

Limnological Monitoring of Lake Becharof

Final Report to the
U.S. Fish and Wildlife Service

• ————— •

by

Jacqueline D. LaPerriere, Assistant Leader

Research Work Order 58 of the
Alaska Cooperative Fish and Wildlife Research Unit

April 1998

Executive Summary

Lake Becharof is a national treasure due to its pristine condition and to its large size. It is one of the remaining great lakes (> 500 square kilometers) of the world that is unexplored. The water quality of this lake is outstanding from every measure that has been taken so far. This lake, however, is somewhat unusual because it is intersected by a large fault that degasses magmatic carbon dioxide. Fairly recent explosive activity at the area of Gas Rocks shows interaction of the magma with this lake and its watershed. This study is exploring the general limnology of the lake and is particularly focused on looking for evidence of the influences of the magma on the chemistry and heat content of the lake. Thus far there are no conclusive findings of these influences.

The major ions of the lake water are higher in sodium and chloride than world average for lakes or rivers. If this elevation were for chloride alone, then volcanic influence would be likely. Because sodium is also elevated, it is more likely that there is an evaporite rock source of the salt, or that the nearby ocean produces airborne salt that falls dry or with precipitation onto this lake and its watershed. Lake Becharof resembles Brooks Lake in the nearby Katmai National Park for concentration of major ions and proportion of positive ions. However, among the negative ions, Lake Becharof has slightly less bicarbonate and more chloride. Sulfate is not measurable in Brooks Lake but is measurable in Lake Becharof. This sulfate could be from volcanic interaction with the lake but is also possibly from reduced sulfur rocks in the basin.

Certain of the measured trace metals such as boron, lithium, and silicon could indicate volcanic influence, but have not been found yet in high enough concentrations to conclude this. Silicon is lower in concentration than in all the Katmai lakes, except that in the Ruth Arm it is slightly higher than in Kukaklek Lake where it was the lowest of the Katmai lakes. All of these mentioned trace metals are necessary nutrients for algal growth, and silicon is a major nutrient for diatoms. None of the nutrients measured as major or trace ions are identified as being in limiting concentrations.

Temperature profiles showed uniform temperature as deep as 60 m at Station 4, and while there is some curvature in the profile at Station 1, there was no thermocline that would indicate stratification. Measurements at Station 1 were restricted to 60 m due to the length of the cord for the meter, but the lake is about 185 m at the deepest. Therefore, we cannot be sure that the lake is not colder at the bottom. However, the temperature of 6 to 8°C at 60 m indicates that there is a very large volume of this lake being heated in the summer. A recent study has shown that this extra heat deep in coastal lakes gives a boost in growth to juvenile sockeye salmon. Therefore, the sockeye leaving this lake to go to sea are probably larger than they would be if the lake stratified.

Light penetration and Secchi depth measurements of water transparency were indicators of the amount of plankton algae in this lake. These measurements were the most shallow in the Ruth Arm where another study of the ecosystem studies has found the highest concentration of plankton algae. Low concentrations of major ions in the Ruth Arm might lead us to conclude that it is less productive, but the algal evidence indicated it might be higher in production than the rest of the lake. However, if zooplankton abundance were lower in the Ruth Arm, then the algal evidence might be of high standing crop rather than of low productivity or growth. Light penetration was not steady at Station 4; at 9m the indication was of higher turbidity. This is probably a turbidity plume from the Kejulik River.

Abstract

Analysis of the major ions of Lake Becharof showed the dominant positive ions to be calcium (44%) and sodium (38%), with magnesium, usually the second most important cation in fresh waters, third most important (18%), and potassium (less than 1%) barely represented. The dominant negative ions were bicarbonate and chloride (both 41%) with sulfate (18%) next. Therefore, Lake Becharof is a calcium bicarbonate-chloride chemical type. Sodium and chloride are overrepresented in this lake as they are in nearby lakes in Katmai National Park, but to an even greater degree. Trace element analyses demonstrated measurable amounts of boron at all four sampling stations and lithium at three stations; higher concentrations of both were measured near the "bubbler," where gas erupts from the lake surface offshore from Gas Rocks. These two trace elements indicate geothermal waters. Iron and manganese were elevated at Station 3 in the southernmost, shallow basin of the lake (Ruth Arm), probably due to chelation by humates. Both iron and manganese were also elevated near the bubbler.

