

Hydrochemistry of Lake Glubokoe

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Keywords: hydrochemistry, sediment chemistry, microelements, Lake Glubokoe

Abstract

Results of hydrochemical observations in the summer of 1983 are presented and compared to the data of previous years. Some trends in the changing conditions of the lake over the last fifty years are characterized. Data on the chemical composition of bottom deposits are also reported.

Analytical methods

Chemical elements in air filters, in snow-precipitated dust, and in soils were determined by the spectrochemical method; those in water, suspended material and bottom sediments were analysed by the atomic-absorption method. Macrocomponents in water were investigated by chemical methods according to standard procedures (Reznikov *et al.*, 1970). Redox potential and pH were determined by the potentiometric method; dissolved oxygen and manganese in water were measured respectively by the Winkler method and colorimetrically.

Geographical landscape conditions determining the geochemical features of the lake

Lake Glubokoe is located in the mid-part of the very swampy Gluboko-Istrinskaya Hollow which occupies a central position in flat-hilly upland. The latter, according to the physiographic subdivision scheme of Moscow region (Atlas of Moscow region, 1976), makes up a part of the Mozhaisko-Volokolamskaya Upland composed of a thick mass of quaternary deposits. In particular, the upland, in the center of which is the Gluboko-Istrinskaya Hollow, is almost completely made up

of glacial deposits, 35 to 85 m thick, with a basement complex of the upper series of the Jurassic system (Shcherbakov, 1967). The slopes of the hollow, in the center of which is Lake Glubokoe, are cut with ravines that channel the runoff from the upland first to the swamp and then to the lake.

Up to 80% of the catchment area of the lake is covered with forests. This region belongs to the northern part of the subzone of mixed spruce and broad-leaved forests, where oak is the main type of tree, together with spruce.

The swamps occupying most of the lake watershed correspond to the basic flood-plain type with eutrophic vegetation and are also covered with forest. Most of the soils in the lake surroundings are medium to strongly podzolic, and medium to heavy loamy in mechanical composition, on blanket loams which cover all the area as a continuous layer. Wet meadow land surrounding the swamps is characterized by soddy-meadow soils with a dark humus horizon, which are gradually replaced by meadow-boggy and peaty-gley soils closer to the swamps (Shcherbakov, 1967).

The lake water balance has never been studied specifically. Quantitative estimations of such basic components as drainage into and out of the lake present great difficulties. Drainage to the lake occurs, in large measure, through filtration from swamps on the southern and south-western shores

and through several small ditches (Shcherbakov, 1967). Gravity surface drainage can be directly observed only on the eastern shore. Precipitation on the lake surface plays a certain role, though not a substantial one. The Malaya Istra river drains water from the lake.

The soils of the surrounding low moors are frequently saturated with water to the surface; groundwaters are shallow. Conditions are thus unfavorable for a complete decomposition of plant residues. Free oxygen in the water is rapidly consumed for oxidation of a part of the plant remnants and they are further decomposed in the gley medium; therefore the soil accumulates peat, where many heavy metals are often concentrated (Kreshtapova, 1974). It is well known (Perelman, 1975; Tyuremnov, 1976) that bog waters are in the acid to subacid class. Their acidity arises from the processes of decomposition of organic substances and the entry into the water of carbonic acid, and fulvic and other organic acids: they are rich in Fe^{2+} and Mn^{3+} , and are characterised by extremely low mineralization rates, and by the presence of a large number of biogenic elements and humic substances. A study on the distribution of pH on the surface of the swamps surrounding Lake Glubokoe in the summer of 1983 showed that this value fluctuated within 5–6, reaching 4.5 in deeper layers (determinations by V. F. Matveev).

Lake Glubokoe is located among industrial, urbanized and agricultural regions in the center of the

Russian Plain. However, due to such factors as its remoteness from industrial and urbanized centers, its inaccessibility, and the absence of intensive farming within the boundaries of the catchment area, it is one of the few lakes of the Moscow region which is protected to some extent from anthropogenic influences. These influences must basically only involve rather distant (20–50 km) atmospheric transfers of pollutants. Therefore to estimate the level of regional effects, prior to the beginning of hydrochemical work, studies were carried out on the distribution of chemical elements in soils, snow cover and atmospheric air in various parts of the catchment basin of Lake Glubokoe.

Atmospheric air was sampled at a location deep in the forest in 1980–1982 in 6–10 day cycles of observations by means of an aspiration unit for 8–10 hours daily. Sample volume was, on average, 40 m^3 . Altogether, 30 samples were taken in three years. Most of the samples detected zinc, lead, and manganese; nickel, vanadium, tin and chromium were recorded in one third of the samples. No other determinable elements, such as cadmium, bismuth, beryllium, tungsten, and molybdenum were found in the air. Comparison of the average data for Lake Glubokoe with those for other world regions shows (Table 1) that the levels of heavy metals for the lake are much lower than the average levels for the suburbs of industrial cities in Europe and the United States, though they are considerably higher than the reference Antarctic zone. The influence of the

Table 1. Concentration of chemical elements in atmospheric air in remote regions, suburban areas, Lake Glubokoe and Moscow ($\mu\text{g m}^{-3}$).

