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Pollution and Eutrophication in Lake Baikal*

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Abstract: *The long term systematic investigations of ion composition components (bicarbonates, chlorides, sulphates, magnesium, calcium, sodium, potassium) and trophic status components (suspension, chlorophyll-a, mineral and organic forms phosphorus and nitrogen, carbon, silica) of water from the lake proper, its tributaries and atmospheric precipitation, which make up the main share of substance supply in to the lake, as well as the Angara river, being the source of substance discharge allowed the lake recent state to be evaluated in terms of both chemical pollution and possible eutrophication of its water. The similar (in terms of river runoff) periods of 50-ies and 80-ies have been compared. It was revealed that as a result of industrial activity 409 thousand tons of mineral substances (27.2 thousand tons of chlorides, 162 thousand tons of sulphates and over 200 thousand tons of organic substances) are supplied in the lake annually. The supply of substances of the anthropogenic origin is higher for the South Baikal than that for the North and Middle Baikal (the sum of mineral substances in 3.6 times; sulphates in 5 times, organic substances, including hydrocarbons in 7 times).*

The absence of abundant phytoplankton in the period studied when the ratio of silica to phosphorus is optimum (over 100), as well as a revers correlation between winter nitrogen content and spring of chlorophyll-a concentration in the Baikal water and revers dependence between the suspension and chlorophyll-a along the Selenga river valley lead to the conclusion that Baikal water contains toxicants. It is verified by the presence of polychlorbiphenyls (PCB), polychlordibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF) for the whole food web with the maximum PCDD/PCDF (TEQ to 175 $\rho g \cdot g^{-1}$) concentration in the seal blubber. The levels are comparable with those reported for ringed seal (phoca hispida), living in the Baltic sea and Barrow Strait Inlet in the Canadian Arctic.

Keywords: *Lake Baikal, pollution, eutrophication, polychlorinated compounds Lake*

1. Introduction

In 1996 Lake Baikal was entered into the list of World Heritage sites (Natural). Lake Baikal is located in Central Asia between 55°46' N and 51°29' N. It is 636 km long and between 25 and 79.5 km wide. The more than 2 000 km of shoreline enclose an area of 31 500 km^2. More than 300 rivers and rivulets flow into the lake, and only the Angara River flows out of it. Lake Baikal is the deepest lake in the world (1 637 m) and contains 23 000 km^3 of water, more than the volu-

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me of all five Great Lakes combined and nearly 20 % of the world's surface fresh water. It is an ancient lake, about 25 million years old. Considerable changes in Lake Baikal' s ecosystem have occurred since 1960: the cycle development of endemic mass type phytoplankton- Aulacoseira baicalensis-has been disturbed; zooplankton biomass decreased in two times; the phisiological characteristics of Baikal fish have deteriorated and their rate of growth has also fallen (Galazy, *et al.*, 1987); small diatomic algae Achnanthes minutissima have been found at great depth in the lake (from 0.9 to 3.3 million cells·l^{-1}) (Kozhova, Kobanova, 1994) and, finally, the mass death of seal occurred in 1987.

Lake Baikal is regarded to be the well studied water reservoir in the world in terms of hydrochemistry (Votintsev, 1961; Tarasova, Mescheryakova, 1992) (Fig. 1).

The present paper reports about many years systematic research allowed the lake recent state to be evaluated in terms of both chemical pollution and possible eutrophication of its water.

2. Materials and Methods

The long terra, systematic research into the components of the ion composition of the lake's waters, its tributaries and atmospheric precipitation, together composing the main input of substances into Baikal, and also the river Angara, as the output part of the balance matter have been carried out since 1947. The period of the 1950s (Votintsev *et al*, 1965) is compared with the 1970's and 1980's which are close in their river flow.

The sources of substances of anthropogenic origin are distributed around the perimeter of the lake very unevenly. The main ones being: the Baikalsk Pulp and Paper Plant; the river Selenga, which undergoes the impact of the Ulan-Ude industrial complex; the Selenginsk Pulp and Carton Plant; scattered sources in the basin in the Buryat republic, and also the input of substances as a result of development in Mongolia; and other tributaries under the impact of towns and large settlements (Sliudyanka, Kultuk, Baikalsk, Severobaikalsk, Nizhneangarsk etc.). Enterprises situated on the shores of the lake are semilocalised sources of dust and gaseous emissions. Fuel filling points for lake' s fleet, at Kultuk, Sakhurte in the Maloye Morye etc., ports and also individual vessels and small boats, are sources of pollution by oil products. Extractive organic substances enter the lake during logging. Calculation has been made of the input of several chemical substances from sources of natural origin, as are rivers (chemical denudation of rocks), containing the main bulk of minerals and a considerable part of the organic substances.

