

POTENTIAL HYDROLOGICAL RESTRICTIONS ON WATER USE IN THE BASINS OF RIVERS FLOWING INTO RUSSIAN ARCTIC SEAS

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ABSTRACT. Water consumption has been evaluated for the basins of the rivers flowing into the Arctic seas of the Russian Federation and, separately, for the Arctic zone of Russia (AZR). Long-term dynamics of the major characteristics of water consumption are given for the period from the 1980s to 2017 along with data on its structure. The possible effect of the total water withdrawal and consumptive water use on river water inflow into the Arctic seas has been evaluated for the 1980s (a period of maximal anthropogenic load), for 2006–2017 and up to 2030. The volumes of water consumption in limits of AZR are relatively low. Moreover, the water withdrawal has dropped considerably compared with the situation in the 1980s, in particular, by about 30% in the Pechora, Lena river basins, and from the rivers of Murmansk oblast, and by 50% in the Northern Dvina, Yenisei, and Kolyma river basins. It has increased in the Nenets and Yamalo-Nenets AO because of the intense development of the local oil-and-gas complex. Nowadays, according to the authors' estimates, 21.28 km³/year is being withdrawn in the drainage basins of RF Arctic seas and 2.58 km³/year, within the AZR, or 28.8 and 3.5% of the total volume in Russia. The largest contribution to this value is due to the water-management complexes in the basins of the Ob (14.7 km³/year), Yenisei (2.77), Northern Dvina (0.64), and Murmansk oblast (1.72 km³/year). The volumes of water discharges back into water bodies at the drainage basins of Russian Arctic seas are comparable with the volumes of freshwater withdrawal -71% of water intake. Even lesser is the difference within AZR. The major water users are the industry (with a high proportion of mining plants), thermal power engineering, and municipal economy. But considerable and diverse hydrological restrictions exist at the municipal level and for some water users in AZR. These local hydrological restrictions have been formulated and analyzed in detail, for the first time. They form three large groups. Original maps are given to illustrate the specific features and regularities in the present-day distribution of water-management characteristics over AZR.

KEY WORDS: Russian Arctic Region, water consumption, wastewaters, water-management system, rivers, hydrological restrictions on water use

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INTRODUCTION

In the present-day world, northern regions and the Arctic are growing in significance because of, first, their role in the formation of global climate and the maintenance of biospheric stability, second, the presence of huge hydrocarbon resources; and, third, the strategic and transport significance of the region, which has a colossal space resource. The exploitation rate of Arctic resources has been growing in the recent decades, accompanied by heavier anthropogenic load onto the Arctic ecosystems. At the same time, the Arctic regions are especially vulnerable to anthropogenic impact because of their extreme natural and climate conditions, the fragility of their ecosystems, the separation from large economic and political centers of the

country, the poor development of transport thoroughfares and infrastructure as a whole, the higher sensitivity of the population to changes in the environment, and the lesser adaptation capacity of the organisms.

The availability of water resources in polar regions has been high enough not to cause troubles regarding their quality. However, the intense development of rich mineral deposits in the Extreme North and the transboundary pollution transport cause rapid disturbance of the fragile environmental equilibrium in many urbanized regions of the Arctic, thus leading to a qualitative depletion of water resources. The further development of the Arctic is also associated with its protection from hazardous natural phenomena, including hydrological. The recent decades have been showing an increasingly extreme character

of changes in the characteristic of water discharges and levels, channel processes, ice phenomena, and water quality. This is largely due to a series of climate changes: a rise of the annual and seasonal air temperature and changes in precipitation depth and the volume and the annual distribution of river runoff.

The requirements to ensure the hydroecological safety of water use in various areas, including the Arctic (Aleksievskii et al. 2011; Khristoforov 2010) are reflected in a system of restrictions on the admissible changes in parameters of the state of water bodies and the economic activity within a period under consideration. The hydrological restrictions take into account the natural specifics of changes in river runoff components and specify the values of hydrological characteristics at which the safe water use is ensured with an admissible level of the risk of hazardous hydrological phenomena. The type and the magnitude of restrictions depend on the type of economic activity in river basins and channels (Frolova 2006).

The hydrological restrictions are of quantitative nature and probabilistic character. The meeting of the hydrological restrictions ensures the safety of the population and water bodies and enables the economically efficient water use (Aleksievskii et al. 2011). Some hydrological restrictions depend only on the natural conditions, changes in which can be forecasted with a degree of reliability for preventing possible adverse effects. Other restrictions are associated with economic activity, and they are introduced in accordance with water user demands.

The determination of hydrological restrictions on water use is hampered by the complexity of the operation of water management systems, the diversity of the approaches to planning and implementing nature-protection measures in the basins of water bodies, and the contradictions in the interests of different sectors of water economy.

The introduction of hydrological restrictions ensures the hydroecological safety of the population, economy, as well as aquatic and nearshore ecosystems. This process is based on the social need, natural admissibility, environmental safety, as well as the technical and juridical provision of water use in the developed segments of river valleys. The regulations determine the activity of water users with respect to water bodies, implying the establishing of a method of their use at which the parameters and the major properties of a hazardous hydrological phenomena are determined and limited as is admissible for the implementation of the water management activity within the boundaries of a water body or its drainage basin

(Aleksievskii et al. 2011). The main types of restrictions that determine the hydroecological safety of water use (HSWU) are given in Fig. 1.

