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Studying Water, Sediment and Contaminant Runoff of Siberian Rivers
Modern Status and Prospects

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Introduction

The natural environment of the Arctic is greatly influenced by river and sediment runoff, as well as by different contaminants both natural and man-made, inflowing with river water into the entire catchment basin of the Arctic Ocean. Out of the total volume of river runoff (5140 km^3 per year) incoming to the ocean, the rivers of Russia discharge 56%, or 2890 km^3/year. Annually hundreds of millions of tons of suspended sediments and dissolved salts are transported to the ocean, the greatest portion from the Siberian rivers.

In the last few decades, along with the runoff of water, sediment and natural ions, the Arctic began to be loaded with enormous amounts of contaminants because of intense activities of man in the river catchments. This has taken place in all countries located in river basins of the Arctic Ocean, especially in Russia with its 70% of river runoff incoming to the Arctic. In the territory of Russia, the basins of such Siberian rivers as the Ob and Yenisey were being intensely developed because of the rich mineral resources, oil fields, and gas deposits that were discovered, but also as a result of the large industrial centers built in the region, as well as the intense shipping lanes created there.

Studying the dynamics and qualitative composition of the contaminants incoming to the Arctic regions with the river runoff is of great importance for monitoring and protecting the Arctic environment and improving Arctic Ocean water quality.

Water and Sediment Runoff

The stationary network of hydrological stations of the Russian Federal Service for Hydrometeorology and Monitoring of the Natural Environment (Roshydromet) is the major source of initial data for studying water and sediment runoff. The water level and runoff of Siberian rivers in the lower reaches are being studied at 63 level and 35 runoff observational stations, which is obviously insufficient for so large territory. Location of major stations is shown in a diagram (Figure 1). Table 1 gives major characteristics of runoff of 13 large and mid-sized Siberian rivers at the lowest gauging sites. On a number of rivers these sites are located at a distance of 300-600 km from the mouth. Catchments of the indicated rivers cover 83% of the entire Asian catchment area of the Arctic Ocean and on the whole they characterize well enough the regime of surface water income to the ocean. Total annual runoff of the above rivers is about 1800 km^3, its year-to-year variability being insignificant. (The variation coefficient of the Yenisey runoff is Cv = 0.08, for the Lena it is 0.10, and for the Ob, 0.17).

Intrayear runoff distribution for Siberian rivers is rather homogeneous; minimum discharges are observed in winter period when even some large rivers are able to be fully frozen. During spring flood, May until July-August, about 60-75% of the annual discharge occurs (Table 2, Figure 2), with typical monthly discharge during one spring month being 30-40% of annual volume.

Until recently man's activities in the basins of Siberian rivers (construction of reservoirs, irrigation, industrial and public water consumption, etc.) slightly affected the annual discharge in the lower reaches. The greatest value of annual discharge decrease, due to anthropogenic factors, is characteristic of the Ob. It is about 18-20 km^3/year, or 5% of annual runoff. As for the rest of large Siberian rivers, these values are within 1%. Insignificant are also man's effects on intrayear distribution of the inflow of Siberian rivers to the Arctic region. Even construction of the largest reservoirs in the upper reaches of Yenisey and in the basin of Angara, a tributary to Yenisey, slightly affected the intrayear runoff distribution in the lower reaches of the river.

The network of observational stations for suspended

Symbols for kinds of observations:

- • water level
- ✧ level, water quality
- ✦ level, water quality, sediments
- ▾ level, water discharge
- ▪ level, water discharge, sediments
- + level, discharge, water quality
- ✱ level, discharge, water quality, sediments
- o water quality in places where stations are unavailable

Figure 1. Location of basin standard network of observation stations.

Table 1. Hydrological characteristics of Siberian rivers inflowing to the Arctic Ocean.

River - section	*Drainage area ($km^2 \times 10^3$)*	*Distance from mouth (km)*	*Onset of observation*	*Long-time ave. discharge c(m^3/s)*	*Volume of runoff (km^3)*	*Low discharge (m^3/s)*	*Maximum discharge (m^3/s)*
Ob - Salehard	2950	287	1930	12,600	397	2840	36,700
Pur - Samburg	95.1	86.0	1939	897	28.3	204	6,300
Taz - Sidorovsk	100	259	1962	1050	33.1	161	6,300
Nadium - Nadim	48	110	1955	458	14.4	12.5	4,710
Khatanga - Khatanga	275	217	1961	2,220	70.0	—	24,400
Yenisey - Igarka	2440	697	1967	18,100	571	3,910	131,000
Olenek - 7.5 km from mouth of Pur River	198	210	1964	1,020	32.2	1.1	15,800
Lena - Kyusyur	2430	211	1934	16,500	520	1,000	132,000
Anabar - Saskilah	78.8	209	1954	416	13.2	94.2	9,000
Yana - Jangkli	216	381	1938	929	29.2	0.37	8,270
Indigirka - Vorontsova	305	350	1936	1,590	50.2	6.52	7,550
Kolyma - Sredne -Kolymsk	361	641	1927	2,220	70.0	50.7	17,000
Anguzma - near bridge 174 km	26.4	121	1944	271	8.6	0	3,720

sediments is much more scarce than that for water runoff. In the lower reaches of the Russian rivers inflowing to the seas of the Arctic Ocean, observations of sediment runoff are being carried out at 23 sites, more than half of which are located in the north of the European part of Russia (see Figure 1). Observations of sediments are conducted by the standard technique developed at the State Hydrological Institute. The program of studies includes collecting single water samples for turbidity at a gauging site and time-to-time measurements of suspended sediment discharge with simultaneous sampling to determine grading sediment composition. The runoff of suspended sediments is calculated by both turbidity measurement data on single samples, and by the diagrams of the relationships between discharges of suspended sediments and discharges of water.

