E3S Web of Conferences **407**, 02004 (2023) https://doi.org/10.1051/e3sconf/202340702004
APEEM 2023

Comprehensive Hydrological Survey of Glukhoye Lake, a Typical Forest Lake on Kunashir Island (Kuril Islands)

Mikhail Y. Grishchenko[1,2,3,*], *Anna A.* Alaverdova[1], *Aleksandra D.* Razaryonova[1], *Andrey A.* Shishov[1], *Ivan V.* Kazakov[2]

[1]M.V. Lomonosov MSU, Faculty of Geography, 119991, Moscow, Russia
[2]HSE University, Faculty of Geography and Geoinformatics, 109028, Moscow, Russia
[3]State nature reserve "Kurilskiy", 694500, Yuzhno-Kurilsk, Russia

Abstract. In order to study a typical forest lake on Kunashir Island, which is Glukhoye Lake, a bathymetric mapping was conducted using a Lowrance echo sounder, during which 25 transects and 3 longitudinal tacks were measured. According to the results of bathymetric mapping, 5 points of hydrological and hydrochemical synchronous survey were carried out, within the framework of which hydrochemical indicators were measured and 9 water samples were taken for further analysis. At the same locations, 5 sediment samples were collected and described during the ground survey. Based on these studies, a comprehensive hydrological characterization of Glukhoye Lake, a typical forest lake on Kunshir Island, has been formulated. It is located in a forested area between the hills, has a shallow basin, few tributaries and slow water exchange. The lake is characterized by very little variability in hydrochemical parameters in depth and in plan. The predominance of hydrocarbonate and sodium ions is quite typical for surface water bodies of volcanic massifs. The hypothesis of a continuing close link between the lake and the ocean has not been confirmed.

1 Introduction

Glukhoye Lake is located in the Pacific sector of the Sernovodsky Isthmus on Kunashir Island in the Great Kuril Ridge. It stretches from north to south with a length of 680 m, an average width of 110 m and a water area of 74,000 m^2. The Sernovodsky Isthmus separates the massifs of the Mendeleev (from the north) and Golovnina (from the south) volcanoes, and previously was a relatively shallow strait [1]. A large part of the isthmus is occupied by Peschanoye Lake, where complex hydrological investigations were carried out by staff and students of Lomonosov Moscow State University [2]. In 2019, Glukhoye Lake was not studied, and information on its characteristics is not available in the literature. It should be noted that the hydrological knowledge of Kunashir is very uneven: studies are concentrated

[*] Corresponding author: m.gri@geogr.msu.ru

almost exclusively on objects of volcanic origin or confined to volcanic apparatuses, for ex. [3]. Lakes of other origin, in particular Lake Glukhoe, are practically not studied.

According to oral reports by A.P. Milichkin, an old local resident and inspector of the Kurilsky Nature Reserve, it is known that the village of Sernovodsk was situated on the of Sernovodsk Isthmus in the vicinity of Glukhoye Lake until the end of the 1960s. The lake was used by the locals for bathing, and had no fish (no large-scale fishing was perormed). In the vicinity of Glukhoye Lake, there were a number of areas of thermal mud that supposedly gave name to the isthmus and the village. Earlier, during the Japanese development of the Southern Kuril Islands, a Japanese fishing village Tofutsu was located on the site of the village of Sernovodsk. There has been a Japanese cemetery around Glukhoye Lake ever since. At the end of the 1960s, the village of Sernovodsk (Figure 1) was evicted and a border outpost and fortifications were built in its place, as well as in its surroundings. The outpost was closed in the early 1990s and is now a ruin. Since then, Glukhoye Lake has had no economic importance.

Fig. 1. Remains of the border guard buildings at the site of the former village of Sernovodsk.

With this in mind, the objective was to carry out a series of hydrological and hydrochemical works in the water body in order to determine the general characteristics of a typical forest lake on Kunashir Island, which is Glukhoye Lake, and its origin, hydrological regime and economic use. Given its geographical position and general information about the lake, it is assumed that it was part of the sea bay and was later separated by a spit of land. It has been hypothesized that, at present, the lake has a close connection with oceanic waters, under the influence of which more saline water, due to the difference in density, accumulates near the bottom, forming density stratification and possibly anaerobic conditions.

2 Reconnaissance survey of the lake

A reconnaissance survey of the lake, its shores and catchment area was carried out on August 15 and started from the southern end. On this side, the lake is separated from the ocean by a positive landform (part of a marine terrace) 3–4 meters high and 100–150 meters wide, along which the Yuzhno-Kurilsk-Golovnino motor road passes. The lake is drainless, with water flowing apparently by filtration into the ground and then through an aquifer into the South Kurile Strait of the Pacific. In the southern part of the lake, Hydrometra and Corixidae species of water bugs were found, as well as a species of fish that were not determined during the observations.