The objective of the study is to evaluate the water use and its long-term changes in the basins of all rivers that flow into RF Arctic seas, including only within the Arctic zone of Russia (AZR) (Fig. 3), and the effect of water use on the water runoff of Arctic rivers and river water inflow, and general effect of hydrological restrictions on water use.

The aim of this work is to quantify water consumption and its long-term dynamics in the basins of all rivers that flow into the Arctic seas of the Russian Federation, including only within the territory of the Arctic zone of Russia (AZR).

MATERIALS AND METHODS

The main source of data on the volumes of the use of surface water and groundwater in RF was the data of the Federal Agency of Water Resources and the Federal Service of State Statistics (State Water Cadastre 1981–2018; Water in Russia 1991–2002; Russian Water Resources and Water Economy 2006–2018). These reference books give the volumes of withdrawn, consumed, and discharged water for constituent entities of the RF and for drainage basins of large rivers and seas, as well as evaporation losses from reservoirs and losses for their filling, and anthropogenic changes in runoff.

The Arctic rivers for which such data are available are the Pechenga, Onega, Northern Dvina, Mezen, Pechora, Ob, Yenisei, Pyasina, Lena, Indigirka, and Kolyma. Long-term series of appropriate water-management characteristics have been obtained for major Arctic rivers over period 1981–2017, for individual RF constituent entities, including Murmansk (since 1996) and Arkhangel'sk (since 2003) oblasts, Yamalo-Nenets (since 2004) and Chukotskii (since 2004) autonomous districts, and for RF as a whole.

In addition, this study uses the materials of «The Schemes of Integrated Use and Protection of Water Bodies» (SIUPWB). They are available on open access, in particular, on the sites of the Amur, Yenisei, Lower-Ob, and Dvina–Pechora Basin Water Management Departments (Amurbvu.ru, Enbvru.ru, Nobwu.ru, Dpbvu.ru). They give much wider list of rivers with data on water intakes and discharges (commonly, for 1–2 years), data on specific water users, and forecasts of changes in the volumes of water consumption by the middle and late 2020s.

Finally, an important sources of data were the open documents of municipal formations, primarily, «Schemes

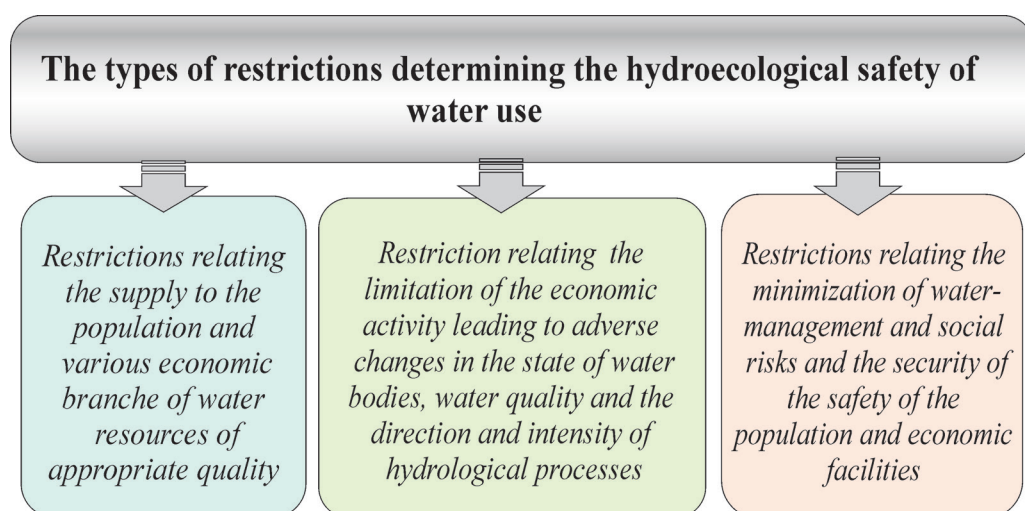


Fig. 1. Diagram of types of restrictions determining the hydroecological safety of water use

of Water Supply and Disposal and Heat Supply,» «The Program of Integrated Development of Community Facilities Infrastructure» in populated localities, as well as annual reports of plants. These documents allowed the authors for the first time to compile an «Electronic Catalogue of Water Users in the Arctic Zone of Russia» (ECWU AZR), though, by now, only for the members of the water-management complex in the territories of the Chukotka Autonomous Okrug, Arctic districts (uluses) in the Republic of Sakha (Yakutiya), and Krasnoyarsk Krai, with various water management data over the past 5–10 years. The number of such members was 229: 70.7% were the enterprises of housing and public utilities (HPU), i.e., in essence, populated localities; 18.8% were mining enterprises; 6.6% were thermal-engineering facilities; and 3.9% were all others. In addition, ECWU AZR contains data on the permanent or occasional problems in water use. The comparison of data from official reference books and those underlying the ECWU AZR showed them to be consistent.

Additionally, materials of other experts and research groups were used in the study and the analysis of its results.