Profiles at the established stations showed lack of thermal stratification in late August 1996 except for the deepest station, Station 1, which was not at uniform temperature through depth, but measurements there were only to 60 m due to the limited length of the cord for the multimeter. Oxygen was essentially uniformly distributed down through the depths measured and at near-complete saturation at all stations. Conductivity was also uniform with depth but was about half at Station 3 compared to the other stations, as were the concentrations of all major ions.

Light penetration to 1% of the surface value was shallowest at Station 3 (11 m), deeper at Stations 2 and 4 (29 m), and deepest at Station 1 (58 m), the farthest west and deepest spot. Secchi depth, which measures the effect of scattering materials, was likewise shallowest at Station 3 (5 m), deeper at station 4 (8.5 m) and at Station 2 (10 m), and deepest at Station 1 (16 m). The two measures of light effects in the lake, therefore, vary together. Color and turbidity do not explain the variability in either light measurement among stations. This variability may be explained by the biomass of the plankton algae (measured as chlorophyll *a*), as was found for the Katmai lakes.

Introduction

Under the definition that a great lake is one larger than 500 km², Lake Becharof, Alaska, is a great lake at 1190 km² (Fizler and Serruya, 1990). Excluding the Laurentian Great Lakes, Lake Becharof is the sixth largest lake in the United States and is third among strictly freshwater lakes. The lake has been recently mapped bathymetrically by the U.S. Fish and Wildlife Service (USFWS) and Dr. Ole Mathisen (1996), and the maximum depth is now estimated as 185 m, rather than the 92 m tabulated in Fizler and Serruya (1990).

This lake has not been studied limnologically and is considered to be one of the three great lakes of the world still unexplored (also included as unexplored great lakes are Iliamna in Alaska and Taymir in Siberia). The only limnologist who has published concerning this lake is Charles Goldman (1960), who found the algae of the lake to be nitrogen limited.

In the early 1970s, there was an explosion of gas near the area called Gas Rocks created two small maars that formed small lakes (Symonds et al., 1997). The U.S. Geological Survey (USGS) studied these ponds and the general area, and identified the gas as mainly CO₂ on land and where it degasses visibly through the water column of the lake at a site popularly called "the bubbler" (Symonds et al., 1997).

Four main stations have been established on the lake where sampling has been conducted (Figure 1).

The objectives of this study are:

1. To evaluate the major ions of Lake Becharof;
2. To begin to evaluate the trace metals of Lake Becharof;
3. To evaluate the light characteristics of Lake Becharof, and the characteristics that influence light transmission; and
4. To explore the effects of geothermal inputs on Lake Becharof.

Methods

Profiles: Temperature, depth, conductivity, and dissolved oxygen were profiled at the four sampling stations in August 1996 using a YSI Model 3800 multimeter. Oxidation-reduction potential and pH could not be measured at that time because a pH probe was not available from the factory to replace one that had failed.

Ions: Samples were taken with a clean 2-L Van Dorn sampling bottle at about 0.5 m at each station. Anion samples were dispensed into polypropylene bottles, and major cation and trace metals samples were dispensed into metal-free (certified) ICHM polypropylene bottles. An alkalinity sample (200 mL) was taken from the anion bottle for the bubbler and titrated with a HACH digital titrator and 0.16 NH₂SO₄ to the pH 5.1 endpoint (bromocresol green-methyl red indicator) at the field laboratories. The remainder of the anion samples were analyzed by Northern Testing Laboratories, Fairbanks, Alaska, for sulfate and for chloride by EPA Method 300.