Major runoff characteristics for suspended sediments of Siberian rivers in the lower reaches are presented in Table 3. Under the natural conditions in the lower reaches, the large Siberian plain rivers are characterized by turbidity within 12-50 g/m^3. On rivers in

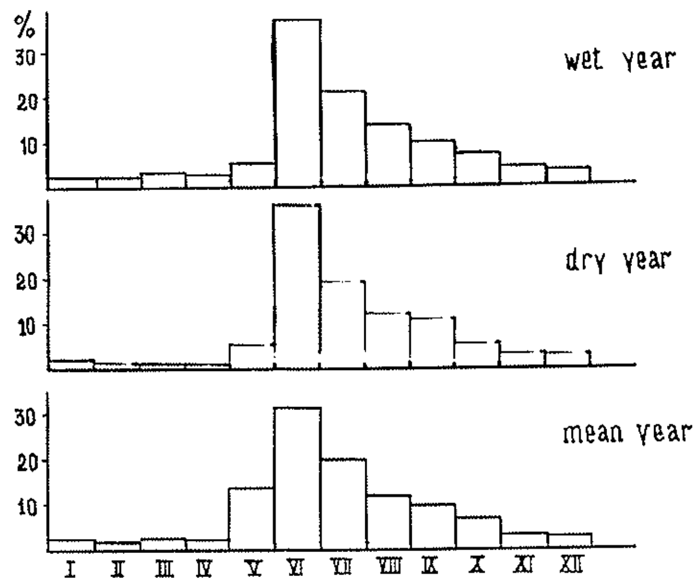

Figure 2. Total inflow of the Siberian rivers to the Arctic Ocean (percent per month) for years characteristic of water availability.

Table 2. Intrayear distribution of the Siberian rivers runoff inflowing to the Arctic Ocean in years average in water availability.

River - section	*Monthly runoff distribution % of annual flow*											
	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*
Ob - Salehard	3.1	2.5	2.2	2.2	9.8	21.6	19.5	15.2	9.5	6.9	4.0	3.5
Pur - Samburg	2.8	2.4	2.1	2.1	6.0	35.3	16.2	9.2	8.8	6.7	4.7	3.7
Taz - Sidorovsk	2.2	1.9	1.6	1.4	5.6	35.3	22.6	8.4	7.6	6.5	4.0	2.9
Nadium - Nadim	2.9	2.5	2.4	2.6	14.8	31.5	11.2	7.9	8.7	7.0	4.9	3.6
Yenisey - Igarka	3.3	3.5	3.5	3.4	9.5	38.9	11.7	7.4	7.4	5.9	2.9	2.6
Olenek - 7.5 km from mouth of Pur River	0.1	0.0	0.0	0.0	2.4	58.6	19.3	7.7	8.7	2.4	0.6	0.2
Lena - Kyusyur	1.3	1.0	0.7	0.6	2.6	37.3	20.0	13.8	12.5	7.1	1.7	1.4
Anabar - Saskilah	0.0	0.0	0.0	0.0	1.1	63.8	16.5	10.2	6.4	1.4	0.5	0.1
Yana - Jangkli	0.0	0.0	0.0	0.0	5.6	33.4	27.2	21.0	10.9	1.5	0.3	0.1
Indigirka - Vorontsova	0.2	0.1	0.1	0.0	1.7	30.0	29.6	22.2	12.3	3.7	1.2	0.7
Kolyma - Sredne - Kolymsk	0.4	0.3	0.2	0.2	7.2	39.2	19.7	15.0	12.2	3.7	1.2	0.7
Anguzma - near bridge 174 km	0.0	0.0	0.0	0.0	1.4	44.0	26.2	17.2	8.7	1.9	0.5	0.1

Eastern Siberia with great slopes and current velocities the values of turbidity are more significant; in a number of basins they are distorted because of intense human activity in the river valleys related to gold mining. Preliminary estimates indicate that 50-60 million tons of suspended sediments annually come to the Arctic with the Siberian river runoff. Eighty to ninety percent occur in the spring flood. It should be mentioned that the cited values characterize, but not fully, the total inflow of sediments to the ocean, because they do not take into account the role of the Arctic zone itself. For instance, the studies made recently in the State Hydrological Institute on erosion and sediment runoff formation on slopes on the Yamal peninsula show that under the conditions of permafrost, developing thermokarst and intense anthropogenic load (when developing oil-and-gas fields), there are areas with catastrophic erosion and sediment runoff amounting to 4000-8000 tons per hectare per year.

The Network of Observations of Water Quality

Monitoring of surface water quality in Russia is conducted by the administrative organs of Roshydromet at the network of steady observational stations. Observations are carried out according to complex programs including measurements of physical, chemical and hydrobiological indices. The network observations are based on the following principles: they should be complex and systematic; sampling has to agree with water regime phases; water quality indices are to be determined by the same methods at all stations.

In Siberian river basins, the observational network

Table 3. Mean annual turbidity and sediment runoff of rivers inflowing to the Arctic Ocean (within the catchments of the Kara, Laptev, and East Siberian Seas).

River - section	*Drainage area ($km^2 \times 10^3$)*	*Distance from mouth (km)*	*An average over the period of record*			
			Onset of obs.	*Sediment discharge (kg/s)*	*Turbidity (g/m^3)*	*Annual sediment (runoff, 10^3 t)*
Ob - Salehard	2953	312	1938	480	40	15,200
Pur - Samburg	95.1	86	1941	22	25	690
Yenisey - Igarka	2440	697	1941	220	12	6,900
Anabar - Saskilah	78.8	209	1967	12	29	380
Olenek - 7.5 km from the mouth of Pur	198	210	1971	38	41	1,200
Lena - 4.7 km from Stolo	2460	—	1958	350	29	11,000
Omoloi - Nami	10.8	—	1979	1.1	30	36
Yana - Yubileinaya	224	157	1973	110	116	3,500
Alazeya - Andryushkino	29	—	1979	3.1	77	98
Kolyma - Kolymsskoe 1	526	—	1977	280	115	12,000
Polyavaam - 8 km from the mouth of the Glubokaya River	6.81	195	1972	2.0	48	54

Table 4. Number of stations for hydrochemical observations in the basins of rivers inflowing to the Arctic Ocean (the status for 1991).