First of all, these are the studies (Zaitseva and Koronkevich 2003; Chernyaev 2000; Shiklomanov 2008; Demin 2011; Ratkovich 2003). The comparison of the characteristics of total water consumption in the drainage basins of Arctic rivers in RF and the values of flow at their mouths was made with the use of data on its magnitude (at the outlet and mouth sections), collected by the authors in earlier studies, processed, and partially published in (Alekseevskii 2007, 2013; Magritsky et al. 2013, 2018; Agafonova et al. 2017).

As a result, it was possible for the first time to reliably assess the values of the present-day withdrawal of surface water and groundwater, as well as wastewater discharge for the basins of the major rivers and the inter-basin areas of the Arctic Zone of Russia; make the thematic maps and diagrams; study the economic sector and hydrographic structure, the spatio-temporal variations of water consumption characteristics; compare data from various sources; improve the results published in (Alekseevskii 2013; Magritsky 2008); and identify major hydrological restrictions of Arctic water use and their correlation with

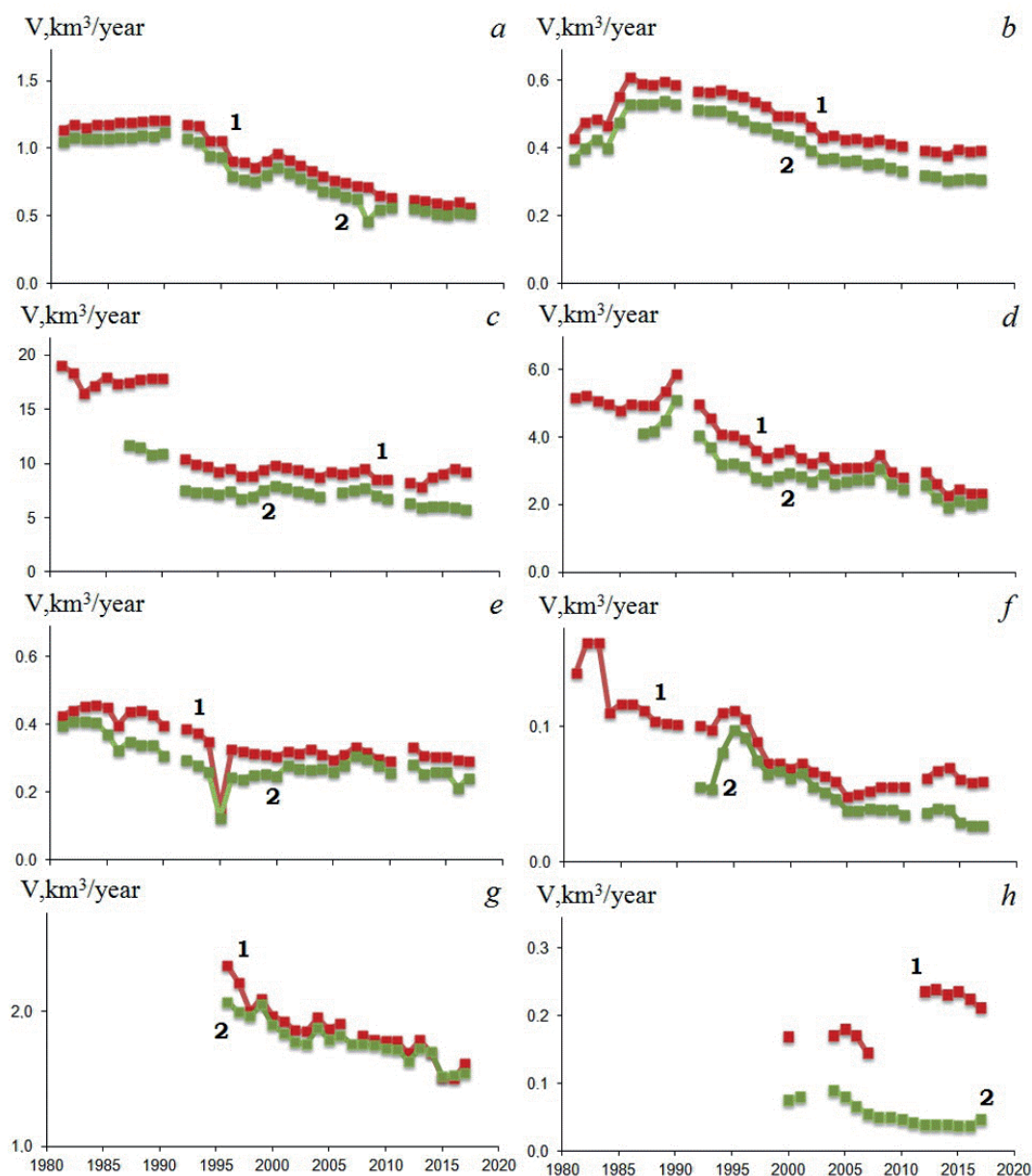


Fig. 2. Charts of long-term variations in the volumes of (1) surface water and groundwater withdrawal and (2) wastewater discharge in the basins of (a) the Northern Dvina, (b) Pechora, (c) Ob, (d) Yenisei, (e) Lena, and (f) Kolyma in the territory of Murmansk oblast (g) and Yamal-Nenets Autonomous Okrug (h). The data for the Ob basin after 1991 are given only for RF territory. The source of primary data is (State Water Cadastre 1981–2018; Russian Water Resources and Water Economy 2006–2018; mpr.gov-murman.ru)

the natural conditions of the territory and the character of nature development.