Trace metal samples were returned to UAF where they were preserved with redistilled (Ultrax) nitric acid and shipped to Environmental Trace Substances Laboratory in Missouri, where they were analyzed for potassium by atomic adsorption

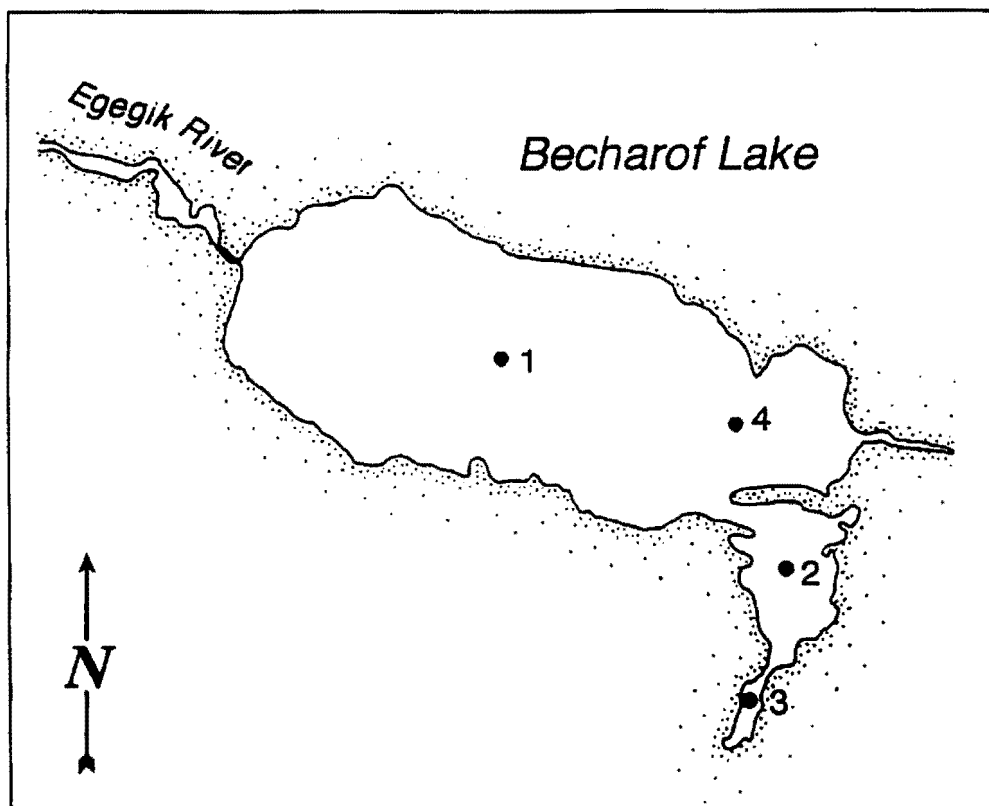


Figure 1. Becharof Lake with sampling stations marked.

spectrophotometry and for 31 total recoverable metals by induced coupled plasma (ICP) spectrophotometry.

Light Conditions: A standard (20-cm) Secchi disk on a calibrated line was used to determine the lake transparency called Secchi depth. The disk was lowered until it disappeared, retrieved until it could just be seen, and the depth read on the calibrated line at the water surface.

Light penetration was measured with a Li-Cor LI-189 quantum radiometer photometer with an underwater quantum sensor that measures downward irradiance as quanta of photosynthetically active radiations. The sensor was held facing upwards in an underwater lowering frame attached to a calibrated (for depth) wire-line. Readings were taken every meter of depth until values fell to approximately 1% of the surface irradiance. Percentage of surface irradiance was plotted versus depth on semi-log graph paper, and the slope of the best straight line was calculated as the vertical attenuation coefficient, K_d , of downward irradiance.