Source element	1 Antarctica	2 North Pole	3 Alps	1 Suburbs of industrial cities of U.S.A. and Europe	4 l. Glubokoe	4 North of Moscow	4 West of Moscow
Lead	—*	63 10^{-5}	—	0.3	0.0063	0.036	0.02
Zinc	3 10^{-5}	3 10^{-5}	12 10^{-3}	0.3	0.0231	0.090	0.047
Manganese	1 10^{-5}	1 10^{-5}	0.4 10^{-3}	0.06	0.0126	0.047	0.09
Chromium	4 10^{-5}	—	—	0.009	0.006	0.015	0.03
Nickel	—	—	—	0.06	0.0036	0.065	0.06
Vanadium	0.1 10^{-5}	0.15 10^{-5}	—	0.07	0.0031	0.009	none
Tin	—	—	—	—	0.0016	0.001	none
Cadmium	1.5 10^{-5}	—	—	0.005	none	none	none
Molybdenum	—	—	—	0.02	none	0.009	none
Cobalt	0.04 10^{-5}	0.08 10^{-5}	0.06 10^{-3}	0.0009	none	none	none

* Data unavailable; 1. Mikhailov *et al.*, 1979; 2. Zoller *et al.*, 1974; 3. 1979; 4. Author's data.

background regional pollution is especially notable when considering such technogenic elements as zinc, manganese, chromium and vanadium. The concentration of these elements is three orders of magnitude higher than in Antarctica. It is characteristic that the behaviour of lead is not so contrasting; this is apparently due to the global nature of pollution for this element. In general, it is to be expected that the closer we are to the largest discharger of wastes in the region (i.e. in this case Moscow) the higher are the levels of pollutants in the air.

The composition of snow cover was studied in the same location during the two winter seasons of 1980–81 and 1981–82. Snow was sampled, to its full depth, prior to the snow melting period (in March). The treatment involved separation of each sample into a liquid phase and a solid residue (snow-precipitated dust). The absolute concentrations of chemical elements in the snow dust ranged from several fractions of a mg kg^{-1} (mercury, cadmium) to hundreds of mg kg^{-1} (zinc, manganese, copper).

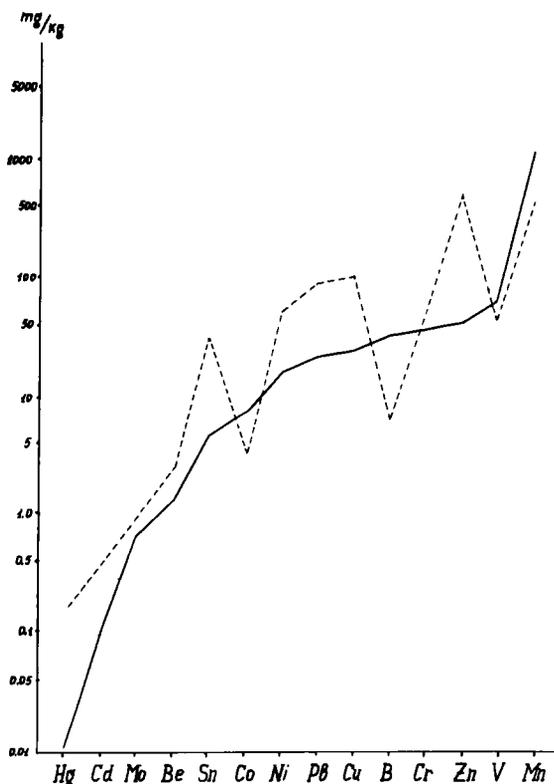


Fig. 1.

Fig. 1 shows the distribution of chemical elements in the snow dust and underlying soil. The dust precipitated on the snow cover is enriched as compared to the soil in such elements as mercury (24 times), zinc (12 times), tin (8 times), cadmium (5 times), copper (3.7 times), lead (3.5 times), and nickel (2.5 times). This indicates the anthropogenic origin of these elements. In winter, when the soil is covered with snow, the concentration of soil dust in the atmospheric air is much lower and the concentration of elements of anthropogenic origin is higher. The concentration of naturally occurring chemical elements decreases at this time. These include boron, the soil content of which, in this study, is 5.5 times as high as in the snow dust, and manganese (its concentration in the soil is 2.4 times greater than in the snow dust). The concentrations of beryllium, vanadium, cobalt and chromium in the soil and snow dust were found to be comparable.

The amount of dust fall in the Lake Glubokoe district, measured over two years, averages 23.1 kg km^{-2} per day. The average daily fall of chemical elements per 1 km^2 is as follows: 14.1 g of zinc, 6.1 g of manganese, 2.3 g of copper, 2.1 g of lead, 1.3 g of nickel, 0.92 g of tin, 0.61 g of chromium, 0.58 g of vanadium, 0.082 g of boron, 0.05 g of cobalt, 0.035 g of beryllium, 0.023 g of molybdenum, 0.01 g of cadmium, 0.0030 g of mercury.

The background concentrations of chemical elements in snow water recorded in this study are not high and for most of the elements they are below the sensitivity level of analysis. Zinc and copper are exceptions. They considerably exceed the contents recorded in snow water from Antarctica. It is characteristic of these elements to precipitate predominantly in water soluble form. Thus, 77.2% of the total fall of copper (10.1 g km^{-2} daily) is in water soluble form; the fall of water soluble zinc accounts for 79.2% of the total.

Thus, Lake Glubokoe is subjected to a certain anthropogenic influence from industrial regions in the center of the Russian Plain.

As indicated above, Lake Glubokoe is separated from agricultural lands located outside the catchment area by a wide belt of swampy forest. In 1977 and 1978 (Smirnov, 1983) early in the spring, fluorescein was spread about at a distance of some three kilometers from the lake with the purpose of finding out whether the runoff from the fields

would reach the lake. The experiment showed that no fluorescein was transported to the lake. This suggests that the effect of farming on the lake ecosystem is insignificant. The effects of recreational activities on the lake and its surroundings are more considerable. Littering of the strand has been observed to increase and anthropogenic changes of vegetation have been noted. This is caused by the growing number of tourists and amateur fishermen who trample down the vegetation, leave much refuse and throw a considerable amount of bait into the lake to attract fish. Entry of such substances as various synthetic detergents, gasoline, kerosene, etc., is not ruled out. There are many indications in the literature that the eutrophication process in water bodies is intensified as a result of increased entry of biogenic elements due to trampling of lake-side vegetation by tourists and holiday makers (Dickman & Dorais, 1975).