The collected data were processed with the use of standard software packages Statistica and Excel; the space analysis of hydrological and water management characteristics was made with the use of ArcGIS 10.2.

RESULTS AND DISCUSSION

The availability of a required volume of water resources of appropriate quality in a certain area is a major limiting factor of natural resource and water use. However, the river runoff volumes alone cannot provide adequate knowledge about the sufficiency or deficiency of water resources. To determine whether there is a deficiency in water resources, one has to incorporate data on the use of water resources in different economic sectors.

Water consumption in the basins of Arctic rivers in the 1980s

Water consumption and the disposal (discharge) of wastewater in the basins of RF Arctic rivers has reached its peaks in the second half 1970s and in the 1980s (Fig. 2) – about 28.9 km³/year and 20.7 km³/year, respectively. 15.8% of freshwater was taken on the watersheds of the White and Barents seas, 82% – within the drainage basin of the Kara Sea. For comparison, the total water consumption in Russia from 1981 to 1990 was equal ~111 km³/year (117 km³/year with seawater included) and wastewater volumes were ~75.6 km³/year.

The increase was due to the growing demand of the production complex in the period of extensive development of the country's economy, an increase in the population, and the connection of many populated localities to centralized water and heat supply. Nevertheless, water intake in the basins of many Arctic rivers was relatively small or practically absent. Even in the basins of the best economically developed rivers the volume of water withdrawal in 1981–1990 was 1.26 km³/year (the Northern Dvina), 17.85 km³/year (the Ob: 67% of this volume in Russia and 33% in Kazakhstan) and 5.36 km³/year (the Yenisei), or 1.2. 4.3. and 0.8% of their long-term annual water runoff into seas considering data from (Magritsky et al. 2018). In Murmansk oblast, which is the most industrially developed entity in AZR, ~2.5 km³/year (or 3.6% of annual water runoff) were withdrawn. These volumes are comparable with errors in the calculation of the average annual flow; therefore, we can say that there is no statistically significant anthropogenic effect on river water resources. This area also has not suffered the so-called water stress in the 1980s, which, according to the World Water Assessment Program (UNESCO WWAP), starts to manifest itself at the ratio of water withdrawal to water resources equal to 10% (<http://www.unesco.org/new/en/natural-sciences/environment/water/wwap>).

The largest amounts of freshwater were withdrawn from rivers: from 73–79% in the basins of the Pechora, Lena, and Kolyma to 85–90% in the basins of other rivers under consideration. The remaining part included groundwater (up to 10–20%), lake water, and even seawater (at the mouths of some rivers). The main water consumers in the 1980s were the industry and heat power engineering, as well as municipal services. In the basins of the Ob and Yenisei, these accounted for 80–90% of the withdrawn water, and, in the northern European Russia and Siberia, they reached almost 100% (Alekseevskii 2013). The irrigation and water supply to agricultural enterprises is among the water consumers in the steppe and forest-steppe areas in the Ob, Yenisei, and Lena basins.

Unlike the rivers of the southern seas of Russia, the major portion of water withdrawn in the basins of Arctic rivers is returned into the water bodies (Fig. 2). The difference between these volumes is the irrevocable water use, which leads to a systematic decrease in river water runoff (Shiklomanov 1979). In the case of the Pechora, Northern Dvina, Yenisei, and Lena, the irrevocable water use was 0.15. 0.12. 1.0, and 0.07 km³/year, respectively, or 12, 20, 19, and 16% of the initial water intake from these rivers. At the same time, the direct anthropogenic decrease in the annual runoff (as a difference, on the one hand, the withdrawal of river and ground waters and, on the other hand, the discharge of wastewater into rivers) was lesser: ~0 km³/year for the Onega, 0.09 km³/year for the Northern Dvina, ~0 km³/year for the Mezen, 0.025 km³/year for the Pechora, 0.67 km³/year for the Yenisei, 0.043 km³/year for the Lena, and 0.03 km³/year for the Kolyma, i.e. <0.1% of the annual water resources of those rivers. For other rivers, no data are available for the 1980s and 1990s.

The consumptive water use has reached its maximum values in the 1980s in the Ob–Irtysh basin (6.4 km³/year) because of the arid conditions of water supply, the higher development of the production complex, in particular, agriculture, a larger population, and the inter-basin runoff diversion. With the losses due to evaporation from reservoirs in the Ob basin and the filling of the Shul'binskoe Reservoir in the 1980s taken into account, the consumptive losses increase to 12 km³/year (or 3.1% of the Ob annual runoff in those years). If only wastewater discharges into rivers are taken into account, the value of irrevocable water use increases to 13 km³/year (or 3.4%). At the same time, the error in the average annual runoff is 2.5%. Similar estimates (12 km³/year) are given in D.Ya. Ratkovish's study (2003). For earlier years, he has obtained: 1.6 km³/year in 1936–1940, 2.4 km³/year in 1946–1950, 7.5 km³/year in 1956–1960, 8.1 km³/year in 1966–1970, and 10.2 km³/year in 1976–1980. This is maximally possible anthropogenic impact! Because, if we take into account only additional evaporation losses from reservoirs (Vuglinskii 1991) and the decrease in runoff losses in regulated rivers due to shorter duration and lesser scale of floodplain inundation (Pryakhina 2003), the anthropogenic decrease in the Ob annual runoff would be at least 6 km³/year less. In some rivers in the southern Ob–Irtysh basin and in the Ural Economic Region, the economic management of runoff has reached maximal values at which freshwater deficiency can develop (Stoyashcheva and Rybkina 2014; Magritsky 2008; Frolova and Vorob'evskii 2011). As it has been showed by the authors, in a year with median water abundance (50% exceedance probability) and under current conditions, there is no deficiency of water resources (Frolova and Vorob'evskii 2011). In low-water years (95% reliability), the natural deficiency of water resources can be seen in the basins of the Upper and Middle Irtysh, Iset, and Tura. Because of the steady increase in water intake in Kazakhstan territory (from 3.5 to 4.0 km³ per year) and the high rate of increase in the consumptive water use in China (from 1 to 4 km³/year), the deficiency of natural water resources in the Russian part of the Irtysh basin during low-water period can be more than 5 km³.