River basin	*Total number*	*Including major rivers*
Ob	237	15
Yenisey	156	13
Lena	88	10
Pur2	2	
Taz	4	4
Anabar	1	1
Olenek	3	3
Omoloi	1	1
Yana	9	5
Indigirka	5	2
Alazeya	1	1
Kolyma	41	6

numbers approximately 550 constant observational stations. Table 4 shows their distribution over basins. The network density in the region in question is much lower than in the European part of Russia. It is 9-10 stations per 100 thousand km^2 in the Ob River basin and 1-4 in river basins in Eastern Siberia. At present, in the lower reaches of large Siberian rivers, there are 18 observational stations for water quality combined in the majority of cases with hydrological gauging sites. This allows the estimation of the dynamics of total contaminant income with river runoff to the Arctic zone.

The earliest hydrochemical observations in the lower reaches of Siberian rivers date from the 1930s. At approximately half of stations, observation were started in the 1940s-1950s; however the programs of water quality observations began to be conducted in full volume only since the last half of the 1970s.

Hydrochemical observations by the most full program envisage determining 30-50 indicators within four major groups of chemical substances:

1. Physical properties, major ions, dissolved gases: temperature, transparency, suspended substances, pH, oxygen, carbon dioxide, ion sum, hardness, Ca, Mg, Na, K, HCO_3, SO_4, Cl, Eh.
2. Natural and contaminating organic substances: color, chemical oxygen demand (COD), biochemical oxygen demand (BOD), phenols, petrol products, detergents.
3. Biogenic ingredients and inorganic contaminants: total nitrogen, nitrates, nitrites, ammonium, total phosphorus, phosphates, silicon, copper, nickel, cadmium, ferrum, zinc, chromium, lead, mercury, manganese, sulphides, cyanides, fluorine, iodine, cobalt.
4. Specific organic contaminants and pesticides: resins, asphaltens, pesticide dusts, hexachlorane, etc.

Frequency and composition of observations at each station depend on its category (four categories at all) established taking account of a number of factors: economic significance of water object, pollution, value as a natural object. Depending on the category of station the frequency of observations varies from a daily one to once a month or season. At lower parts of the large Siberian rivers, where stations of categories 3 and 4 are located, the frequency of sampling is 5 to 14 times per year. Samples are taken as a rule on three verticals at two or three levels at each.

Natural Quality of River Waters

Under the natural conditions the quality of river waters in Siberia is formed under the influence of climate, soil and vegetation, geomorphological and geological structure. Excessive moistening of soil-ground thickness, low temperatures and widespread permafrost cause the formation of slightly mineralized river waters (50-200 mg/l) with hydrocarbonate ions and calcium ions. On all rivers, distinctly expressed intrayear variations are recorded in the concentration of dissolved substances due to the character of water income to the river system. In spring high-water period, there are minimum values of water mineralizing (within 30-100 mg/l). In winter low-water period, when river system is fed by ground waters, mineralizing reaches maximum values (150-400 mg/l). For rivers with intense discharge of head ground waters (e.g., Lena, Olenek), mineralizing increases in winter period up to 500 mg/l with increasing chloride and sodium ions in the ion composition.

The content of dissolved organic contaminants in river waters is characterized by indicators of color and chemical oxygen demand (COD) and changes considerably over the territory depending on the extent of catchment swamping. It is water humus content that has the most considerably effect on these indicators. In the spring period, the water color index is the greatest, with the most considerable color index pertaining to river waters formed in tundra zone. COD varies in spring within 10-60 mgQ/l and it is 2 to 3 times less in winter low-water period.

Acidity indicators in stream waters of large rivers are within the limits typical of neutral water reaction (pH = 6.8-7.2). However, in individual parts of hydrographic network, river waters can have an elevated acidity (pH ≤ 6.5), because of a great role of swamp nutrition. As for the chemical content of biogenic substances, there are predominately compounds of nitrate nitrogen, silicon, and ferrum. Migration of the two last is carried out to a great extent in a colloidal state. The presence of mineral compounds of nitrogen and phosphorus in pure waters of Siberian rivers is associated mainly with biochemical destruction of natural organic substances as well as with falling atmospheric precipitation. Analysis of natural hydrochemical characteristics made at the State Hydrological Institute for river catchments in Siberia shows that the total amount of mineral compounds removed from one square kilometer of catchment area to the Arctic zones is within 14-19 tons per year; removal of dissolved organic substances makes up 2 to 6 tons from one square kilometer per year. It should be mentioned that natural geochemical migration of microelements with river runoff is studied but insufficiently because of the scarcity of full-scale observational data on Siberian rivers in the pre-industrial period. This information is available only for some river catchments.

The Dynamics of Contaminating Siberian Rivers

The intensity of man's activities in the territory of Siberia, especially beginning with the 1970s, caused considerable changes in the chemical composition of river waters. The levels of contamination depend on volumes and composition of chemical substances incoming to water bodies as well as on their self-purification ability. It should be mentioned that until now the pollution and self-purification processes, migration, accumulation, and transformation of chemical substances in water systems of Siberia have been studied, but insufficiently.

Major sources of man-made pollution of natural waters in the territory under consideration are the developed oil-and-gas fields, poly-metallic ores, petroleum, gas and petrochemical industries, metallurgic, machine-building industries as well as wood pulp and paper industry, etc. The intense development of large cities on river banks (Novosibirsk, Omsk, Irkutsk, Krasnoyarsk, Tomsk, Kemerovo, etc.) with populations of more than 0.5-1.0 million people has led to a considerable organic and biogenic substance loading of rivers incoming with waste waters, river transportation inserting a considerable contribution into water pollution of large rivers. One more source of polluting the river catchment area is dust-gas emissions into the atmosphere of contaminating substances from industrial enterprises as well as from burning casing-head gas on oil fields. High sorption ability of swampy soils and peat bogs widely distributed in Siberia promotes accumulating on catchments different contaminants, which creates the conditions for secondary pollution of river systems.

The materials of regular observations at the Roshydromet network show that at the majority of controlled objects, water quality does not correspond to the specification requirements imposed in Russia upon the economic and drinking water installations as well as fish industry. Criteria of estimating water pollution in the shape of the so-called admissible concentration limit (ACL) are given in Table 5. It should be mentioned that these norms developed for other conditions cannot be fully applicable to the ecosystems of Siberia, especially in its Arctic zone existing under the extreme conditions of unstable equilibrium.