Results and Discussion

Profiles: Thermal profiles on 28 August 1996 (Figure 2) show that this lake was not stratified in late August 1996 and, in fact, at the deep station (Station 1), while there is an inflection in the graph, it is not a thermocline, defined as $\geq 1^\circ\text{C}$ per m. Because the lake is ~185 m at this station, and the meter used was restricted to the top 60 m, we cannot know the thermal conditions deep in the lake. However, because the water at 60 m was 5.7°C , I suspect this lake mixes very deeply on occasions throughout the summer. This condition is called cold, discontinuous polymixis (Lewis, 1983).

Note that the conductivity and dissolved oxygen were uniform at all stations, so they are written on Figure 2 as a single value. The conductivity at Station 3, the Ruth Arm station, is about half that of the other stations, as was true of major ions there.

Major Ions: Analysis of the major ions of Lake Becharof found the dominant positive ion was calcium (44%) with sodium at 38%, magnesium at 18%, and potassium (less than 1%) barely represented (Table 1 and Appendix 1). Usually, magnesium is the second most dominant cation. Here, sodium was overrepresented due to the proximity to the Pacific Ocean, particularly to Bristol Bay and Cook Inlet. While there are sedimentary sodium chloride deposits in the area, the water content is meteoric (Terry Keith, USGS, 1996, personal communication). The dominant negative ions were bicarbonate and chloride (both 41%), and sulfate (18%) was second. Therefore, again, the overrepresentation of chloride, which is often less than sulfate in lakes, shows the influence of the nearby ocean. Thus, Lake Becharof is a calcium bicarbonate-chloride chemical type at all stations.

Trace Ions: Trace element analysis (Table 2) demonstrated boron was measurable at all four stations on the lake, and lithium at three stations. Both elements were at even higher concentrations at the bubbler where CO_2 is jetted out of the water. These two elements indicate geothermal activity; thus, it was unexpected that even the Ruth Arm was so affected, although to a lesser extent than the other stations. Manganese and iron were also measured at Station 3, in the Ruth Arm, and may also indicate geothermal waters but may be a function of humates that keep metals in solution by chelation.