In the 60s, meliorative work was carried out on the swamps surrounding the lake. At a distance of several hundred meters from the lake, a deep meliorative ditch was cut along the entire western and southern shores thereby draining the swamp water into the Malaya Istra River. Due to draining most of the runoff to the river, the water in the lake lost its yellowish tint, and its transparency increased (Matveev, 1975). The influx of allochthonous organic substances and other chemical elements has been drastically reduced. A fall of the lake level by about 0.3 m was recorded.

Morpholithological characteristics of Lake Glubokoe

A most thorough survey of Lake Glubokoe was carried out in 1906 by Voronkov and Troitski (1907) that provided L. L. Rossolimo (Shcherbakov, 1967) with the basis for drawing a bathymetrical map. This map shows that the character of the lake shores has changed little since the time the survey was made in 1906. The sounding of the bottom that we performed in 1983 and the map of Rossolimo coincide. The lake basin in the main section is shaped as a regular funnel with expanded edges. The depth changes gradually throughout the lake and there are no steep cliffs. The bay adjacent to the northern part of the lake is separated by a small bottom rise. This rise can hardly be an obstacle for

water exchange between the main part of the lake and the bay, i.e. their water mass should be regarded as a single whole. This is confirmed by hydrochemical data.

In studies on bottom sediments of Lake Glubokoe, and specifically when identifying their types, Rossolimo (1964) proceeded from the genetic principle, i.e. he regarded the different types of sediments as various quantitative combinations of several initial sediment-forming materials. He considered sand, residues of swampy and terrestrial vegetation and detritus as the main materials, and the residues of aqueous microphytes and clay as secondary materials. Altogether he distinguished 7 basic types of sediments (Shcherbakov, 1967) (Table 2).

The lithological survey that we made in 1983 confirmed in essence the character of spatial distribution of the sediments. However, it should be noted that the lake has no distinct boundaries between different sediment type zones, i.e. one type of sediment gradually changes into another along the bottom.

As seen from Table 2, the greater part of the lake bottom is covered with silty sediments, i.e. silt per se and sandy silt. Sand and resedimented peat are less widespread and areas with silt-covered sand, peaty silt and peat-covered sand are quite small.

The central deepest part of the main section in the lake is covered with silt. X-ray diffraction analysis showed that this type of sediment is composed mainly of amorphous substances (detritus with a small quartz sand content and sporadic grains of feldspar); moreover, the greater the depth the

Table 2. Distribution of bottom sediments in Lake Glubokoe (according to Rossolimo, 1949).

Bottom sediments	Area of bottom sediments	
	m ²	% of total bottom area
Sand	91200	15.4
Silt covered sand	39700	6.8
Sandy silt	169400	28.5
Silt	140000	23.6
Resedimented peat	89500	15.1
Peat-covered sand	30400	5.1
Peaty silt	33100	5.5
	593300	100

higher the sand content, while the content of vegetal residues approaches zero. Almost complete absence of clay minerals in bottom sediments is very characteristic. Here, however, mechanical analysis shows a maximum average content of fine fraction (physical clay) in the sediments of Lake Glubokoe of 35.7% (Shcherbakov, 1967). The content of organic carbon is on an average 11.2% (Table 3). The content of dissolved iron (Table 3) is rather high. During almost the entire summer stagnation period the silt gave off (when interacting with 10% HCl) a constant odour of hydrogen sulphide.

The central zone, composed of silt, is surrounded with a strip of sandy silt. The latter also consists mainly of amorphous substances, but with a considerable content of fine-grained quartz sand having infrequent inclusions of feldspar. Here we can encounter the residues of macrophytes, wood vegetation and peaty particles. In terms of mechanical composition, sandy silt differs from pure silt by having a relatively smaller amount of the fine-grained fraction, a relatively higher quantity of the fraction next in particle size and a lower amount of the fraction with a particle size 0.1–0.25 mm (Table 3). The content of mobile iron and organic substances is much lower.

The bottom sediments described above cover the central part of the main section and are fairly uniform throughout this area. The local differences in their composition could hardly be detected visually. The other types of bottom sediments are markedly dependent on the character of the shore; therefore they do not form continuous circular zones but appear as individual patches.

Thus, most of the bottom sediments in the lake are autochthonous in origin. They are noted for their reducing ability, clear differentiation of terrigenous mineral parts, and abundance of iron and organic substances. All these features are mainly associated with the specific intra-reservoir processes and exchange between the water mass and the sediments.

General hydrochemical characteristics of the water mass.

The general features of the thermal conditions of Lake Glubokoe are very characteristic. This aspect has been studied rather well, especially in the warm

period (Bogoslovski, 1951; Rossolimo, 1950, 1959; Shcherbakov, 1967; Sadchikov, 1983).

In its thermal regime, Lake Glubokoe belongs, according to Forel's classification (Hutchinson, 1969), to the temperate type of lakes which are characterized by two circulation periods and distinct summer and winter thermal stratification.

In summer, the thermal stratification (Fig. 2) appears to be very distinct and stable. The depth of the epilimnion early in summer is 1.5–2 m and, late in summer, it increases to 5–6 m. At the beginning of the stagnation period, the thermocline is from 2 to 6 m deep, and at the end it is from 5 to 9 m deep.

The autumn isothermal condition sets in every year and lasts from 20 to 30 days. A complete spring turnover commences at a water temperature of 5 to 7°C. Warming at this time occurs through the ice as a result of increasing insolation and is characterized by the development of convection currents, the maximum depth of which mainly depends on the lake temperature and its vertical profile prior to the convection. Following the ice-break, the water mixing continues chiefly under the action of wind, although in some years the convection may continue to play a certain role.

