¹	Mid-Summer ²
Water Temperature (°C)		
Mean	2.35	1.19
Standard Deviation	1.30	0.10
Maximum	6.06	1.68
Minimum	0.48	0.87
pH (standard units)		
Mean	8.05	8.48
Standard Deviation	0.03	0.13
Maximum	9.01	9.05
Minimum	7.87	7.76
Specific Conductivity (µS/cm)		
Mean	95	31
Standard Deviation	7	1
Maximum	117	36
Minimum	62	24
Dissolved Oxygen (mg/L)		
Mean	12.20	14.30
Standard Deviation	0.50	0.11
Maximum	14.10	14.70
Minimum	9.85	12.72
Stage (ft) ³		
Mean		1.34
Standard Deviation		0.66
Maximum		3.81
Minimum		0.19
Parameter	Greatest Diel Fluctuation*	
	Date	Range
Water Temperature (°C)	May 20 th	4.95
pH (standard units)	July 27 th	0.62
Specific Conductivity (µS/cm)	May 13 th	25
Dissolved Oxygen (mg/L)	May 20 th	1.82
Stage (ft)	July 30 th	0.96

¹ Deployment period: May 13th – 25th

² Deployment period: July 23rd – August 1st

³ Deployment period: May 13th – September 25th

* Based on hourly measurements over a 24-hour period.

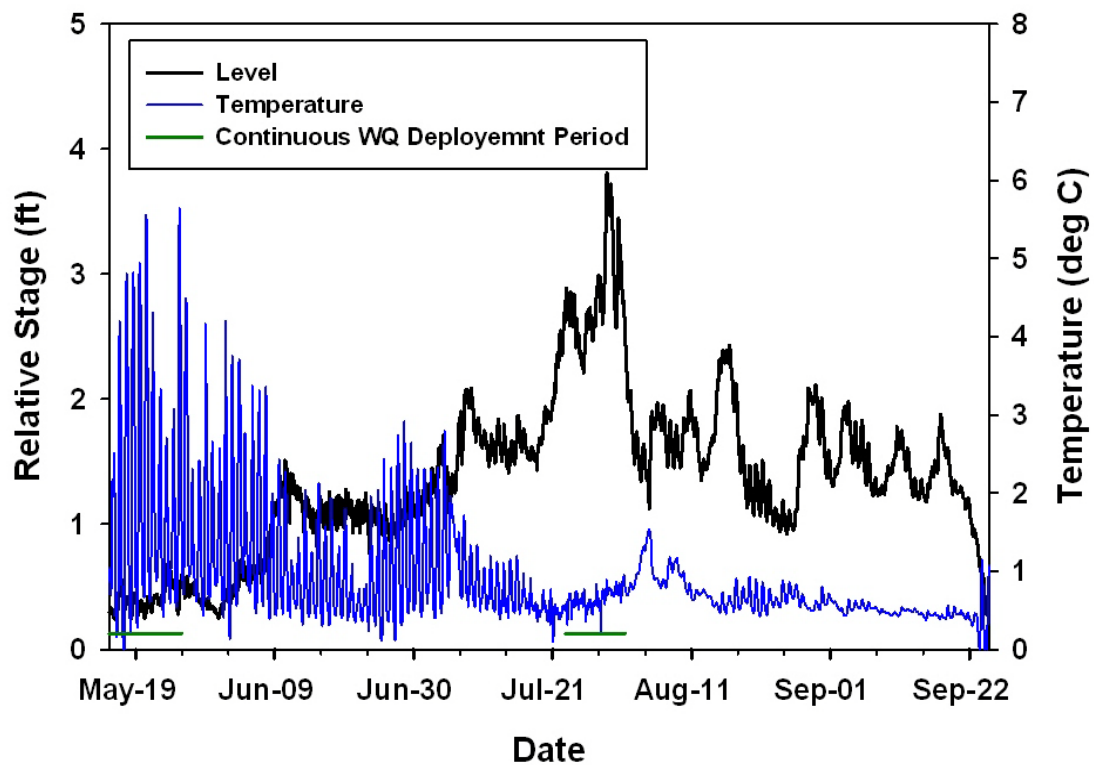


Figure 23. Relative stage (black), water temperature (blue), and continuous water quality deployment period (green) for Exit Creek.