The anthropogenic decrease in the Yenisei runoff, taking into account the filling of the numerous and huge reservoirs and the total evaporation from their surface, was 5.55 km³/year. According to Ratkovich D. (Ratkovich 2003), in 1936–1940, 1946–1950, 1956–1960, 1966–1970, and 1976–1980, it amounted to 0.2, 0.3, 0.8, 7.6, and 19.4 km³/year.

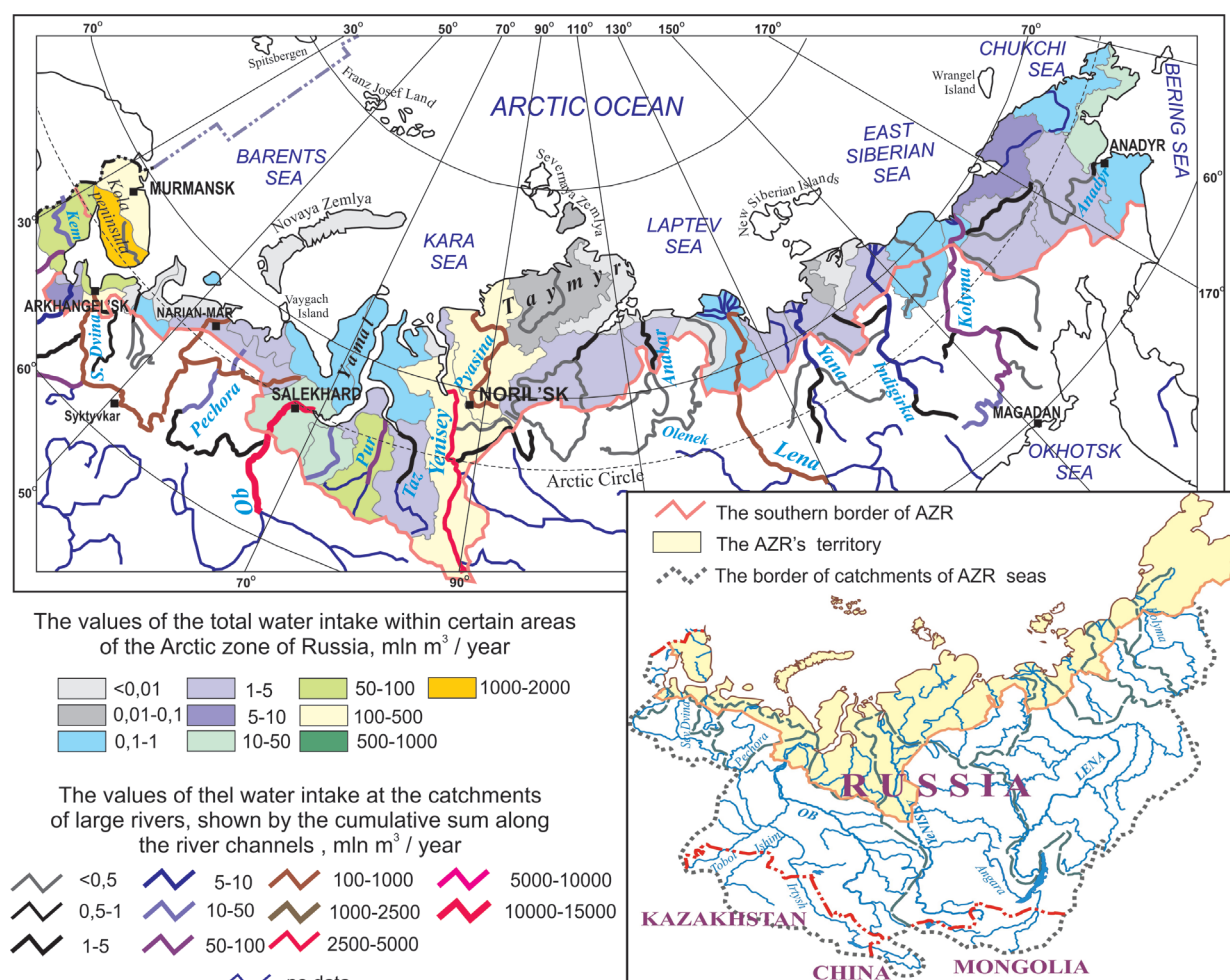


Fig. 3. Map of the present-day (2006–2017) anthropogenic withdrawal of natural waters in the basins of large Arctic rivers and in separate parts of the continental and insular Russian Arctic Zone. The left map shows the boundaries of the Arctic zone and basins of the Arctic seas of Russia