Becharof Lake, 28 August 1996

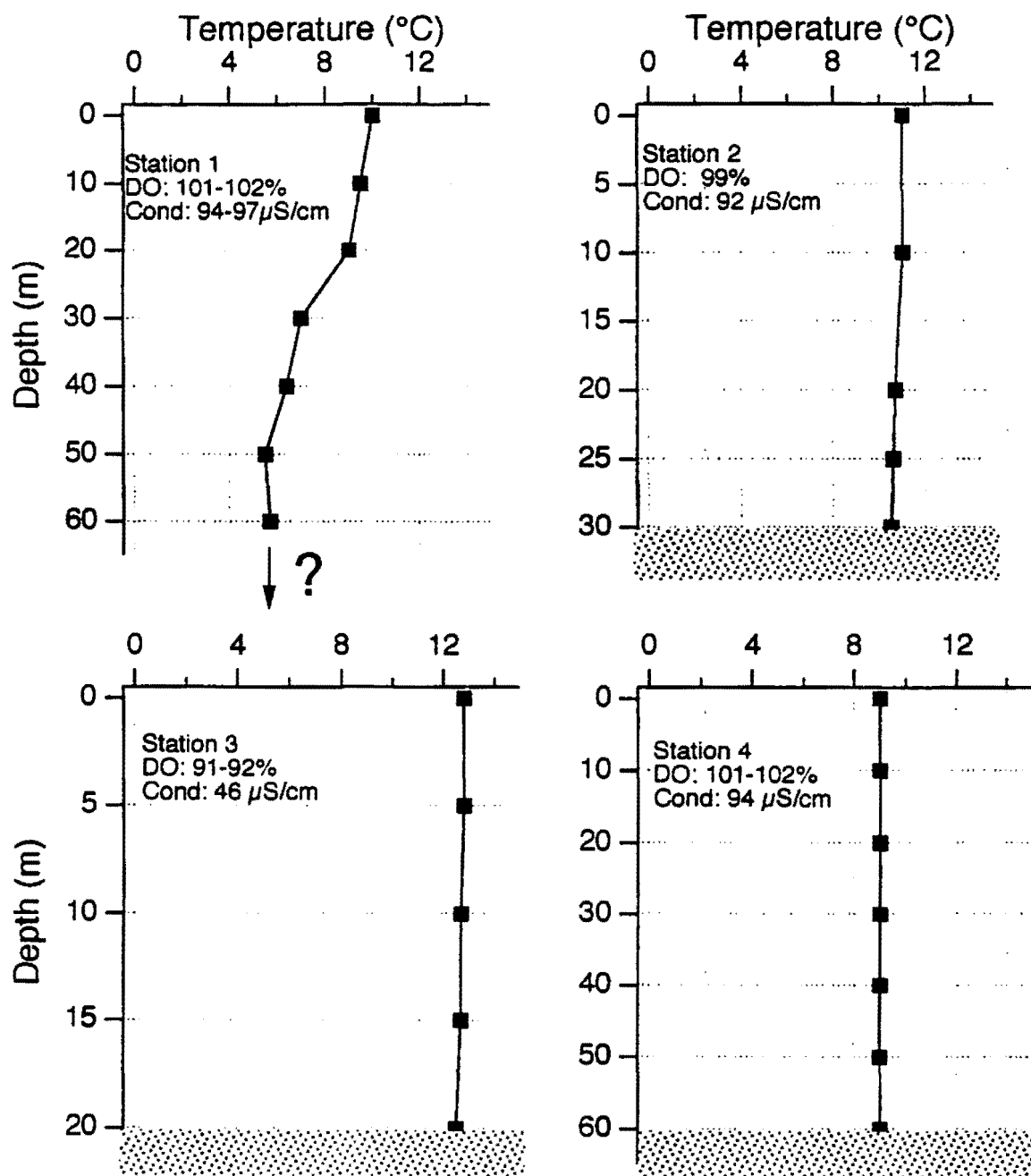


Figure 2. Thermal profiles and dissolved oxygen and conductivity characteristics at study stations.

Table 1. Major ions at Station 1,^a Lake Becharof, 28 August 1996.

	(mg/L)	(meq/L)	(%)
Ca ⁺²	7.09	0.35	44
Mg ⁺²	1.69	0.14	18
Na ⁺	7.00	0.30	38
K ⁺	0.33	0.01	< 1
HCO ₃ ⁻	20.7 ^b	0.34	41
SO ₄ ⁼	6.79	0.14	18
Cl ⁻	12.1	0.34	41

^a Proportions were the same at all stations. Concentrations were about half other stations at Station 3, Ruth Arm.

^b Datum from ADF&G Limnology Laboratory, Soldotna.

Table 2. Measurable trace elements at Lake Becharof, 28 August 1996.

Element	Station 1	Station 2	Station 3	Station 4	Near Gas Rocks
	(µg/L)				
Boron	87	89	17	87	190
Barium	— ^a	2	2	2	3
Iron	—	20	57	—	92
Lithium	8	9	—	9	24
Manganese	—	—	14	—	7
Silicon	527	653	1500	470	58
Strontium	26	25	14	27	58

^a Blank means below method detection limit.

Light Conditions: Secchi depth was shallowest in the Ruth Arm at Station 3 (Table 3) and deepest at the center of the lake along the fault where the lake is deepest at Station 1. Light penetration showed the same pattern (Table 3) with the shallowest penetration at Station 3 and deepest at Station 1. The relation between the two measurements was very strong:

$$\text{Secchi depth} = 2.450 + 0.2339 (1\% \text{ light depth})$$

($r^2_{ADJ} = 0.973$, $p = 0.009$). However, note that the "rule of thumb," that three times the Secchi depth equals the 1% light depth, varies up the lake from 3.6 at Station 1 to 3.4 at Station 4, to 2.9 at Station 2, and to 2.2 at Station 3 (Table 3). Thus, it only "fits" at Station 2. There was no relation between either of these light characteristics and color or turbidity (Table 4).