The territorial unevenness of anthropogenic load on water objects and their different self-purification ability caused considerable differences in the extent of contamination of Siberian rivers. Figure 3 presents the modern level of water contamination by major indicators in the streams of the three major rivers of Siberia. These data do not refer to certain sites; they characterize mean annual concentrations over the length of main

Table 5. Criteria of estimating water contamination accepted in Russia.

Ingredients and indicators	*Limiting index of harmfulness*	*Admissible concentration limit (ACL) mg/l*
BOD full	common requirements	3.0
Nitrogen nitrate	toxicological	9.1
Nitrogen nitrite	toxicological	0.02
Nitrogen ammonium	toxicological	0.39
Oil products	fishing industry	0.05
Phenols	fishing industry	0.001
Copper compounds	toxicological	0.001
Zinc compounds	toxicological	0.01
Chrome six-valent compounds	sanitary-toxicological	0.001
Sulphate ions	sanitary-toxicological	100.0
Chloride ions	sanitary-toxicological	300.0
Mercury compounds	sanitary-toxicological	0.0005
Sulphades	general sanitary	absent

river channels. They are obtained by statistical processing of water samples observed over a year at all observational stations on the main stream from river-head to mouth. As seen in Figure 3, the Ob River is to be considered as most contaminated. In its basin, large industrial centers of Siberia are concentrated. In addition, the river channel accepts a portion of sewage from the industrial Urals. Stream waters of Yenisey are very contaminated; however, this is much less for the Lena River. It could be also mentioned that, as a whole, in the last few years (since the late 1980s to the early 1990s), there is some stabilization of the contaminated major Siberian water courses in question. Unfortunately, this stabilization is reached at a high level of contamination: for example, on the three rivers mean annual concentrations of petroleum products, phenols and copper are 2-5 ACL (admissible concentration limit).

The calculations made at the State Hydrological Institute show that a relative duration of the runoff period for river waters contaminated with phenols, petroleum products, and copper ions recorded at a number of sites of river systems in question amounts to 60-90%. This indicates that contamination is distributed over the greater part of annual volumes of river runoff.

Because of the large length of major water systems of Siberia, contamination levels at individual river sites

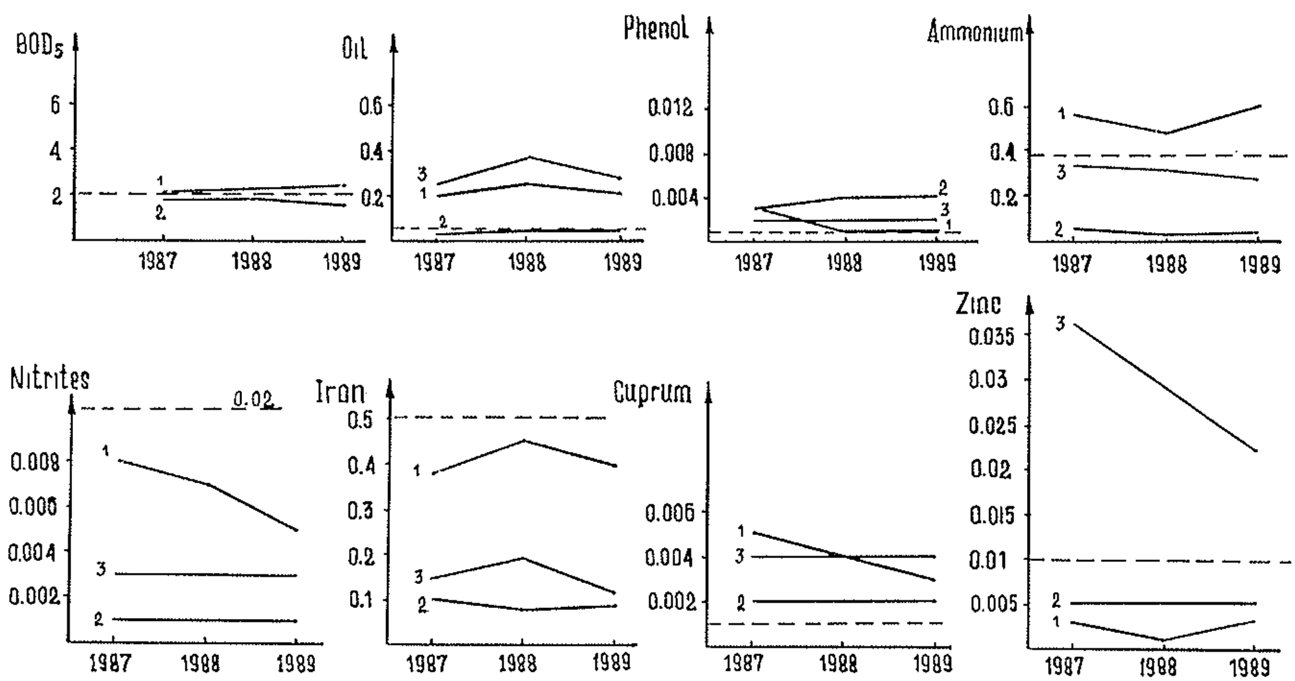

Figure 3. Modern contamination level of stream waters of major Siberian rivers (mg/l); 1– Ob, 2–Lena, 3– Yenisey.