The present-day water consumption in Arctic river basins and its economic sector and territorial features

The period of maximal anthropogenic impact on river water resources was followed by years of economic crisis and a considerable decrease in water use volumes. By 2006–2017 (i.e., by the present-day stage with relatively stable water use characteristics), the total decrease in water intake volume was about 30% in the Pechora, Lena basins and for rivers of Murmansk oblast, and 50% in the Northern Dvina, Yenisei, and Kolyma basins. A part of decrease in water consumption volume is due to the passage to water-saving technologies. A vivid example is the Norilsk Integrated Plant.

Currently, water intake is maximal in Murmansk oblast (1.72 km³/year), in the Northern Dvina River basin (0.64 km³/year); and, obviously, in the Ob River basin (about 14.7 km³/year: ~8.9 km³/year in RF territory, ~2.8 km³/year in Kazakhstan (National Atlas of the Republic of Kazakhstan 2010), and ~3.0 km³/year in China (Kozlov 2018); and the Yenisei River basin (2.77 km³/year) (Table 1). Water intake has increased in the Nenets and Yamalo-Nenets Autonomous Okrugs because of the intense development of the oil and gas complex (Fig. 2). However, many territories and rivers in AZR still remain beyond the water management activity (Fig. 3). Water withdrawal volume in the basins of RF Arctic seas is 21.28 km³/year (Table 2), while only within the AZR is 2.58 km³/year. In Russia in these years, the average water intake volume was 68.3 km³/year (with seawater taken into account, it is about 74). The authors' estimates of water consumption in RF Arctic sea basins given in the first part of Table 2 are in a good agreement with data from (Russian

Water Resources and Water Economy 2006–2018) for the Barents, Laptev, and East-Siberian seas; and they are 2.2 and 1.5 times greater than the characteristics for the White Sea and Kara Sea, respectively. The latter can be explained by the fact that water consumption in the territories of Kazakhstan and China is not taken into account in (Russian Water Resources and Water Economy 2006–2018).

According to SIUPWB estimates, the characteristics given above can increase in RF by a factor of 1.5 within 10–15 years, that is, approximately by 2030. This will not cause adverse changes in water runoff of Arctic rivers, because even now it is compensated for by its climatic increase. For example, in 1976–2015, the annual river water inflow into the seas of the Russian Arctic is about 150 km³/year greater than it was in 1936–1975 (Magritsky et al. 2018).

As can be clearly seen (Table 1), the structure of water intake from some rivers has somewhat changed in compared with the 1980s. In the economic sector structure of water intake and water use, the leading sectors are industry, heat power engineering (TPS) and municipal economy. The water intake for production needs dominates exclusively (from 78 to 93%) in Murmansk oblast and Chukotskii AO (Fig. 4), in the basins of the Northern Dvina, Pechora, Yenisei, Lower Taimyra, Pyasina, Indigirka, and Kolyma rivers. The relative value of water intake for municipal needs is high in the areas where there are no or little development of industrial production. It is 63% in the Mezen basin and 53% in the basin of the Khatanga. It is relatively high in the basins of the Northern Dvina (18–25%), Ob (16–22%), Lena (25–27%), Yana (34%), Anadyr (41%), and generally, in the Arctic part of the Republic of

Table 1. Data on the volumes and structure of water use at key areas of the basins of Russian Arctic Seas in 2006–2017 according to data from (State Water Cadastre 1981–2018; Water in Russia 1991–2002; Russian Water Resources and Water Economy 2006–2018) and Reports on the State and Protection of the Environment for constituent entity of the Russian Federation

Territory	Taken from water bodies, km ³ /year		Discharged wastewater, km ³ /year		The structure of wastewater by the degree of their meeting background quality characteristics ¹ . %		
	total	including river water	total	Including those into river network	clean to meet the standards	cleaned to meet the standards	polluted
Murmansk oblast	1.715	1.526	1.681	1.681	78	1	21
Northern Dvina basin	0.641	0.596	0.549	0.545	17	3	80
Pechora basin	0.405	0.311	0.331	0.320	71	15	14
Ob basin (within RF territory)	8.900	-	6.615	6.396	53	10	37
Yenisei basin	2.765	2.212	2.398	2.350	57	5	38
Pyasina basin ¹	0.280	-	0.160	-	53	2	45
Lena basin	0.309	0.158	0.268	0.222	52	13	35
Indigirka basin ¹	0.008	-	0.004	-	23	3	74
Kolyma basin	0.059	0.053	0.036	0.034	60	20	20
the Chukotka AO	0.026	-	0.020	-	77	1	22