To the east, the lake is separated from the Sernovodka River basin by a coniform hill, round in plan, with an absolute height of 40–45 meters. The slopes of the hill are quite steep, covered with mixed forest with dense shrub and grass-bush tiers, cut by shallow small erosion forms. At the foot of the slope there is a 2–4 m wide marshy hollow. The top of the hill is fairly flat, covered in Sasa Kurilensis with a height of 0.5–1.5 meters. An old Japanese cemetery was found on the hillside facing the lake, which is confirmed by information from inspector A.P. Milichkin. The ruins of a frontier outpost were also discovered on the southern side of the hill, and fortifications (trenches) were found on the top and slopes.

To the north, the lake is adjoined by the vast lowlands of the Sernovodsk Isthmus without a clearly defined watershed between Glukhoye Lake and Peschanoye Lake, with the Sernovodka River flowing out of it. The lowland is an over-wetted meadow with predominantly herbaceous, moisture-loving vegetation such as sedges and ferns, as well as oppressed forms of conifers. There are no pronounced watercourses in this lowland area and the stream marked on the topographical map is characterized by a stagnant water regime due to its low gradient. The northern part of the lake is shallow and densely overgrown with lilies. The distance to the Peschanoye Lake basin is approximately 1.2 km.

From the west, the lake is separated from the Belkin stream basin by a chain of hills with absolute heights of 70–90 m. The narrow strip of shore immediately adjacent to the lake, 50–100 metres wide, is covered with thickets of grassy and shrub vegetation, followed by steep slopes with coniferous-broadleaved forests.

During the reconnaissance survey, the lake and its surroundings were surveyed using a DJI Phantom 4 Pro v2.0 unmanned aerial vehicle (UAV) from a height of 217 meters.

3 Bathymetric survey

A bathymetric survey on the lake is needed to determine the bottom topography and plan further work. Depths were measured on 13 August using a Lowrance HDS-7 echo sounder with a built-in GNSS receiver. The receiver operates by emitting sound waves and recording their reflection from various obstacles, and then calculates the distance to the bottom and other objects based on the speed of sound in the water. The GNSS receiver determines the position of the instrument by calculating the ranges from the satellites (you need at least 4 satellites) and synchronizes the measured depth with the planimetric coordinates.

In order to eliminate errors and inaccuracies, before starting work the sonar sensor must be submerged in water to a shallow depth and positioned strictly on a horizontal plane, waves and hydrodynamic cavitation must be avoided [4]. The depth survey was carried out from the side of the rowing boat by transverse oblique and longitudinal transects over the entire water area of the lake. The fieldwork resulted in a data set of points with known coordinates and depth.

The recorded echogram in .slg format was exported to the Reef Master software and converted into a shape file suitable for processing in GIS packages. The boundaries of the lake were vectorized using an orthophoto with a spatial resolution of 4.83 cm, taken during the reconnaissance survey. Depth interpolation using the Topo to raster method was performed, after which the automatically plotted isobath lines were manually corrected to eliminate geographically unreasonable curvatures. The result is a map of the depth distribution of Glukhoye Lake, shown in Figure 2.

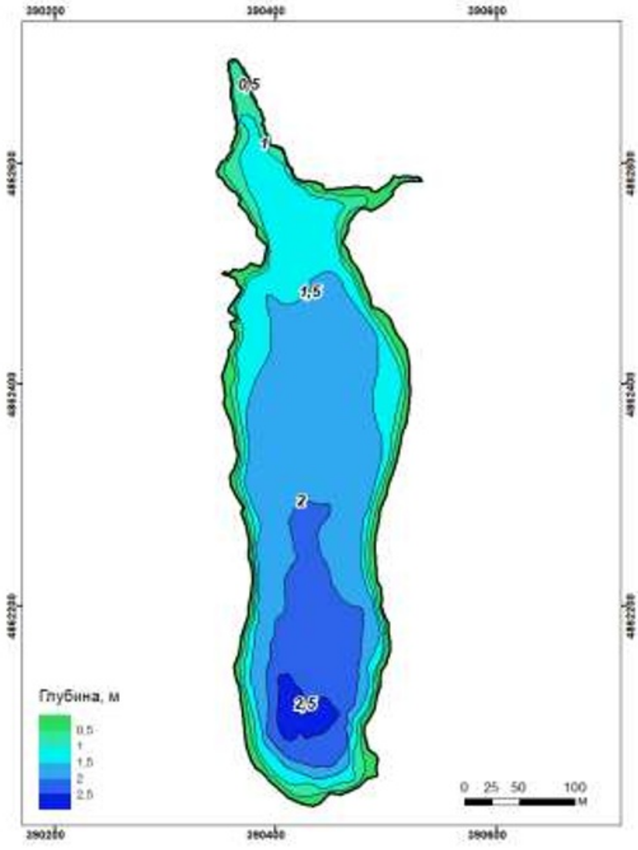

Fig. 2. Bathymetric map of Glukhoye Lake.