Systematic investigations into the main components of the trophic status of water bodies (mineral and organic forms of carbon, nitrogen, phosphorus in suspension and in unfiltered water, and silicon, chlorophyll-a and suspended matter) in the waters of Lake Baikal have been carried out since 1965, and in its tributaries since 1968 (Tarasova, 1975). It is in this period from 1965 to 1989 that vigorous economic development has taken place around Baikal.

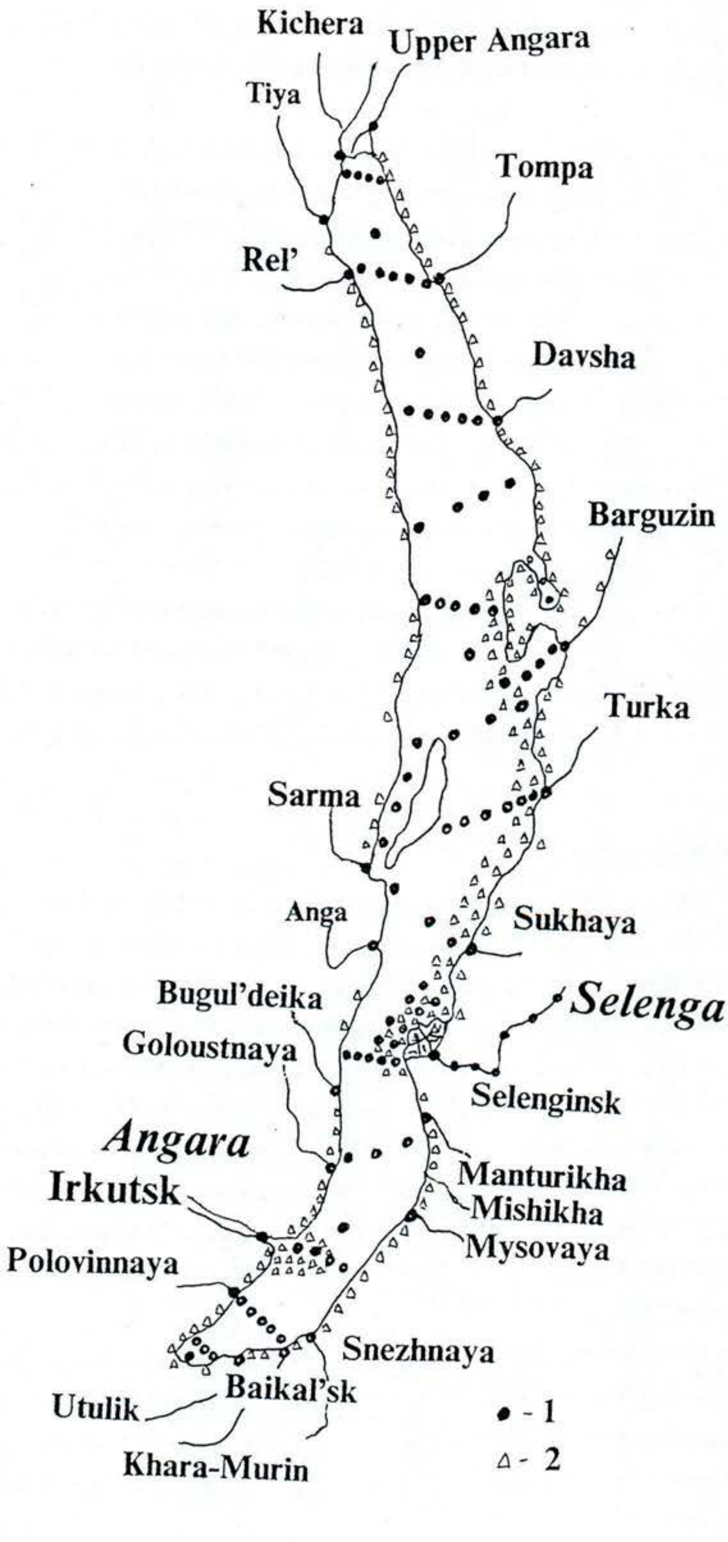

Fig. 1 Location of the sampling sites: 1 - every month, 2-several seasons

The variability in content of the above mentioned components in the waters of the open, deep water part of the lake has been defined on the basis of comparison of averaged data in the body of waters for a station 12 km from Cape Polovinny (South Baikal) 1967-1969, 1982-1985 and 1986-1989.