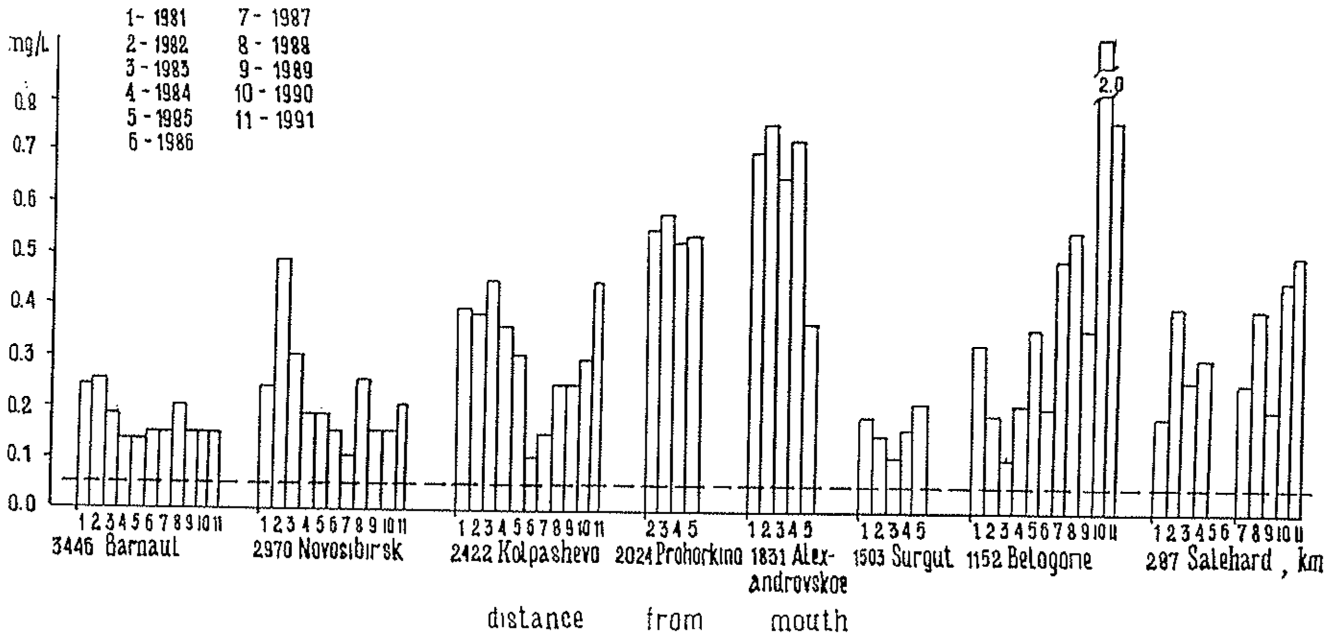

Figure 4. Changes in mean annual oil-product concentrations over the length of the Ob River for years 1981-1991.

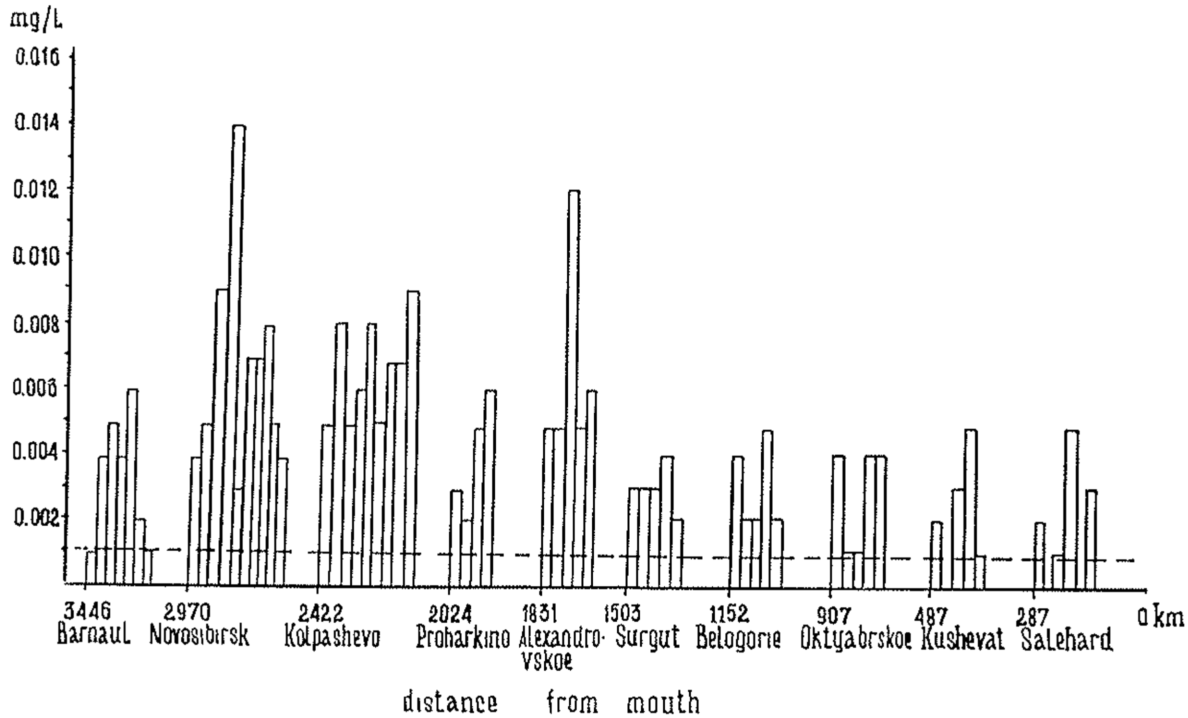

Figure 5. Changes in mean annual phenol concentrations over the length of the Ob River for year 1981-1990.

are far from being equal. Changes in the mean annual concentrations of petroleum products and phenols over the length of Ob for the last decades are shown in Figures 4 and 5. Differences in concentrations are quite stable over the entire long-term period in question. Extremely high levels for oil pollution of Ob (above 10 ACL, Figure 4) are characteristic of the middle and the lower reaches of the river (Alexandrovskoye, Belogorjye), which is, primarily, due to intense oil production. In the mouth zone (Salekhard), due to self-purification and dilution processes, the level of oil contamination is being considerably lowered. Maximum phenol contamination (up to 12-14 ACL) is observed near Novosibirsk where chemical enterprises are located. Down stream of the river, the content of phenol is lowering by 2 or 3 times (Figure 5). Comparison of annual contamination