4 Hydrological and hydrochemical synchronous survey

A hydrological-hydrochemical synchronous survey of Glukhoye Lake was carried out on August 14. During the work, samples were taken and the following parameters measured: pH, temperature, electrical conductivity, salinity, and chemical analysis for oxygen content using the Winkler method.

The survey was carried out at 5 points pre-marked on a depth map of the reservoir: three verticals were marked on the longitudinal axis of the lake, as well as points at the confluence of the eastern and western tributaries of the lake (Figure 3). In the verticals, measurements were made at two or three points, depending on the depth; in the tributary areas, measurements were made only at the surface, as the depths are less than one meter.

Fig. 3. Hydrological-hydrochemical synchronous survey on Glukhoye Lake (left) and the location of the survey points (marked with red stars) superimposed on the UAV image (right).

HANNA HI-98129 was used to measure pH, conductivity, salinity and temperature; measurements were taken in a specially selected sample taken using a shaking bathometer [5].

The oxygen content was analyzed in the field using the Winkler method with the HANNA HI-3810 titration kit. The analysis procedure is as follows: a sample is taken into a glass flask, in which oxygen is fixed (precipitated into a chemically bound form) by the addition of manganese sulphate and an alkaline solution of potassium iodide. This precipitate is then dissolved by adding sulphuric acid (42.4%), which releases free iodine in an amount equivalent to the amount of dissolved oxygen [6]. A certain volume of this solution is poured into a titration vessel, the starch indicator is added and the sample is titrated with sodium thiosulphate until discolored. The volume of thiosulphate used for the titration is converted to dissolved oxygen concentration (mg/l) by multiplying by 10.

The water samples were processed in the laboratory of the Land Hydrology Department of the Faculty of Geography of Lomonosov Moscow State University to determine concentrations of major ions: hydrocarbonates, chlorides, sulphates, calcium, magnesium, and sodium. Main anions and cations characterize the salt composition of water in a water body and their total content is an important indicator of water quality and its suitability for drinking and domestic purposes.

The hydrocarbonates assay is carried out using the acidimetric method, which is based on the interaction of weak acid anions, primarily hydrocarbonates and carbonates, with hydrochloric acid. Carbonates are usually present in natural waters at a pH of about 8, so in the analysis the sample is first titrated for carbonates until it becomes discolored (the medium becomes acidic). At pH=5.4, during the determination of hydrocarbonates with the addition of phenolphthalein and a mixed indicator, the point of equivalence is observed, when the reaction ends and the amount of acid consumed is used to judge the total alkalinity. In order to eliminate the influence of the CO2 generated during the reaction, which acidifies the medium, a sample must be blown through an Ascarite tube.

The concentration of calcium ions as well as the total hardness of the water (sum of calcium and magnesium ions) is determined by the trilometric method due to the ability of trilon B (sodium salt of ethylenediaminetetraacetic acid) to form strong complex compounds with calcium and magnesium ions in an alkaline environment. For the determination of total hardness the reaction is carried out in a pH=10 medium (created by adding ammonia buffer solution) with the addition of black chromogen first with calcium ions and then with magnesium ions. When determining the calcium concentration, the reaction takes place in a strongly alkaline pH>10 (created by the addition of a 10% NaOH solution) medium with the addition of purpuric acid ammonium salt which does not react with magnesium ions [7].

The mercurometric titration method is used for the determination of chloride concentration and is based on the interaction of chloride ions with divalent mercury ions in an acidic medium with pH=2.5. Mercury forms a strong complex compound with chlorides, colored violet when the mixed indicator is added, and when it appears the titration stops and the chloride concentration in the water sample can be calculated.

The content of the other main ions — sulphate and sodium — is calculated from the known value of the total water salinity and the equality of the sums of equivalent concentrations (mg-eq/l) of cations and anions.

Analyzing the results obtained, it can be concluded that according to Alekin's hydrochemical classification the waters of Glukhoye Lake are low saline (<200 mg/l) and belong to the hydrocarbonate class and sodium group (by predominant anion and cation respectively), type I, as the equivalent hydrocarbonate content is greater than the sum of calcium and magnesium for the overwhelming majority of samples [8]. Waters of this type are generally confined to areas where eruptive rocks rich in sodium and potassium are distributed, as is typical of the volcanic massifs of Kunashir Island [9]. The high content of chloride ions is due to their increased concentration in precipitation in the vicinity of the sea coast.