Note. 1 — over period 2009, 2012–2017

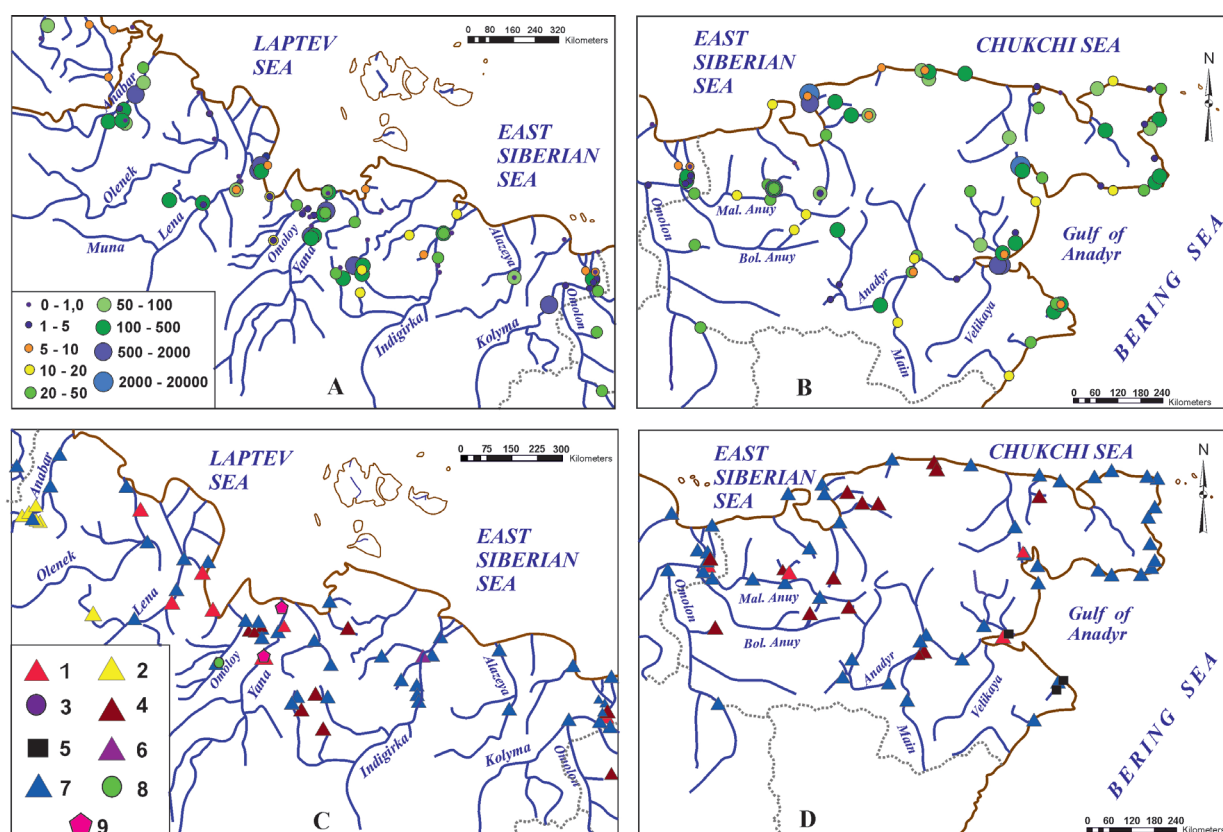


Fig. 4. The volumes of water consumption (thous. m³/year) in Arctic districts of the Republic of Sakha (Yakutia) (A) and in Chukotka Autonomous Okrug (B), and the types and distributions of the major water users (C, D): (1) heat power engineering, (2) diamond mining, (3) metallurgical plants, (4) mining, (5) coal mining, (6) petroleum tank farm, (7) municipal economy, agricultural plant, (8) transport enterprise

Sakha (Fig. 4). In the basins of the Ob, Yenisei, and Lena, a few percent are due to water intake for irrigation: 1, 2, and 7%. The data on the structure of sectoral water intake in the Pur and Taz rivers cause some questions.

The volumes of the present-day wastewater disposal into water bodies, in particular, into rivers (commonly >90%) are comparable with the volumes of their withdrawal 15.19 km³/year, or 71% of the total water intake volume. The difference between water intake and disposal

Table 2. Present-day water intake and discharge volumes in the basins of RF Arctic seas and in RF Arctic zone (AZR)

Sea	Water consumptions in sea basins			Water consumptions in the AZR		
	water withdrawal		discharges, km ³ /year	water withdrawal		discharges, km ³ /year
	total, km ³ /year	including in the basins of large rivers, %		total, km ³ /year	including in the basins of large rivers, %	
Barents	0.54	75.0	0.43	0.161	2.0	0.100
White	2.43	26.8	2.31	1.921	10.9	1.844
Kara	17.9	99.9	12.1	0.457	98.3	0.236
Laptev	0.32	99.1	0.28	0.010	78.2	0.009
East-Siberian	0.07	91.8	0.05	0.012	44.4	0.011
Chukchee	0.001	0	~0	0.001	0	~0
Bering	0.02	2.2	0.02	0.017	2.2	0.016
Total	21.28		15.19	2.58		2.22