One of the most comprehensively studied hydrochemical parameters, of Lake Glubokoe, is dissolved oxygen (Shcherbakov, 1967; Sadchikov, 1983). Observations that we made in the summer of

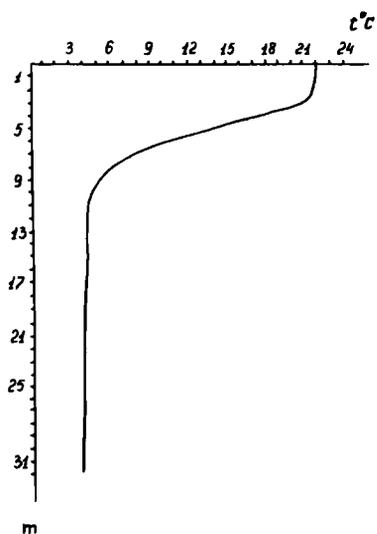


Fig. 2.

Table 3. Characteristics of bottom sediments in Lake Glubokoe.

Type of sediments	1		Mechanical composition (% of dry weight), fraction, mm		2	minerals of sandy fraction	3	C _{org} , %	4		5	6
	>0.25	0.25-0.1	0.1-0.05	0.05-0.01					<0.01	mobile iron mg kg ⁻¹		
Silt	10.6	21.2	2.6	29.4	35.7	quartz	11.2	11.2	2200	1100	-165	6.75
Sandy silt	5.7	15.9	5.1	45.8	27.3	quartz	9.7	9.7	380	290	-65	7.0
Silty sand	1.1	4.5	10.0	60.6	23.9	quartz	3.7	3.7	230	150	-70	7.0
Sand	13.5	22.0	31.1	19.3	8.9	quartz	none	none	30	10	-75	5.6
Peaty silt	14.5	24.5	5.4	37.8	17.8	quartz	10.8	10.8	360	270	-	-
Peat-covered sand	7.8	15.2	16.8	38.3	21.9	-	-	-	-	-	-	-
Resedimented peat	36.7	28.6	4.9	17.0	12.8	-	-	-	-	-	-	-

Notes: 1) ' - ' - no data; 2) mobile iron was determined after acetate extraction (1:10; pH=4.2); 3) the table presents (1) Rossolimo's data (1949); and the author's data (2-6).

1983 showed that the oxygen regime of the lake had improved as compared to previous years. This was also noted by Sadchikov (1983) in 1976–78. Thus, every year in the summer, oxygen used to disappear completely in the lower part of the hypolimnion and in some years in the entire hypolimnion (Shcherbakov, 1967). In 1976–78 Sadchikov (1983) observed the appearance of an anaerobic zone only in the deepest layers. We did not find an anaerobic zone at all. We detected no hydrogen sulphide in the water in the summer period unlike previously. One of the main reasons for the changes in the gas regime of the lake was the creation of the meliorative ditch that intercepted the main inflow of swamp waters into the lake. This resulted in a drastic decrease in the inflow of waters rich in organic substances into the lake.

So far as is known, we are the first to determine the redox potential in Lake Glubokoe. In this lake, rather rich in oxygen, it amounts to about 200 mV. This is a comparatively low value, which may be partly due to the presence of organic reducing substances, coming from the catchment area. This suggestion is supported by the character of the vertical distribution of the redox potential values. Thus, the epilimnion is characterized by values ranging from 150 to 170 mV. Deeper the values irregularly range from 200 to 230 mV, increasing in some places near the bottom in shallow waters (down to a depth of 5–8 m) to 270–300 mV and in deeper parts of the lake to 250–270 mV.

Observations in previous years on the pH of the water show that, during the summer stagnation, pH in the epilimnion increases, ranging from 7.0 to 8.0 as a result of photosynthesis diminishing the content of carbonic acid. In the meta- and hypolimnion during summer, due to accumulation of carbonic acid, pH decreases, falling to 6.5 near the bottom. Our observations in 1983 showed a similar distribution of pH values during practically the whole of July (up to July 26).

Observations carried out on July 27, 1983, showed a drastic change in pH. The entire water mass was below pH 7.0. In the epilimnion, pH values ranged from 4.5 to 5.5. A similar distribution of this index was observed with insignificant

fluctuations until August 18, 1983. The next day pH distribution was again typical of the lake*. Such a drastic change in the acid-alkaline conditions cannot be unequivocally accounted for. It is noteworthy that neither noticeable change in the planktonic communities at this period, nor changes in the general hydrochemical indices were observed. pH determination for rain water at this period (pH = 6.95–7.10) and analysis of its hydrochemistry, did not reveal any deviations either. It may be assumed that due to an extremely low buffering capacity of the water mass (see below), Lake Glubokoe is very sensitive to any changes in the acid-base balance. Such changes could be due to, for example, drainage of microbially active swamp water. The observed phenomenon is certainly of great interest and requires further detailed studies.

The content and distribution of organic substances in the lake water mass was measured by oxygen demand which we determined by the permanganate method on filtered water. It should be recalled that, according to Skopintsev (1950), in waters containing organic substances of planktonic origin, this method gives oxidation values of less than 40% of the total content. Our analysis gave values ranging from 8 to 9 mg O₂l⁻¹ and showed a uniform depth distribution independent of the stratification of the water mass. Data from the 1930's indicate that the oxygen demand (permanganate) for unfiltered water during the summer period ranged from 16 to 22 mg O₂l⁻¹ in the upper layers and from 15 to 18 mg l⁻¹ in the lower layers of the lake.

Earlier analyses of Lake Glubokoe waters for the concentration of various ions are far from being numerous, but give the following results: calcium (7.1–9.1 mg l⁻¹), magnesium (2.2–2.4 mg l⁻¹), bicarbonate (29.3–33.2 mg l⁻¹), and sulphate (2.6 mg l⁻¹). Our investigations showed that the waters in Lake Glubokoe have a low mineral content (Table 4). No heterogeneity in vertical and spatial distribution was revealed, i.e., the general composition of the water as a whole is rather uniform. Most cations of the salt complex are bound with the bicarbonate ion. Attention is drawn to the rath-

* Editors note: Daily determinations made by V. F. Matveev in 1985 from July 10 to September 20 revealed pH values in the epilimnion of 7.4–7.6. On March 9 and 19, 1986, under ice, pH was 6.9 from the water surface to a depth of 20 m and 6.6 at 25 m deep. In the littoral zone pH was 6.6.

er high content of ammonia-nitrogen and potassium. On the whole, the general hydrochemistry of the lake reflects the peculiarities of the landscape and geochemical conditions under which the water composition is formed; the swamps surrounding the lake serve as filters that absorb minerals from the water when it passes through them.