The material was obtained by monthly sampling of the water at 0, 5, 10, 25, 50, 100 m horizons and so on down every 100 m to the bottom. Previously methodological work had been carried out to estimate the reliability of the data obtained from the samples taken in the day time and at one point. For this, during different seasons, the daily (24 hour) variability in the content of components in a 5 km square, the centre of which was the station already mentioned, was studied. The coefficients of variations in the concentrations of C, N and P did not exceed the accuracy of their measurement. In addition, monthly samples of water were taken in the 0-50 m layer over a number of years over the whole of the lake. Determination of the concentration of the components under investigation-was conducted in 16 - 18 tributaries of the lake every month (they make up 85% of the Baikal's river water). Analysis of above mentioned chemical components has been carried on Strickland and Parsons (1968).

Polychlorinated dibenzo-p-dioxins(PCDD) and dibenzofurans (PCDF) were determined in zooplankton, fish (autumn 1996) and seal (nerpa) (May 1995). The HRGC/HRMS analysis were conducted using a HP-5890 gas chromatograph coupled to a VG- Autospec Ultima mass spectrometer operating in El mode at a resolution at 10 000. A 60 v x 0.25 mm RTX 2 330 (Restek) column with a film.

3.Results and Discussion

By comparison with the 1950s, during the following period 1970-1980 the flow of sulhates, chlorides and organic substances increased (Tab. 1, 2). The main role in the increase was played by the rivers Selenga and Upper Angara, in whose waters two-thirds of the sulphates, more than 80 % of the chlorides and approximately 70 % of the organic substances, of the total amount of these substances that enter the lake with all its tributaries, enter Baikal. Thus, at present the flow of sulphates from the rivers Selenga and Upper Angara has grown by 51 and 35 %, of chlorides - by 29 and 40 %, and of organic matter by 52 and 94 %. The input of the given components from tributaries of southern Baikal has risen considerably. The flow of sulphates in the rivers Mysovaya and Manturikha has risen 1.9 times, in the river Polovinnaya 2.4 time, and of chlorides in the rivers Snezhnaya and Big Sukhaya 4.4 and 4 times respectively, and the rivers Manturikha and Mysovaya 2.0 and 2.5 times.

The main reason for these changes, it can be said with a high degree of certainly, is industrial development in particular the atmospheric emission of the Baikalsk Pulp and Paper Plant (the rivers of the south-eastern coast) and the Selenginsk Plant (the river Sukhaya), and large scale land and construction works (the rivers in the northern part of the lake in the zone of the Baikal-Amur Railway).

The share of atmospheric components as against river ion flow in Baikal's chemical balance increased from 1.5 % in the 1950s to 5.0 % in the years 1976 - 1984. The input of $S0_4^{2-}$, CI^{-1}, Na^+ NH_4^+, $P0_4^{3-}$ and Si into the waters of the lake has especially risen.

Tab. 1The average annual chemical balance of Lake Baikal in 1950s (10^3 t)

Component	Input			Total input	Output throughtr. Angara	Accumu-lation in lake
	18 main rivers	other rivers	Atmospheric precipitation			
HCO_3^-	3 540	531	53.0	4120	4050	70
$S0_4^{2-}$	277	41.6	9.00	328	255	73
$C1^-$	42.2	6.33	0.90	49.4	25.8	23.6
Ca^{2+}	860	129	18.0	1010	1010	0
Mg^{2+}	165	24.8	1.00	191	138	53
$Na^+ + K^+$	204	30.6	4.00	239	258	-18
Fe_{total}	27.7	4.16		31.9	0.60	31.3
SiO_2	466	69.9	4.00	540	1.36	404

Tab. 2 The average annual chemical balance of Lake Baikal in 1970-1980 (10^3t)

Compo-nent	Input			Total input	Output throught r. Angara	Accumulation in lake
	16 main rivers	other rivers	Atmospheric precipitation			
$HC0_3^-$	3820	570	51.6	4440	3390	1050
SO_4^{2-}	384	57.6	27.4	470	234	236
$C1^-$	51.9	7.80	9.10	68.8	26.9	41.9
Ca^{2+}	935	140	15.1	1090	800	290
Mg^{2+}	182	27.4	3.80	213	146	67
$Na^+ + K^+$	258	38.7	27.3	324	196	128
Fe_{total}	22.1	3.30		25.4	0.56	24.8
SiO_2	525	77	7.2	600	141	458

The main part of the output of substances (river discharge with the waters of the Angara) has remained virtually unchanged over the periods compared .

When comparing the average accumulation of components of the ion composition in Baikal's water in the 1950s and 1970-1980s, it should be noted that their quantity has been increasing over recent years, this is paricularly noticeable for chlorides and sulphates. While in the 1950s the rate of accumulation of chlorides was 0.001 $mg \cdot l^{-1}$, at present it is 0.002 $mg \cdot l^{-1}$, for sulphates - 0.003 and 0.01 $mg \cdot l^{-1}$, and for the sum of ion 0.009 and 0.08 $mg \cdot l^{-1}$ a year respectively (Tarasova, Mescheryakova, 1992).