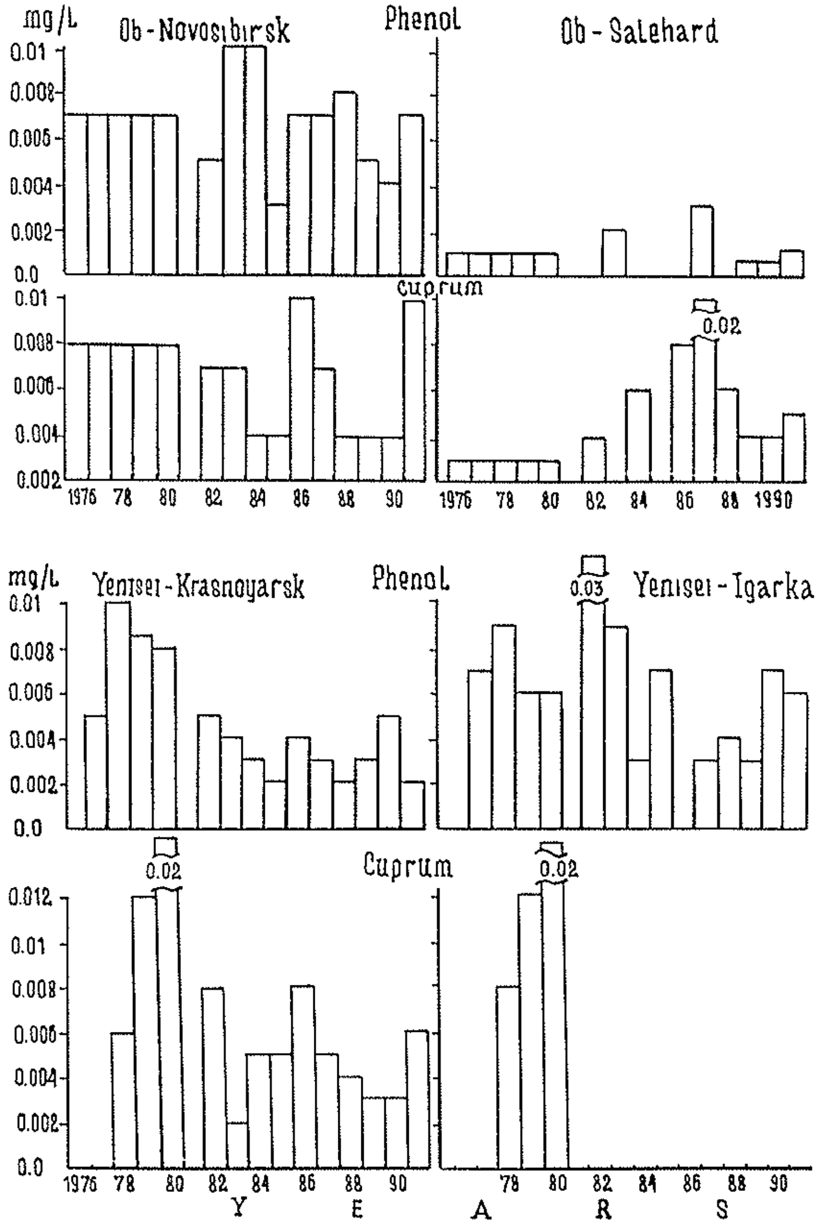

Figure 6. Dynamics of the Ob and Yenisey Rivers contamination for years 1976-1991.

values for phenol and copper over 1978-1991 for Ob and Yenisey at the upper and lower sites shows considerable differences in changing concentrations at the length of indicated rivers (Figure 6). For the Ob River, phenol and copper concentrations drastically decrease from the upper reaches to the mouth. In the channel of Yenisey this does not take place: the concentrations in the lower reaches even somewhat increase. This seems to be due to industrial sewage discharge into the river below Krasnoyarsk.

Successive lowering of the phenol and copper contamination extent of Yenisey near Krasnoyarsk can be considered as the response of water system to the environment protection measures taken in this region. Nevertheless, at almost all observational stations on the Ob and Yenisey, the contamination of oil products, phenols and copper are significant and several times above ACL values.

Contamination of other large Siberian rivers (Lena and Kolyma) are shown in Figures 7 and 8. Contamination levels on these rivers are noticeably less; however, they are still above ACL. As for Lena, there is some decrease in oil product concentration and increase in copper from the upper and middle reaches to the mouth sites. A considerable year-to-year variation of Lena contamination with oil products is seemingly due to the

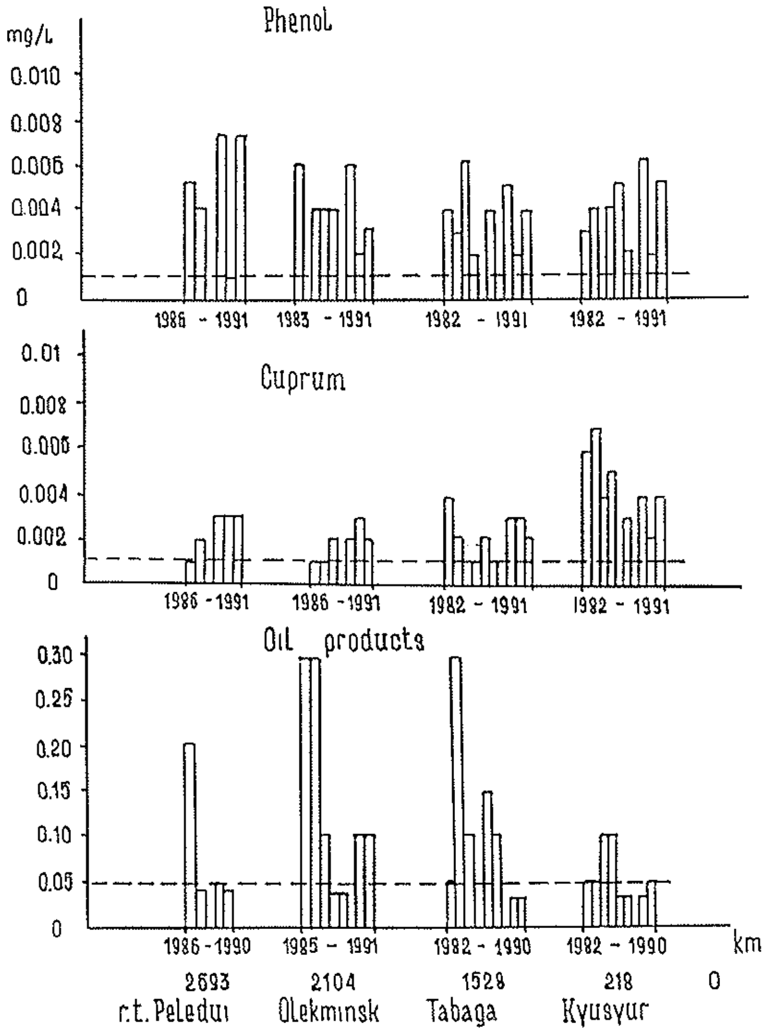

Figure 7. Changes in mean annual phenols, oil products, and copper compounds over the length of the Lena River for the years 1982-1991.