During the investigation period (July–August), considerable concentrations of phosphate (PO_4^{-3}) and nitrate were found only in the deepest layers of the lake ($0.3\text{--}0.5\text{ mg l}^{-1}$ and $0.15\text{--}0.36\text{ mg l}^{-1}$, respectively), as well as in the silt waters, where the content of phosphate reached 1.5 mg l^{-1} . The content of nitrate in the epilimnion is in the order of $0.1\text{--}0.2\text{ mg l}^{-1}$, in the metalimnion it is below 0.1 mg l^{-1} and in the hypolimnion $0.3\text{--}0.5\text{ mg l}^{-1}$ with a tendency toward higher concentrations in deeper layers of the lake. Of some interest is the distribution of ammonia-nitrogen (Fig. 3); the concentration is rather uniform in the epilimnion (about 0.5 mg l^{-1}), higher (up to 1 mg l^{-1}) in the metalimnic oxygen maximum zone, extremely low (down to $0.2\text{--}0.4\text{ mg l}^{-1}$) in the metalimnion, and higher and rather uniform in distribution ($0.57\text{--}0.67\text{ mg l}^{-1}$) in the hypolimnion with a drastic rise (up to 3.5 mg l^{-1}) in the near bottom layer and a maximum concentration in the silt waters (up to 10.8 mg l^{-1}).

Such a distribution (Fig. 3) rather clearly illustrates the leading role both of bottom sediments and biological activity in nitrogen dynamics. Comparing the sporadic data of previous years on concentrations of nitrogen and mineral phosphorus in

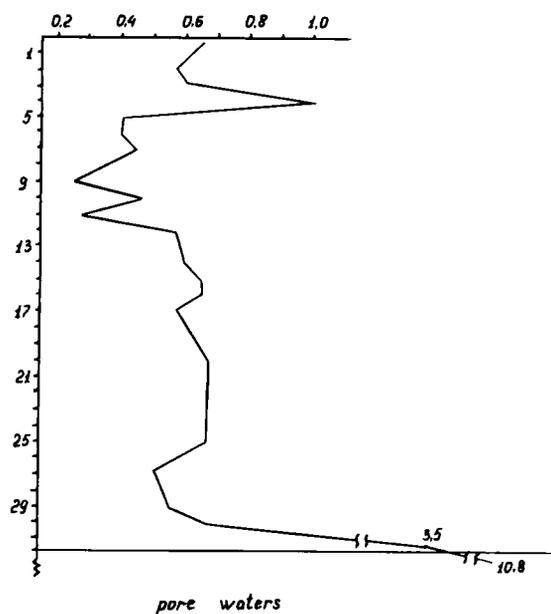


Fig. 3.

the lake, it should be noted that the lake has become somewhat poorer in nitrate and phosphorus, though a more objective evaluation requires further research on nitrogen and phosphorus cycles.

Distribution of microelements

The distribution of chemical elements in Lake Glubokoe water has not been studied before (except for iron). In the summer of 1983, we obtained data on the distribution of certain microelements (Figs. 4 & 5, Table 5). It should be noted that the literature gives few data on the microelements in Glubokoe type lakes, i.e., lakes with water of very low mineral content and rich in organic substances. Considering the concentration of the dissolved microelements as a whole, it can hardly be stated that there is any regularity in their distribution. However, two zones of higher concentrations should be mentioned: upper layers (0–1 m) and near bottom layers beginning from a depth of 8 to 10 meters. Such a distribution can be due to a number of factors, the most important perhaps being plankton activity and the entry of these elements from the bottom sediments. Regional transfer by

Table 4. Chemical components of water in Lake Glubokoe.

Component, mg l^{-1}	Lake Glubokoe	Average content in underground waters of the southern taiga (Shvartsev, 1978)
Bicarbonate	45.7	322
Chloride	5.17	9.41
Nitrite	undetected	1.6
Sulphate	8.77	5.02
Calcium	10.6	51.6
Magnesium	9.03	19.7
Ammonia-nitrogen	1.39	0.31
Sodium	2.4	35.9
Potassium	1.18	1.3
Total dissolved solids (TDS)	61.24	464

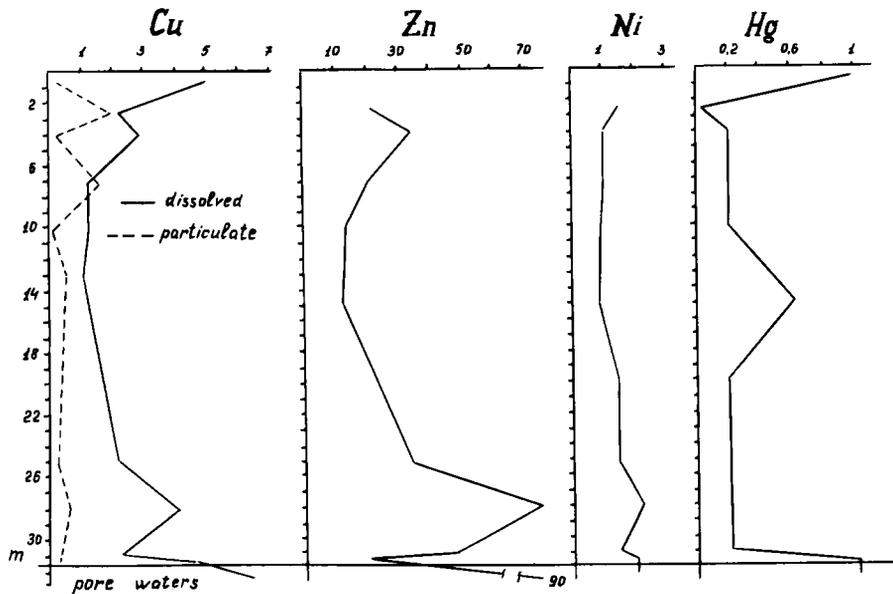


Fig. 4.

polluted air masses and their subsequent entry into the uppermost layers from the atmosphere is also a possibility.