As a result of industrial and other activities each year 409 thousand tons of mineral substances, including 27.2 thousand tons of chlorides, 162 thousand tons of sulphates, 1.5 thousand tons of other sulphurous compounds, 0.131 thousand tons of methyl sulphurous compounds, 0.1935 thousand tons of phenols and 13.4 thousand tons of oil products.

The contribution of transport and logging to the pollution is revealed in two indices - oil products and the total content of organic substances.

The indices of input of pollutants with the waste waters of the Baikal'sk Pulp and Paper Plant should be considered separately as this is the only large enterprise, of those that are sources of pollution for Baikal, that is situated immediately adjacent to the lake and its waste waters are essentially one of the lake's tributaries.

In volume of discharge and input of mineral substances into the lake the waste waters of the Plant correspond to the most mineralized river, the Bugul'deika, in total flow of chlorides only the river Selenga exceeds that of the Plant, in the quantity of sulphates its waste waters contain a little less than the river Barguzin. The input of sulphates and chlorides into the lake with the Plant's waste waters significantly exceeds their input with the waters of all the main tributaries of the lake's southern basin (Tab. 3) In their content of sulphates (260 $\mu g \cdot l^{-1}$), chlorides (78.9 $\mu g \cdot l^{-1}$) and organic matter (45 $\mu g \cdot l^{-1}$) the waste waters of the Plant exceed the average values of these substances in the 16 main tributaries of the lake 34, 77, 4. 1 and 3.6 times respectively, and 28, 53, 3.3 and 2.9 times their content in the waters of the Selenga.

Tab. 3 Substance supply in the tributaries of South Baikal and effluents of the Baikal'sk Pulp and Paper Plant 1970-1980 (thousand tons per year).

Rivers	SO_4^{2-}	Cl^-	Organic substance	Ion total
Utulik	3.90	0. 19	5.00	33.6
Snezhnaya	6.80	0.57	13.6	68.0
Manturikha	1.37	0. 14	2.40	17.4
Khara-Murin	3.30	0.21	8.00	22.2
Bugulgeika	3.30	0.16	2.70	46.3
Goloustnaya	4. 14	0.22	8.20	35.7
Mysovaya	0.42	0.05	0.8	5.70
Polovinnaya	0.62	0.06	1.70	5.10
Total for main tributaries of the basin	20.55	1.60	42.4	234
Sewage waters of Baikal'sk Pulp and Paper Plant	30	7.89	7.0	56

The largest load of pollution as a result of industrial and other activity is experienced by South Baikal, within whose limits the impact of pollution from enterprises and settlements situated here (on the shores of the lake and its tributaries) is localized to a considerable extent. To these should be added part of the pollution caused in the southern basin by the river Selenga.

The carring of atmospheric emission from local pollution sources out of the lake basin is hindered by the high frame of mountains around the shore of the lake and the presence of strong land and water atmospheric inversions.

Calculations of input of chemical substances of anthropogenic origin into the lake waters show a significantly higher load on South Baikal for all components. The input of substances of anthropogenic origin per unit of surface area of lake water in South Baikal exceed the analogous value for Central and North Baikal in total mineral substances 3.6 times, including: chlorides 3.9

times, sulphates 5.1 times, organic substances including phenols 1.3 times, and oil products 7.4 times.