Table 3. Light conditions, Lake Becharof, 28 August 1996.

Station	Secchi Depth (m)	K_d (m^{-1})	1% Depth (m)	$\frac{1\% \text{ Depth}}{\text{Secchi Depth}}$
1	16	0.08	58	3.6
2	10	0.16	29	2.9
3	5	0.42	11	2.2
4	8.5	0.16 ^a	29	3.4

^a Until 9 m, then extremely turbid water was evidently encountered.

Table 4. Turbidity and color of water, Lake Becharof, 28 August 1996.

	Turbidity (NTU)	Color (cpu)
Station 1	0.24	0
Station 2	N.D. ^a	— ^b
Station 3	0.83	6
Station 4	0.31	0

^a N.D. = none detected.

^b Dash means not measured

Relatively shallow light penetration and Secchi clarity at Station 3 in the Ruth Arm is likely due to the higher planktonic algal biomass measured as chlorophyll *a* there (Mathisen, 1992). His nutrient data also show that the whole lake is probably nitrogen limited because the ratio between total nitrogen and total phosphorus calculates between 12 and 29. Val Smith (1979) found that when the ratio is under 13, lakes are usually nitrogen limited and don't become phosphorus limited until the ratio is above 21 (often considerably above 21). Additionally, the low levels of nutrients and chlorophyll *a* (Mathisen, 1992) illustrate the oligotrophic nature of this lake (Nürnberg, 1996).

References

- Fizler, M. M. and C. Serruya (Eds.). 1990. Large Lakes, Ecology, Structure and Function. Springer Verlag.
- Mathisen, O. A. 1992. Studies on the effects of large, successive sockeye salmon escapements into Lake Becharof, Egegik River, Bristol Bay. Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks. Report JCFO 92-05.
- Mathisen, O. A. 1996. Bathymetric maps of Lake Becharof and the Ugashik lakes. Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks. Report JCSFO 96-034, prepared for the Lake and Peninsula Borough.
- Nürnberg, G. K. 1996. Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. *Lake and Reservoir Management* 12:432-447.
- Smith, V. H. 1979. Nutrient dependence of primary productivity in lakes. *Limnology and Oceanography* 24:1051-1064.
- Symonds, R. B., B. E. Ritchie, R. G. McGimsey, M. H. Ort, R. J. Poreda, W. C. Evans, and C. J. Janik. 1997. Investigation of gas seeps and springs in the vicinity of the Gas Rocks, south shore Becharof Lake, Alaska. USDI USGS Open File Report 97-127. 27pp.

Appendix 1. Major ions at Stations 2, 3, and 4, and near Gas Rocks, Lake Becharof, 28 August 1996.

Station 2 (mg/L)			
Ca ⁺²	6.72	HCO ₃ ⁻	— ^a
Mg ⁺²	1.66	SO ₄ ⁼	6.71
Na ⁺	7.00	Cl ⁻	12.00
K ⁺	0.33		
Station 3 (mg/L)			
Ca ⁺²	3.54	HCO ₃ ⁻	—
Mg ⁺²	0.72	SO ₄ ⁼	3.38
Na ⁺	3.70	Cl ⁻	5.24
K ⁺	0.10		
Station 4 (mg/L)			
Ca ⁺²	7.07	HCO ₃ ⁻	—
Mg ⁺²	1.70	SO ₄ ⁼	6.98
Na ⁺	7.10	Cl ⁻	12.10
K ⁺	0.36		
"Bubbler" near Gas Rocks (mg/L)			
Ca ⁺²	8.13	HCO ₃ ⁻	15.90
Mg ⁺²	2.39	SO ₄ ⁼	—
Na ⁺	11.83	Cl ⁻	—
K ⁺	0.49		

^a Blank means not measured.