It is of interest to consider the distribution of chemical elements in particulate form. The maximum amounts of copper are confined to the epilimnion and metalimnion (Fig. 4), where its concentration amounts to 2.0 and 1.5 $\mu\text{g l}^{-1}$,

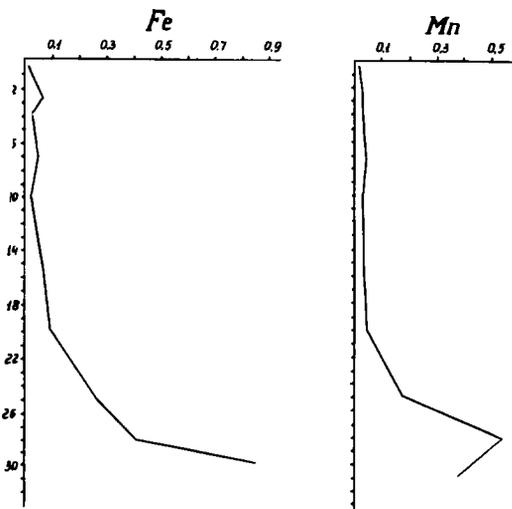


Fig. 5.

respectively: at a depth below 9 m its distribution is rather uniform and ranges from 0.2 to 0.5 $\mu\text{g l}^{-1}$. The distribution of iron and manganese in particulate form is characterized by a distinct tendency toward higher concentrations in deeper layers beginning from 20 m. It is possible that the distribution of copper is associated with the distribution of plankton which is concentrated in the upper layers of the water mass, while the distributions of iron and manganese are connected with the sedimentation and subsequent decomposition of seston.

In comparison to the data from investigations of previous years, which had shown that the total iron during summer stagnation was rather uniformly distributed in the upper 10 meters of the water mass (280–350 $\mu\text{g l}^{-1}$) and markedly increased in deeper layers (to 480–600 $\mu\text{g l}^{-1}$ near the bottom) (which the authors associated with the liberation of iron from the bottom sediments), we distinguished two zones where considerable concentrations of iron were detected, i.e., the epilimnion and bottom waters with a total content of mobile iron in the order of 200 $\mu\text{g l}^{-1}$. None was detected in the remainder of the water mass.

We have already indicated that the near bottom layers contain higher concentrations of most chemical elements. Such a distribution can certainly be

Table 5. Distribution of chemical elements in water of Lake Glubokoe in the summer of 1983, $\mu\text{g l}^{-1}$.

Depth m	Dissolved components						Particulate components		
	copper	zinc	nickel	mercury	manganese	Total iron	copper	iron	manganese
0.5	5.0	-	-	1.0	-	200	0.2	20	10
2.5	2.2-4.0	18-20.4	1.5-2	0.1	30-105	200	1.2-2.0	40-70	20
4	1.7-3.1	10-34	1-2	0.1-0.9	40-120	200	0.3-0.6	40-100	20-40
7	1.2-2.2	10.2-20.4	1-1.5	0.2-0.3	40-180	200	0.2-1.5	30-60	10-30
10	1.2-3.1	13.0-23	1-2	0.2-0.4	110-130	200	0.2-0.3	30-110	20-30
15	1.0-4.5	13-32	1-2	0.6-1.0	90-130	200	0.2-0.5	50-80	20-400
20	1.7-4.0	23-75	1.5-2	0.2	50-100	200	0.2-0.4	80-120	20-130
25	2.2	33	1.5	0.2	20	200	0.2	240	170
28	4.0	75	2.2	0.2	46	200	0.5	420	530
31	2.2	48	1.5	0.2	360	200	0.2	840	360
Typical content in waters of acidic conditions	2.8	5-50	0.8-5	0.5-3	10-50	-	-	-	-

explained by the sedimentation and subsequent decomposition of seston in hypolimnetic waters. However the diffusion of various compounds from the bottom sediments may play a more substantial role. A comparative study on the distribution of chemical elements at the bottom sediment/water interface (Figs. 6 & 7) makes it possible to unequivocally relate the very high concentrations of most components found in silty waters with increased concentrations in the bottom sediment of the lake. The literature contains numerous data on the role of bottom sediments as secondary sources of the

entry of chemical elements into water bodies (Forstner & Wittmann, 1979). Table 6 presents data on the concentration of trace elements in the basic types of sediments in Lake Glubokoe. It shows a gradual increase in their concentrations from the lake shore (sandy sediments) to deeper parts (silty sediments). Moreover, the sandy sediments which, as has been indicated already, are formed primarily by scouring of shores are characterized by concentrations of elements comparable to their concentrations in the soils. The deeper parts of the lake, where the bottom sediments are