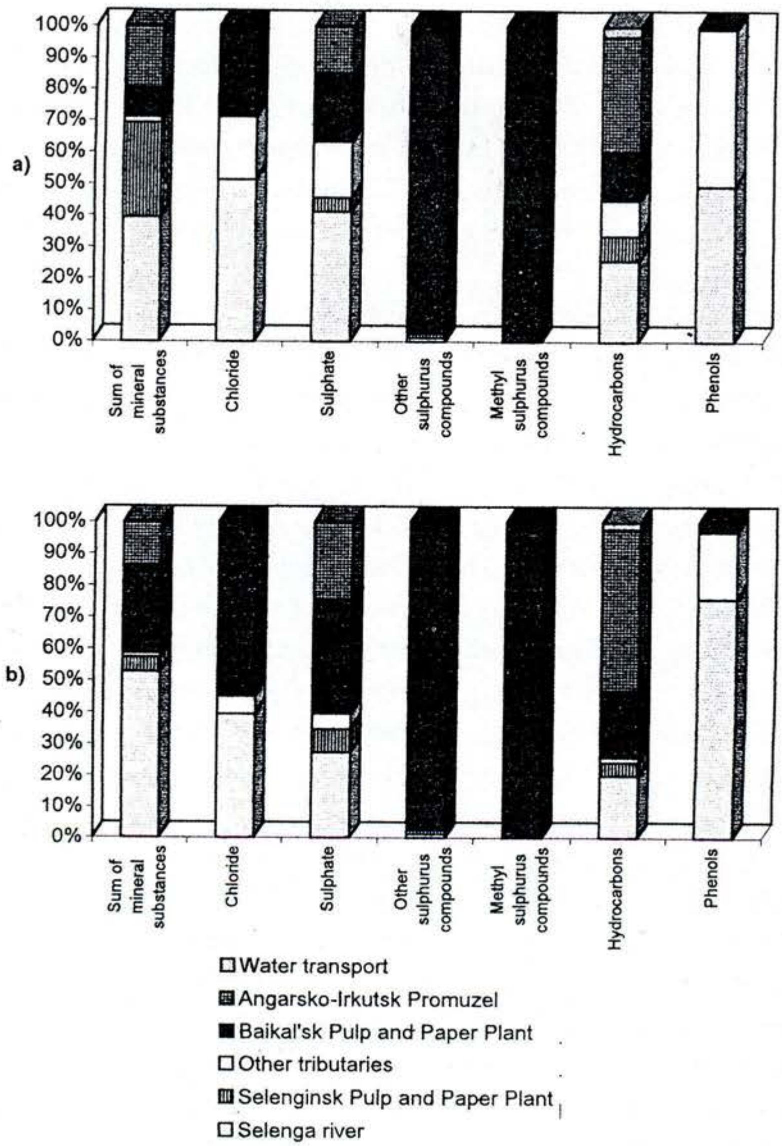

Fig. 2 Contribution of individual sources (in %) in arrival of different contaminated substances into Lake Baikal (a) and individual one its south basin (b).

The waste waters and atmospheric emissions of the Baikal'sk Pulp and Paper Plant contribute 29.1% mineral substances, including 55 % of the chlorides and 39 % of the sulphates to the southern part of Baikal (Fig.2).

The main sources of pollution of the lake are the industrial enterprises in the Selenga basin (in total contribution) and the Baikal'sk Pulp and Paper Plant. Of the unmonitored sources a large role in pollution, especially of the river Selenga, is played by scattered sources and agriculture, the contribution by other sources of pollution - the ports and logging stations do not exceed 10 % (for oil products 50 %) of the total input from the above indicated main sources.

The data given on elements of the chemical balance of Baikal and on the scale of anthropogenic impact witness to the fact that the hydrochemical character of the lake, which formed over a long period of time, has now been disturbed. This violation is expressed in the enrichment of the lake water by a number of chemical components, such as sulphates, chlorides and organic substances.

If the intensity of anyhropogenic origin chemical substances into the lake be as that of the first half of the 1980's until the end of the century, we can expect that by the year 2000 the concentration of minerals substances would rise by 1.5 %, sulphates by 3.6 % and chlorides by 10 %. The growth in organic substances may be more significant (by 18 %) and in the biogenic element nitrogen (by 10 %) and phosphorus (by 9 %). All this could lead to a change in the ion ratio in the lake waters, which is to a change in the hydrochemical facies of Baikal.

The peculiarity of Baikal's water masses (the descent of upper zones of water into lower and revers) (Tolmachev, 1957) means that not only the coastal water are subject to pollution, but also the deep water part. Thus the mean annual content of the sulphates in the deep water at the depth of 1300 meters 20 Km from the Plant has risen from 3.9 $mg \cdot l^{-1}$ 1986-1987 to 6.5 $mg \cdot l^{-1}$ (1986-1987) (Tab. 4). Besides the results of monthly analyses of content at deep water stations in south Baikal which have been carried out since 1957 up to 1987 allowed to make the conclusion that the ion composition of Baikal water can not be considered as homogeneous and unchangable. Background concentration of sulphates doesn't seem to be homogeneeous(5.2 $mg \cdot l^{-1}$) as it was considered before for the whole open part of the lake.

The concentration of biogenic element, and suspended and organic matter in the lake is irregular and determined by their input with river flow, the time of year, development of the dominant forms of planktonic algae and the dynamics of the water masses. Two maximum are observed in the development of lake Baikal's phytoplankton; under the ice and immediately after the clearing of the ice from the lake. As rule, almost pure cultures of Peridinium (1965) or different species of aulacoseira baicalensis (1968, 1982) or Synedra arcus (1969), dominte while in 1984 and 1987- Nitzschia acicularis; in August and September- blue-greens; including ultranannoplankton, with the spring maximum of phytoplankton development being much higher than in the autumn. In recent years, a disturbance in the recurrence of the development of phytoplankton has been observed: if earlier aulacoseira baicalensis in the mass (up to 4 $g \cdot m^{-3}$) developed every 2-3 years, at present this occurs every 5 - 8 years (Popovskaya, 1986).