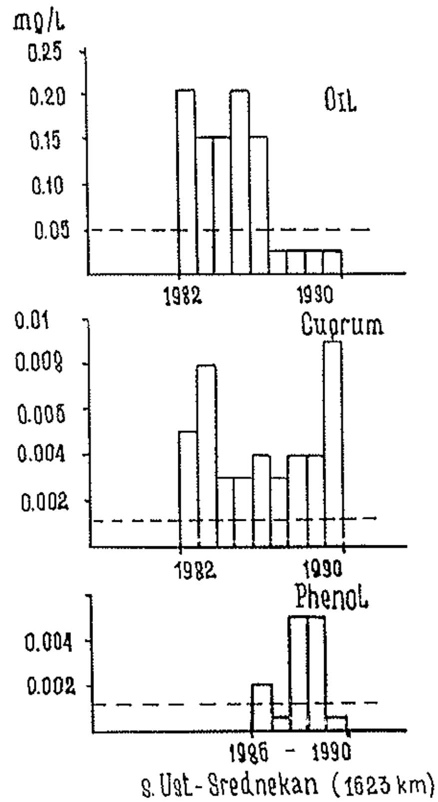

Figure 8. Dynamics of Kolyma River contaminants by the phenols, oil products, and copper compounds during the period 1982-1990.

emergency discharges from the water transport being the only cargo transport means in this basin.

To assess the modern income of contaminants to the Arctic zone, it is necessary to know their concentrations at the lower sites of Siberian rivers. These data for some contaminants are averaged over 1987-1990 and presented in Table 6. As a whole they characterize a rather significant contamination of Siberian rivers in their lower reaches, where concentrations of contaminants are appreciably above ACL values and as for oil products they reach 7-8 ACL for Ob and Yenisey.

Removal of Dissolved Contaminants with River Runoff

The assessment of the removal dynamics for dissolved contaminants inflowing to the Arctic zone over a long-term period is based on the studies made at the Hydrochemical Institute of Roshydromet (Rostov-on-Don, Russia) over 1976-1980 as well as on the approximate results obtained at the State Hydrological Institute over 1987-1991. It should be mentioned that the 1975-80 period can be indicative of the mean annual removal of contaminants to the Arctic zone over the last 15-20 years. Intensifying man's activities in the basins over the subsequent years has been compensated for by more drastic measures taken to protect the natural environment. The runoff of dissolved contaminants from Siberian rivers is calculated for separate groups: inorganic contaminants include a group of major ions (ion runoff), of microelements, and of biogenic substances. Data on organic substances were determined individually. The ionic and microelement runoffs were

Table 6. Concentrations of some contaminants in the lower reaches of large Siberian rivers averaged over 1987-90, mg/l.

River	*Organic contam. by BODs*	*Nitrogen ammonium*	*Oil products*	*Phenols*	*Microelements* Cu	Fe
Ob	2.10	0.88	0.35	0.002	0.003	0.8
Yenisey	1.70	0.43	0.40	0.003	0.005	0.38
Lena	1.32	0.04	0.05	0.004	0.003	0.21
Yana	—	0.03	0.07	0.004	0.003	0.32
Indigirka	1.70	0.60	0.06	0.04	0.004	1.00
Kolyma	2.66	0.68	0.025	0.003	0.005	0.6

calculated by direct method. Calculations are made for each year, concentrations of components being weighted by water runoff in high- and low-water periods. The calculation errors are no more than 20-30%. Calculations of organic and biogenic contaminant removal are made for each year by mean concentrations and annual river runoff values. Then they are averaged over a long-term period. Data on organic contaminants are obtained by multiplying the values of chemical oxygen demand (COD) by coefficient 0.75. Calculation error for organic contaminant runoff is roughly estimated at 20-50%, for biogenic elements at 30-60%.

The results of estimating the runoff of dissolved contaminants to the Arctic zone summarized for major rivers are cited in Table 7. For all groups of contaminants the largest removal occurs on the three major rivers: Ob, Yenisey and Lena because of their high water availability.

The hydrochemical runoff of specific contaminants and its interannual dynamics for Siberian rivers can be presently estimated very approximately because of lack of full-scale data.

The annual removal of easily oxidizing organic contaminants, as for BOD, varies over recent years within 10^3 t/y: 1390 for Yenisey-Igarka, 1180 for Ob-Salekhard and 995 for Lena-Kyusyur, which amounts to 10-30% of the total removal of organic substances calculated by the values of river water oxidation susceptibility. The oil product removal over 1987-88 makes up 10^3 t/y: 162 for Ob-Salekhard, 232 for Yenisey-Igarka and 60 for Lena-Kyusyur. As compared with the previous period of 1981-85, the runoff of oil products would increase by 30% for Ob, by 50% for Lena and 35% for Yenisey.

The largest removal of such man-made contaminants as phenols falls on Yenisey: 2.15×10^3 t/y. The removal of phenols from the Ob River catchment is 0.81×10^3 t and from the Lena River catchment 1.43×10^3 t. Comparison with the previous period indicates a decreased removal of phenols over recent years by 30% for Ob and by about 50% for Yenisey. However, because of large variability of observed concentration values, these data can be considered as very approximate. To obtain more reliable data on the dynamics of removal, it is necessary to conduct a comprehensive scientific research.

On the Possible Prospects of Future Studies

The available standard network observations of water, sediment and contaminant runoff are insufficient to obtain a reliable and detailed estimation of the income of all kinds of contaminants to the Arctic Ocean: rare observational network and lack of samples to be analyzed do not allow for studying chemicals accumu-

Table 7. Mean annual removal of dissolved contaminants by major rivers of Siberia to the Arctic zone over 1976-80.