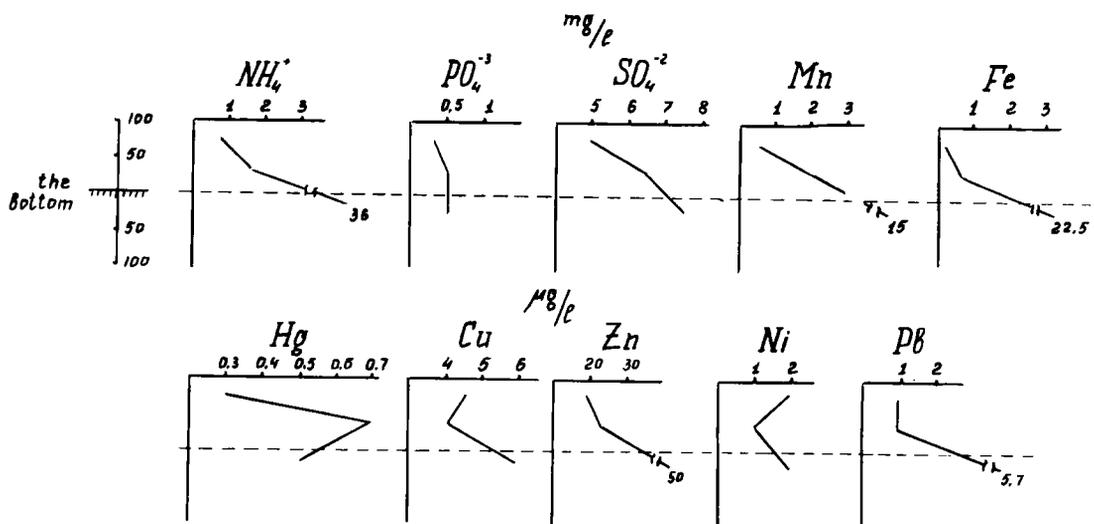


Fig. 6.

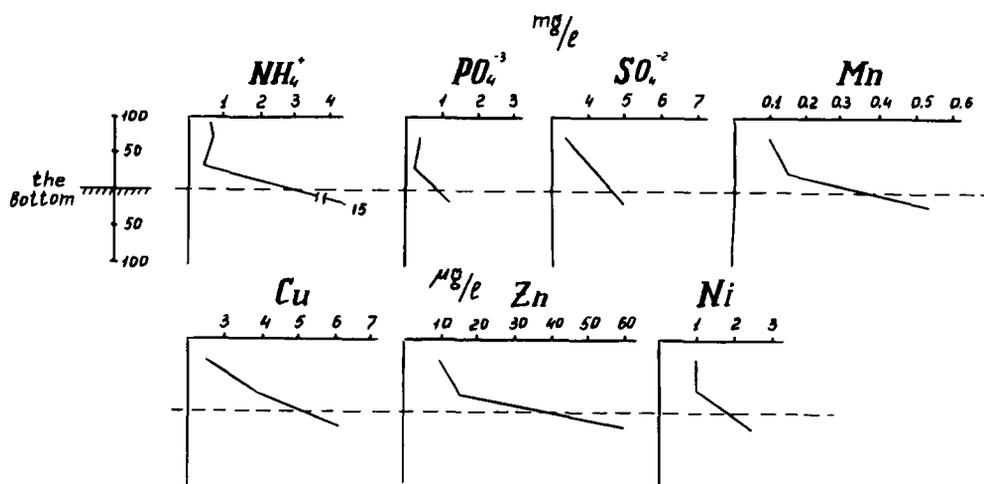


Fig. 7.

mainly autochthonous, are noted for the relatively large amounts of the trace elements studied, exceeding by several-fold their concentrations in the soils surrounding the lake. All this indicates that the geochemical processes in the water mass and bottom sediments may lead to the accumulation of high concentrations of chemical elements in the

sediments, especially in the central part of a lake. This is supported by the data on the chemical composition of the bottom sediments (Table 7) which show a regular decrease of SiO_2 and an increase in the content of organic substances and a wide variety of other compounds towards the lake center. The high concentration of iron, manganese and

Table 6. Microelements (mg kg^{-1}) in bottom sediments of Lake Glubokoe.

Type of sediments	Depth of lake, m	copper	zinc	cadmium	lead	nickel
Sand	2	7.6	30	—	6	—
Silty sand	8	10.0	37	0.4	14	35
Sandy silt	13	13.0	89	0.4	16	32
Silt	24	22.0	200	1.0	46	44
Silt	30	22.0	170	1.0	36	34
Content in soils of L. Glubokoe basin	—	11.7	31.7	0.29	19.0	25.8

Table 7. Chemical composition of bottom sediments in Lake Glubokoe, %.

Type of sediments	Depth of lake, m	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	P_2O_5	cl*
Sand	2	89	0.06	5.40	1.30	0.40	0.02	0.50	0.83	0.86	1.30	0.20	0.04	0.40
Silty sand	8	73.4	0.55	8.20	0.40	1.80	0.05	1.0	2.00	0.95	2.00	1.50	0.09	8.30
Sandy silt	13	68.4	0.53	8.50	0.20	2.40	0.06	0.80	1.50	1.0	2.10	2.00	0.10	12.90
Silt	24	49.44	0.44	9.0	—	4.50	0.17	0.90	1.10	0.68	1.60	4.40	0.25	27.70
Silt	30	39.7	0.40	7.0	2.90	8.0	1.30	0.60	1.10	0.42	1.08	6.00	1.15	30.17

* cl = calcination losses.

phosphorus compounds in the silty sediments is particularly noteworthy.

All this points to the leading role of bottom sediments in the cycles of chemical elements in the lake. They are not only accumulators, but also intensive suppliers of chemical elements and their compounds to the water mass.

Conclusion

Lake Glubokoe is one of the few water bodies in the centre of the Russian Plain which is practically free from a direct anthropogenic influence. It is, however, subjected to pollutant transfer from the surrounding industrial and agricultural regions. The meliorative work carried out in the lake basin and the high degree of recreational activities have led to a number of changes reflected in a partial rearrangement of the gaseous and hydrochemical regimes. Apparently, this has given rise to certain changes in biological communities, described in other chapters of this collected work.