A characteristic peculiarity of Baikal waters in the 1950s and 1960s was the almost complete absence of ammonia and nitrite nitrogen, and only at night during the period of development of

Aulacoseira some traces of ammonia were noted. At present as much as 10-20 $mg \cdot l^{-1}$ of ammonia and nitrite nitrogen is found quite frequently at different horizons, including deep waters ones.

Comparison of seasonal variations in the content of suspension, organic matter and biogenic elements in pelagic Baikal has shown that, in the trophogenic layer, in recent years, an increase in the concentration of the above enumerated components over the whole period of open water, with a maximum in autumn, has been observed. In 1967 - 1969 two clearly expressed maximum and two minimum of their concentration coincided with seasonal variations in the development of planktonic organisms.

In 1986-1989, in the 0-1 300 m layer of unfiltered waters, average concentrations of the components under study remained at the level of the highly productive years for phytoplankton development of 1967-1969, with the exception of organic phosphorus (Tab. 5)

Tab. 5 Content of some components of the trophic status of Baikal (average over depth 0-1300 m).

Years of research	Suspension $mg \cdot l^{-1}$	Chlorophyll-a $\mu g \cdot l^{-1}$	Corg. $mg \cdot l^{-1}$	$N\text{-}NO_3^-$ $\mu g \cdot l^{-1}$	$N_{org.}$ $\mu g \cdot l^{-1}$	$P\text{-}PO_4^{3-}$ $\mu g \cdot l^{-1}$	$P_{org.}$ $\mu g \cdot l^{-1}$
1967-1969	0,53±0,10	-	0,87±0.05	92±5	8±7	11±1	4±1
1982-1984	0,48±0.11	0.19±0.15	1.04±0.18	81±10	63+30	-	-
1986-1989	0.57±0.16	0.16±0.11	1.04±0.13	84±10	103±50	10±2	9±3

In the 0-1300 m layer the average concentration of carbon in the total amount of suspension 1986-1988 increased 5.75 times (23 %) by comparison with 1968-1969 (4 %), and in the total amount of carbon 3 times (9 and 3 %).

Concentration of nitrogen in suspension in 1986-1988 (25 $mg \cdot l^{-1}$), according to the mean values, rose 5 fold, while suspended phosphorus doubled by comparison with the same in 1983-1984 (0.75 $mg \cdot l^{-1}$).

A considerable change over the period studied by comparison with 1967- 1969 was found in the character of the vertical distribution of mineral and organic forms of nitrogen and phosphorus. While in 1967-1969 there was an increase in the content of mineral and decrease in the organic forms of nitrogen and phosphorus, in 1986-1989 on horizons below 100 m synchronous variation in their values was observed (Fig. 3). This seems to be due to a rise in the input of substances from the Baikal'sk Pulp and Paper Plant (the sulphate content in the 0-1 300 m layer rose from 3.9 $mg \cdot l^{-1}$ in 1967-1968 to 6.5 $mg \cdot l^{-1}$ in 1986-1987, Tab. 4) and with the process of the downward movement of upper zones of water into lower zones (and the reverse) down the slope, first noticed in Baikal by V.A.Tolmachev (1957).

The main sources determining the dynamics of organic substances and biogenic elements in the lake waters, that is, the waters of its tributaries and atmospheric precipitation, has been taken into consideration. The input of nitrogen with river waters over the period 1968-1987 depends on the water flow (the coefficient of correlation is 0.90), for the flow of phosphorus the link is weak (0.67). The annual input of nitrogen into the lake via the tributaries is 19.1 thousand tons (with a fluctuation from 10.4 to 25.6 thousand tons), and of phosphorus 1.6 (1.5-1.7) thousand tons. Atmospheric input into the lake only of dissolved forms of nitrogen and phosphorus by comparison with the river flow is 37 %and 44 % respectively. The annual output of nitrogen and phosphorus via the river Angara on average is 9.6 thousand tons of nitrogen and 1.1 thousand tons of phosphorus.Thus, from 50 % to 70 % of the input of biogenic substances accumulates in the lake. The external biogenic load on Baikal in terms of nitrogen was 0.832, and in terms of phosphorus 0.073 $g \cdot m^{-2} \cdot a^{-1}$. The internal load of phosphorus was 0.047 $g \cdot m^{-2} \cdot a^{-1}$, calculated according to the difference between sedimentation and the accumulation of phosphorus(Tarasova, Mescheryakova, 1992).