River - station	*Sum of ions, 10^3, tons*	*Organic contam. 10^3, tons*	*Nitrates 10^3, tons*	*Phosphates 10^3, tons*	*Silicium 10^3, tons*	*Sum of microelements, 10^3, t*	*Cuprum incl., 10^3, tons*
Ob -Salekhard	49,800	3680	25.4	18	1860	78.89	5.5
Yenisey-Igarka	41,300	8420	5.62	5.88	1600	89.19	3.0
Khatanga-Khatanga	8,490	—	—	—	—	12.47	0.3
Anabar-Saskylakh	513	—	—	—	—	0.973	0.08
Olenek-Taimylyr	14,300	—	—	—	—	8.09	0.17
Lena-Kyusyur	47,800	7,840	225	3.57	1030	80.65	1.5
Yana-Dzhangky	1770	535	1.52	0.254	54.6	3.9	0.29
Indigirka-Vorontsovo	3730	628	1.91	0.559	104	7.07	0.25
Kolyma-Srednekolymsk	2970	774	4.96	0.782	143	8.1	0.34

Note: Sum of microelements = B, F, I, Cu, Zn, V, Mn, Ni, Mo.

lation and transformation in the river systems, in particular, below closing sites in mouths and estuaries; there are almost no systematic observations of radionuclides, their transport and accumulation on catchments and in streams under the influence of various natural and anthropogenic factors.

To minutely study the removal of contaminants with river water and sediment runoff to the Arctic Ocean, the State Hydrological Institute and the US Geological Survey have prepared preliminary proposals on organizing during 3-5 years complex research on studying the processes of accumulation and transformation of natural and man-made chemical substances and radionuclides in river system and on the catchments of Siberian rivers.

Goals and Aims of Research

Allowance is made for solving the following problems:

- Revealing the natural mechanisms governing the income to the river systems of contaminants and radionuclides from the surface of catchments and their transfer by streams up to closing sites;
- Reliable estimation of the modern river removal of contaminants and radionuclides to the Arctic Ocean;
- Developing proposals on organizing the monitoring over changing contaminants and radionuclides removal to the Arctic Ocean.

Subjects of Inquiry

The two Siberian rivers Ob and Yenisey have been chosen as top priority subjects. This choice can be explained by several reasons.

First, these are the largest rivers in Siberia collecting water from the vast catchments embracing several geographical zones; high water availability of rivers and active processes of transport and dilution of contaminants create good conditions for their studying.

Second, the basins of these rivers are subjected to most intense anthropogenic loading; large amounts of various chemicals income to the rivers whose migration routes are studied but insufficiently.

Third, in the river basins, the stations of standard observations of water regime characteristics, sediment runoff, chemical composition of surface water are being operated for many years; although the network density is insufficient, it is still denser than in other basins of Siberian rivers.

It can be added that in the basins of contaminated rivers in different years the studies were conducted that touched individual aspects of the problem in question.

In spite of the above similar features, Ob and Yenisey differ in the natural conditions of the basins and kinds of anthropogenic load. As a whole, these two rivers are indicative as for Siberian conditions of water and sediment runoff formation as well as of the removal of contaminants to Arctic Ocean.

The Processes in Question and the Technique

To solve the problems raised, allowance is made for studying the following basic processes determining the removal of contaminants and radionuclides:

- Water and sediment runoff in river channels and flood-plains;
- Transformation of basic contaminants along the length of river;
- Changes in concentrations of radionuclides in river systems;
- Accumulation and desorption of radionuclides on flood-plain swampy territories and their income to streams;
- Migration of contaminants and radionuclides associated with river sediments in the bottom-stream system, taking into account the variability of channel forms;
- Accumulation and transformation of sediments, contaminants and radionuclides in mouths and estuaries;
- Transport of contaminants and radionuclides with bottom ice.

To study the above processes, it is supposed to use all the modern research methods applicable in hydrology: analysis of the available observational data and the results of scientific studies, the methods for analyzing spatial and time variations of regime characteristics, the methods for mathematical and physical modeling and the methods for modern laboratory analysis. It is planned to carry out a wide complex of field studies on experimental plots and selected river sites as well as at steady observational stations.

Major Kinds and Stages of Work

In accordance with goals, tasks and accepted methodology the following kinds and stages of work are chosen:

1. Developing a detailed program and the methods for observations, mathematical and physical modeling of processes in question, scientific analysis and summarization;
2. Creating the historical and current data base;
3. Carrying out detailed observations at the stations of standard network;
4. Organizing and conducting expedition ship observations at the sites of Ob and Yenisey;
5. Organizing and carrying out studies on experimental plots;
6. Carrying out laboratory analyses and experimental work.

Expeditionary ship observations are carried out with the aim of studying the processes on the length of the rivers in question; the total extent of routes on each river is up to 1000 km. Observations are conducted in the periods of floods and summer-autumn low-flow.

Experimental plots of four kinds are to be organized to solve various scientific problems.

A swamp plot is to be located on the flood-plain of Ob to determine the chemical composition of boggy water, radionuclide concentration in the swamp thickness and to reveal the routes of their migration.

An erosion plot is to be located in the basin of small tributary of Ob or Yenisey in the zone of active erosion to determine the mechanism of washing out soil and grounds and estimate the removal of contaminants and radionuclides.

Channel plots are organized in the lower reaches of rivers (three on each river) to study the processes of radionuclide migration with suspended and bottom sediments taking into account the type of channel process.

Mouth plots are established to study the dynamics of transport of natural and man-made contaminants under the conditions of interaction with sea waters.

Basic Executers and the Dates of Work Fulfillment

Work is planned to be fulfilled during 3-5 years. The following basic researchers are supposed to be invited from Russia: the State Hydrological Institute, the Water Problem Institute, the Arctic and Antarctic Research Institute, the Hydrochemical Institute and administrative territorial boards of Roshydromet. In addition, it is planned to invite other specialized institutes and laboratories, in particular those that are experienced in the field and laboratory studies of radionuclides. It should be mentioned that experienced American specialists, in particular, of the US Geological Survey, are expected to take an active part in the studies at all stages.

Implementation of the above proposals will allow for obtaining a reliable estimate of removal of various contaminants to the Arctic Ocean and developing a complex of measures for the natural environment protection in the Arctic.