Lake Glubokoe, in spite of its small size, reflects the features of larger water bodies in lithological, hydrological, geochemical and biological parameters. In this connection, it appears to be a unique laboratory for studies of various geochemical and biogeochemical processes which occur in natural water bodies. Such information is of great importance under conditions of ever increasing anthropogenic influences on the environment. Research at this lake will contribute to clarification of many unsolved hydrogeochemical problems. In particular, the existing literature points to the leading role of bottom sediments in the cycles of many chemical elements. A detailed clarification of this problem is of great importance for polluted rivers and lakes, where bottom sediments appear to be powerful accumulators of technogenic pollution (Sayet *et al.*, 1982). Apart from this, study on the temporal distribution of chemical elements under natural conditions will make it possible to ascertain the natural range of their fluctuating concentrations. This is necessary for assessing the extent of pollution effects of water bodies and streams.

Acknowledgements

The authors thank the workers of the Institute:

V. Yu. Gvildis, M. G. Zhuravlyova, E. V. Mankova, and E. P. Sorokina for assistance in writing this article.

Field investigations have been carried out at the Hydrobiological Station 'Glubokoe Ozero'.

References

- Atlas Moskovskoi oblasti, 1976. GUGK, Moscow, 40 pp. (Atlas of Moscow region. Main Administration of Geodesy and Cartography. In Russian).
- Bogoslovsky, B. B., 1951. O termicheskom rezhime ozera Glubokogo v bezlyodnyi period. In *Voprosy geografii* 26: 96–117 (On thermal conditions of Lake Glubokoe in the ice-free period. In Russian).
- Bogoslovsky, B. B., 1961. Ozero Glubokoe. In *Voprosy geografii* 51: 148–163 (Lake Glubokoe. In Russian).
- Dickman, M. & M. Dorais, 1975. The impact of human trampling on phosphorus loading to a small lake in Gatineaupark, Quebec, Can. *J. Environ. Manag.* 5 (4): 335–344.
- Forstner, U. & G. T. W. Wittmann, 1979. *Metal pollution in the aquatic environment*. Berlin, Heidelberg, New York: Springer-Verlag: 486 pp.
- Hutchinson, G., 1969. *Limnologia*, Progress Publ., Moscow: 592 pp. (In Russian).
- Kreshapova, V. N., 1974. Metodicheskie rekomendatsii po otsenke sodержaniya mikroelementov v torfyanykh mestorozhdeniyakh Evropeiskoi chasti RSFSR. Moscow: 200 pp. (Methodological recommendations for estimation of trace element content in peat deposits in the European part of the RSFSR. In Russian).
- Matveev, V. F., 1975. Sravnitel'naya kharakteristika zooplanktona Glubokogo ozera za 1972–1973 i 1951 gg. *Gidrobiologicheskii zhurnal* 4: 40–46 (Comparative characteristics of zooplankton in Lake Glubokoe in 1972–1973 and 1951. In Russian).
- Mikhailov, V. A., S. G. Pushkin, A. A. Nazarov *et al.*, 1979. Issledovanie elementnogo sostava atmosferynykh aerolei s pomoshchyu sovremennykh analiticheskikh metodov. *Trudy ESRNGMI* 40: 55–78 (Studies on the element composition of atmospheric aerosols by means of current analytical methods. In Russian).
- Perelman, A. I., 1975. *Geokhimiya landshaftov*. Vysshaya shkola Publ., Moskva: 342 pp. (Geochemistry of landscapes. In Russian).
- Reznikov, A. A., E. P. Mulyakovskaya & I. Yu. Sokolov, 1970. *Metody analiza prirodnykh vod*. Nedra Publ., Moskva: 427 pp. (Methods for analysis of natural waters. In Russian).
- Rossolimo, L. L., 1959. Nekotorye osobennosti temperaturnogo rezhima malykh ozeor. *Trudy Moskovskogo tekhnicheskogo instituta rybnoi promyshlennosti* 10: 3–20 (Certain features of temperature conditions in small lakes. In Russian).
- Rossolimo, L. L., 1964. Osnovy tipizatsii ozyor i limnologicheskogo raionirovaniya. In *Nakoplenie veshchestva v ozyorakh*. Nauka Publ., Moskva: 5–46 (Fundamentals of lake typification and limnological zoning. In Russian).
- Sadchikov, A. P., 1983. Temperaturnyi rezhim, prozrachnost i raspredelenie kisloroda. In *Biotsenozy mezotrofnogo ozera Glubokogo*. Nauka Publ., Moskva: 181–188 (Temperature

- conditions, transparency and distribution of oxygen. In Russian).
- Sayet, Yu. E., L. N. Aleksinskaya & E. P. Yanin, 1982. Metodicheskie rekomendatsii po geokhimicheskoi otsenke zagryazneniya poverkhnostnykh vodotokov khimicheskimi elementami. Moskva: 74 pp. (Methodological recommendations for geochemical analysis of surface streams polluted with chemical elements. In Russian).
- Shcherbakov, A. P., 1967. Ozero Glubokoe. Nauka Publ., Moskva: 380 pp. (Lake Glubokoe. In Russian).
- Skopintsev, B. A., 1950. Organicheskoe veshchestvo v prirodnykh vodakh (vodnyi gumus). Trudy Gosudarstvennogo okeonograficheskogo instituta 17 (29): 3–290 (Organic substances in natural waters (water humus). In Russian).
- Smirnov, N. N., 1983. Izychenie soobshchestv ozera Glubokogo v 1976–1982 gg. In Biotsenozy mezotrofnogo ozera Glubokogo. Nauka Publ., Moscow: 3–6 (A study on communities of Lake Glubokoe in 1976–1982. In Russian).
- Tyuremnov, S. N., 1976. Torfyanye mestorozhdeniya. Nedra Publ., Moscow: 488 (Peat deposits. In Russian).
- Voronkov, N. & V. Troitski, 1907. Syomka Glubokogo ozera. Trudy Gidrobiologicheskoi stantsii na Glubokom ozere 3: 5–21 (A survey of Lake Glubokoe. In Russian).
- Zoller, W. H., E. S. Gladney & R. A. Duce, 1974. Atmospheric concentrations and sources of trace metals at the South Pole. Science 183 (3): 198–209.