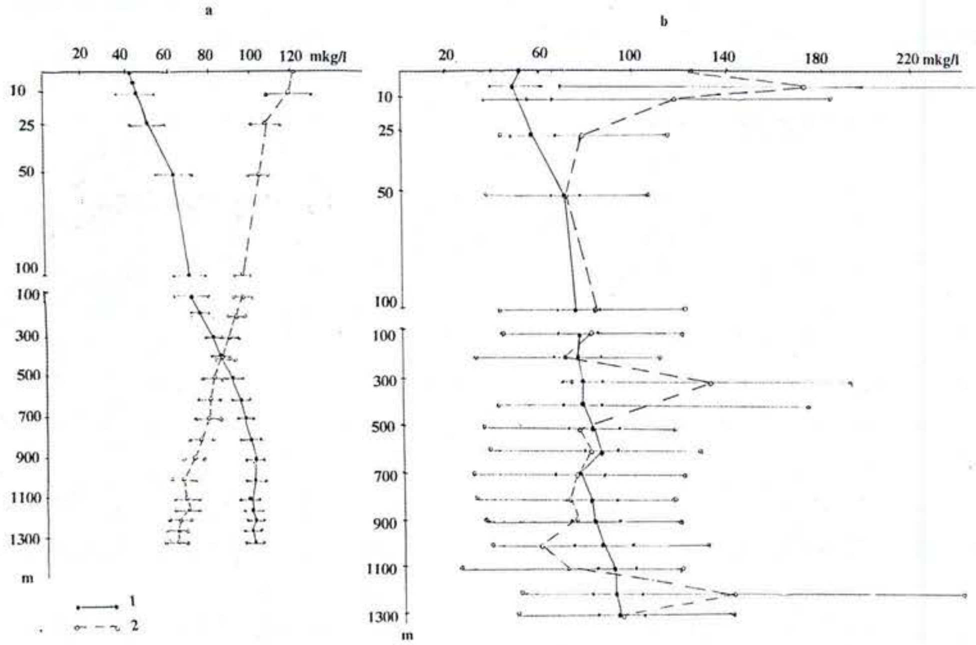

Fig. 3 Vertical distribution of mineral and organic of nitrogen, $\mu g \cdot l^{-1}$. 1-N-NO_3^-, 2-N org.; a-1967-1969, b-1986-1989.

Analysis of the variability in the ratios C:N and C:P of the mineral and organic forms of nitrogen and phosphorus and also Si:P and Si:N in Baikal waters 1967-1969 (in the period of the lake's natural state) showed that in the winter the development of Aulacoseira baicalensis is possible with Si:P>90. It is limited by the content of phosphorus (in the trophogenic layer the mineral forms of N:P rise to 54, and Si:P to 800). Aulacosira baicalensis is more demanding of such elements as Si and P, than Synedra. If the winter ratio of Si:P<90, Synedra develops in a mass. With an intermediate value Si:P = 70-90 in winter, the combined development of Aulacoseira and Synedra is possible.

From a period of low anthropogenic load, 1983-1984, to the relatively higher anthropogenic impact on the waters of the open part of the lake, 1986-1989, a transition of the lake waters from average limiting in terms of nitrogen (C:N in suspension in the trophogenic layer is >10) to complete absence of N- limitation in the development of phytoplankton (C:N<5).

Tab. 4 Distribution of annual sulphate contents (mg · l^{-1}) in the south Baikal, (12 km away from the Polovinnyi)

depth	Years			
	1967-1968	1981-1982	1983-1984	1986-1987
0	3.9	4.8	4.6	7.8
5	-	-	-	7.4
10	4.4	4.8	4.7	7.5
25	4.1	4.9	4.7	7.5
50	3.8	5.3	5.0	6.6
100	3.9	5.2	5.3	6.9
200	3.8	4.9	5.0	6.1
300	4.1	4.6	4.6	6.4
400	4.9	-	4.6	5.9
500	4.1	4.7	4.6	5.7
600	4.1	-	4.5	7.4
700	4.0	4.5	4.4	6.4
800	4.0	-	4.1	6.4
900	3.8	-	4.0	7.7
1 000	4.0	4.7	5.0	6.6
1 100	3.7	-	4.3	6.4
1 200	4.2	4.8	4.4	6.3
1 300	3.8	-	-	6.7
Average in a layer 0-1300m	3.9±1.2	4.7±1.0	4.6±0.6	6.5±2.2

Despite the optimum ratio of Si:P>100 in the winter period 1986-1989, the development of spring forms of phytoplankton in the mass was not observed. This phenomena, as well as the inverse correlation between the winter nitrogen content and spring concentration of chlorophyll-*a* in Baikal's waters (Fig. 4) and the inverse dependence between suspension and chlorophyll-a in winter in the Selenga in, recent years (Fig. 5), permits one to draw the conclusion that at present the lake is threatened to a greater degree by the pollution of its waters by toxicants than by eutrophication.