5 Sediment survey

Bottom sediment sampling was carried out on August 18 by hand, as it was not practical to use a tube because of the shallow depths. Samples were taken at the same points as water samples during the hydrological-hydrochemical survey: at the three main verticals and the tributary mouths; the samples were photographed and their pH was measured.

The sediments on the southern edge of Glukhoye Lake are represented by fine-grained sand cemented with silt. The sand is probably of marine origin, as the southern shore of the lake is located 200 meters from the Pacific Ocean. The pH of the sediments at this location could not be measured as the sand was deposited on the bottom of the sample and it was not possible to form a suspension/paste. At point 001 (see Figure 3) the bottom sediments are dark brown silt with a tinge of green, there are numerous sand flecks and the pH is 6.91. The sediments in the central part of the lake (point 002) are homogenous fine brown silt with a hydrogen index of 6.76. At the northernmost main vertical (point 003) the silt is lighter in shade and contains few plant remains, the pH of the suspension was 6.55. At the mouth of the eastern tributary, the bottom silt contains large amounts of organic residues and is characterized by the lowest pH value of 5.96. At the mouth of the west tributary, the sediments consist predominantly of silt-cemented plant remains, with a pH value of 6.17.

6 Conclusion. Complex hydrological characteristics of Glukhoye Lake

Glukhoye Lake is a typical representative of small reservoirs of the island of Kunashir. It is located in a forested area between the hills, has a shallow basin, few tributaries and slow water exchange. The following conclusion can be drawn from the depth distribution: the southern part of the lake basin, facing the ocean, is deeper, while the northern part, adjacent to the lowland of the Sernovodsk Isthmus, is shallower. The slopes of the basin are quite steep, as they are a continuation of the slopes of the hills along the shores of the lake. There are two elongated, shallow bays in the northern part of the lake, associated with the influx of streams draining the flat space between Glukhoye Lake and Peschanoye Lake.

The shallow depths and geometrically simple shape of the lake basin result in intensive mixing of waters, as evidenced by the very low variability of hydrochemical parameters by depth and between the main verticals (points 001, 002, 003). On the main verticals, oxygen concentrations range from 5.5 to 6.7 mg/l, but the tributary areas of the lake have lower oxygen contents than the waters of the main basin. The tributary areas are shallow bays with dense aquatic vegetation: a lot of oxygen is consumed for the oxidation of dead plants, while at the same time the vegetation makes gas exchange with the atmosphere difficult during wind mixing. For the same reasons, the waters at the mouths of tributaries are characterized by lower pH values: 6.17 at the mouth of the eastern brook and 6.76 at the mouth of the western brook. Electrical conductivity and salinity can be considered constant throughout the lake, except at the deepest point where the values are higher than average, as the more mineralized water has a higher density and accumulates near the bottom. The predominance of hydrocarbonate and sodium ions is quite typical for surface water bodies of volcanic massifs. The hypothesis of a continuing close link between the lake and the ocean has not been confirmed.

When looking at the sediments of Glukhoye Lake, there is also a spatial differentiation from south to north: sandy sediments are replaced by muddy ones as one moves further from the ocean and as depths decrease. The increased proportion of silt and decreased pH values in bottom sediments are also due to the presence of abundant aquatic vegetation. In the shallow bays in the north of the lake, the soils contain large amounts of plant remains and are also characterized by lower pH values because oxygen is consumed during the oxidation of dead organics.

References

1. M.G. Vaskovskiy, Surface water resources of USSR, **18**, 4 (1973)
2. M.Y. Grishchenko, V.I. Krylenko, V.T. Ozhgikhina, A.V. Gorbarenko, Hydrological surveys of the lake Peschanoe and the Sernovodsky isthmus of Kunashir Island (greater Kuril chain), E3S Web of Conferences, **265**, 02007 (2021)
3. I.A. Zhigalov, Y.V. Novikov, E.V. Samko, S.V. Kolosov, Proceedings of the Pacific Fishery Research Center, **130**, 117-122 (2002)
4. RD 52.24.495-2017 "pH and electroconductivity of waters. Measurement procedures with electrometric method"
5. RD 52.24.419-2019 "Mass concentration of dissolved oxygen. Measurement procedures with iodometric titration"
6. RD 52.24.493-2020 "Mass concentration of hydrocarbonate and water alkalinity. Measurement procedures with titrimetric analysis"
7. RD 52.24.403-2018 "Mass concentration of calcium. Measurement procedures with Trilon B titrimetric analysis"
8. O.A. Alekin, Chemical classification of natural waters, Hydrochem. J., **4** (1948)