Recommendations and Conclusions

SWAN staff have field tested, and modified where appropriate, monitoring protocols on Tier 1 lake systems. The challenge is now to apply those protocols to smaller, less accessible Tier 2 and 3 systems. Water quality monitoring within Tier 1 SWAN freshwater flow systems is characterized by three techniques: 1) lake profile sampling during mid-summer index periods to provide a synoptic spatial assessment of core water quality parameters, 2) continuous water temperature monitoring through the use of moored temperature arrays to track intra-annual patterns in thermal stratification, freeze-up, lake cooling and heating, and 3) continuous core parameter monitoring at select tributary and lake outlet sites with multiparameter sondes to assess short-term fluctuations in water quality conditions. Due to the remote nature of Tier 2 and 3 lakes, and thus the expense and logistics of accessing these waters, we will only collect spatial lake profile information as repeat visits to these lakes is not feasible within a given field season. In 2010 we plan to sample Kijik Lake, Lachbuna Lake, Crescent Lake, and Kontrashibuna Lake, all located within LACL, for the first time in addition to continued sampling on Lake Clark, Naknek Lake, and Lake Brooks.

During the planning phases of SWAN's freshwater flow system program, park staff and invited experts proposed a tiered system to classify priority levels for lake monitoring. High priority lakes (Tier 1) were selected due to their management priority for the park, importance as a salmon fishery, relative ease of access, system type, and information gained from previous research. Tier 2 and 3 lakes were medium and low priority waters that were not as high a management priority, were more difficult to access, but would expand the spatial coverage of park waters being monitored. Lake Kontrashibuna was originally selected as a Tier 1 lake; however, in March 2010 we reclassified this waterbody as a Tier 2 lake. This reclassification was meant to avoid potential conflicts between planned freshwater monitoring activities (e.g. installation of moored temperature arrays and water level monitoring sites) and regulations pertaining to authorized activities in designated wilderness areas (Lake Kontrashibuna is within the designated wilderness boundary of LACL). Lake profile sampling will be the only monitoring activities on Tier 2 lakes. Such monitoring activities are more amenable to permitted activities within designated wilderness areas.

Alternative to monitoring Lake Kontrashibuna as a Tier 1 system, we selected Kijik Lake, which was previously a Tier 2 lake, as a high priority waterbody. Kijik Lake is a clearwater lake with a surface area of approximately 4 km² and an average depth of 100 m (Brabets and Ourso 2006) making this lake relatively small compared to the other Tier 1 lakes within SWAN (Lake Brooks is the next smallest at 75 km²). However, Kijik Lake and its inlet and outlet river, the Little Kijik River, are critically important sockeye salmon spawning areas within the Lake Clark watershed (Young and Woody 2007). We feel the replacement of Lake Kontrashibuna with Kijik Lake still meets the selection criteria used to identify Tier 1 lakes and does not compromise SWAN's freshwater flow system monitoring design or information obtained for management of park resources.

While SWAN will continue to focus on large lake systems due to their importance to park management and spatial scale, we recognize the importance of monitoring smaller lakes as well. Small, shallow basin lakes tend to operate more as a microcosm compared to large lake systems and changes are likely to first manifest themselves in these smaller systems (Larsen et al. 2004). In 2010 SWAN will begin to explore options for monitoring small, shallow lakes to track long-term changes in water quality and/or surface hydrology, thus providing a more complete synopsis of all freshwater systems within SWAN parks. One particular monitoring method, repeat aerial photography, has been successfully applied in other regions of Alaska (Larsen et al. 2004, Klein et al. 2005) and may have promise for shallow lakes within southwest Alaska.

In 2010 we will change our strategy for monitoring continuous water quality parameters in glacial streams and rivers. The loss of a multiparameter water quality sonde in Exit Creek illustrates the harsh nature of these systems and the potential damage to monitoring equipment. To continuously monitor stream stage, water temperature, and conductivity in Exit Creek we will use a water level pressure transducer equipped with a temperature thermistor and conductivity sensor. This device will be housed inside a metal pipe and attached directly to a large boulder within the stream channel rather than attached to a free-standing anchor. This method will not allow for continuous monitoring of pH, dissolved oxygen, and turbidity. However, these parameters have displayed little diel fluctuation in past monitoring and will be measured in situ during occasional site visits throughout the summer.

In previous SWAN planning documents and annual summary reports we discussed our intent to monitor a suite of advanced water quality parameters (e.g. nutrients, ions, metals, etc) in addition to our standard core water quality parameter monitoring. However, after further considering of SWAN's freshwater flow system monitoring objectives and logistical constraints of sampling these remote systems, we have decided to forego any water chemistry sampling to analyze an advanced suite of water quality parameters at this time. Both park facilities in LACL or KATM lack a general laboratory for sample preparation and storage. In addition, the extended sample trip duration over which freshwater monitoring is conducted would make getting viable samples shipped from the field to a qualified analytical laboratory, which would most likely be located outside of Alaska, unrealistic. Previous studies by Chamberlain (1989), LaPerriere (1997), and Brabets (2002) have provided a good baseline for major ion concentrations in most large lakes within the SWAN. As such, we will consider the possibility of conducting water chemistry inventories in the future to determine changes from baseline conditions; however, we feel repeat water chemistry sampling on an annual basis is not feasible at this time given logistical constraints of monitoring within SWAN parks.

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