Taking into account the Pulp and Paper mill, available on the shore of South Baikal and Selenga river, wich is the main tributary of the lake, as possible sources of organochlorine compounds in the lake we determinated concentrations of PCB, PCDD and PCDF in biota of lake Baikal(Tarasova *et al.*,1995; Mamontov *et al.,* 1997). PCDD and PCDF were determined in zooplankton, fish and sea (nerpa). In seal females the average TE (value (46 pg·g^{-1}) was lower than that of males (60 pg·g^{-1} wet weight) (maximun 175 pg·g^{-1}wet weight).The TEQ levels are comparable with those reported fo ringed seal (Phoca hispida) living ir Barrow Strait and Admiralty Inlet in the Canadian Arctic (Norstrom *et al.*, 1990 and in the Baltic Sea (Bergek *et al.*, 1992). High concentrations of DDT 4.6-16 (μg·g^{-1}) and PCBs (3.5-64 μg·g^{-1} on lipid weight basis) have been found in the Baikal seal (H. Nakata *et al.*, 1995).

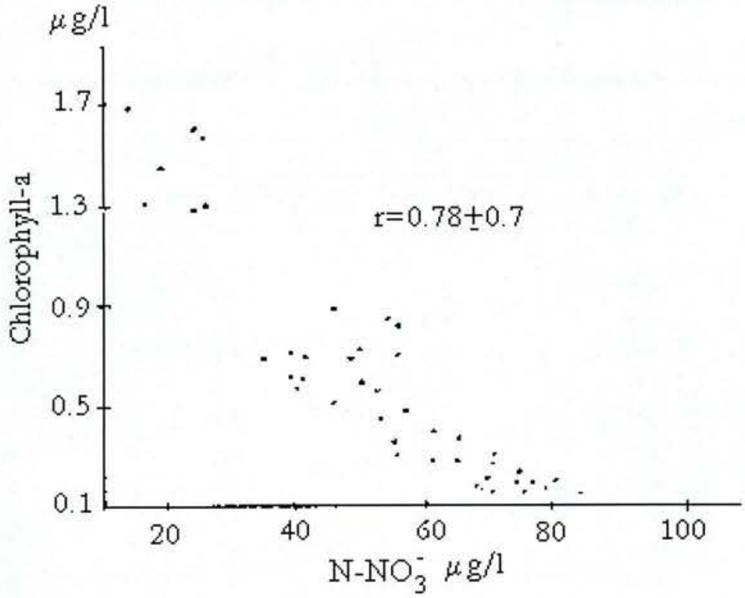

Fig. 4 Correlation between winter nitrogen content and spring of chlorophyll-a concentration in the Baikal water, μg·l-1.

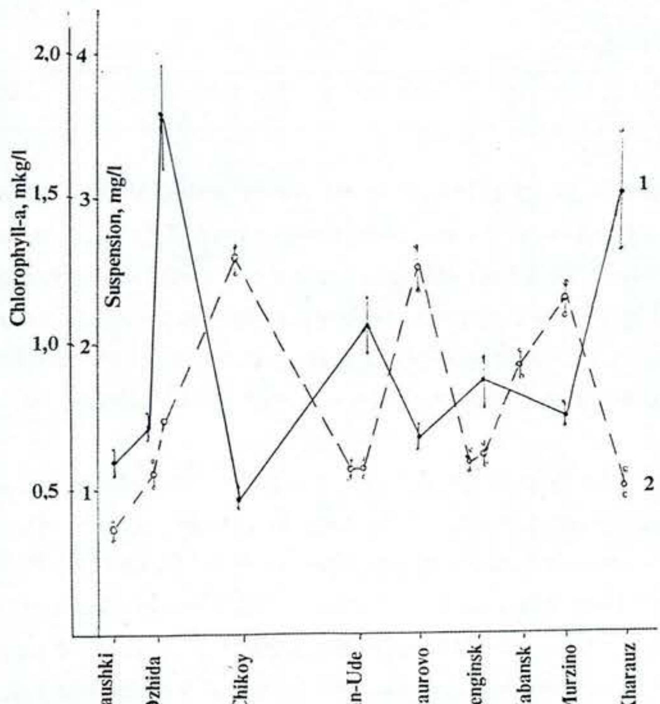

Fig. 5 Dependence between suspension content and chlorophyll-a concentration in Selenga River : 1 - suspension, 2 - chlorophyll-*a*

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