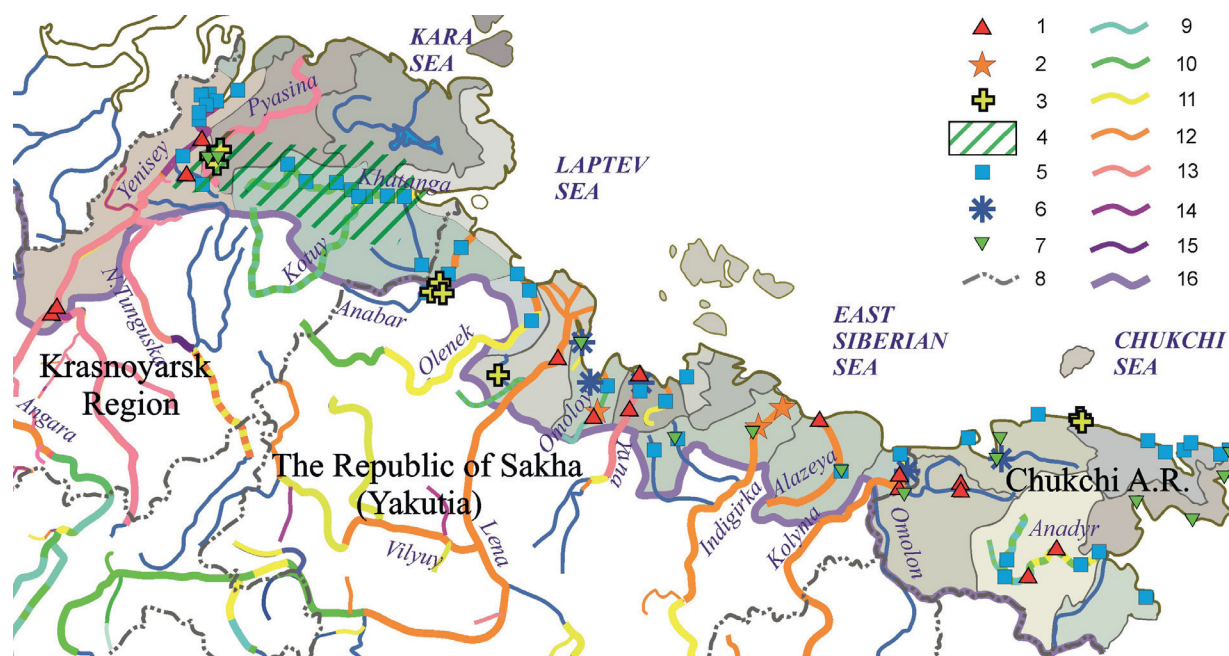


Fig. 5. The features and local features of possible hydrological restrictions in the Arctic regions of the Krasnoyarsk krai and the Republic of Sakha (Yakutia) and in the Chukotskii AO. Denotations: (1) hazard of interruption in water supply because of river flooding, (2) hazard of water supply interruption because of bank erosion and collapse, (3) restrictions because of freezing of a surface water source, (4) restrictions because of low water levels and discharges during summer-autumn dry season, (5) change of water supply sources to ice and imported water, (6) interruption of water supply because of seawater penetration into the water source, (7) other restrictions; water quality classes according to combinatorial water pollution index (KIZV): (9) relatively clean, (10) slightly polluted, (11) polluted, (12) very polluted, (13) dirty, (14) very dirty, (15) extremely dirty, (16) border of AZR

in AZR is even less (Table 2). Therefore, the non-recoverable anthropogenic losses of water runoff here are the far lowest in both the country and the world. Conversely, with the discharge in the rivers taken into account, including the previously withdrawn and used groundwater and lake water, the water use, in some cases, as it follows from Table 1, should lead to an increase in runoff.

Hydrological restrictions on water use in the Arctic

The materials of the previous section, as well as Fig. 4, Tables 1 and 2, indicate strongly that there is no general deficiency of water resources in AZR. This is the consequence, on the one hand, of the abundance of water bodies and the significant river runoff in this area and, on the other hand, the negligibly small volumes of water

intake, especially, consumptive, because of the very sparse population and the extremely low economic development of the area.

However, at the municipal level and for some water users, hydrological restrictions on water use exist (Fig. 5). The character and severity of the hydrological restrictions depend on many factors, including the type and size of the water user, its location, the type of the used natural waters, and the yield and the hydrological regime of the water source. Many factors show spatial, annual, and long-term variations.

The local hydrological restrictions in AZR can be divided into three major groups. The first group includes restrictions on the supply of freshwater to the user of a required amount. This group includes 30.5% of the water

users in the Arctic part of the Chukotskii AO, Yakutia, and Krasnoyarsk krai. The second group is related to the water quality in its source failing to meet the standards (12% does not meet, and 37% does not meet in terms of a small number of characteristics). The third group is related to inundation, damage, destruction, or silting of water intake and discharge structures, the systems of heat and water supply during ice drift, high water discharges and levels (during spring flood and rainfall freshets), as well as because of water freezing in pipes.

The limitations of the 1st type form because of the permanent, periodic, or occasional disagreement between the water abundance (reserves, yield) of a water source and the freshwater demands of a plant or a settlement because of a hydrological–morphological «dying» or seasonal shallowing, freezing, or through-freezing of a water body. Water deficiency can also form because of an increase in the user's demand. These problems can be solved in different ways, including: (1) water transfer; (2) in winter – the change of water supply to river and lake ice and other water sources, including remote, and even to seawater (as is the case with the Chaunskaya TPP in Pevek Town); (3) the construction of water accumulators – ponds and reservoirs (especially, near large populated localities, thermal and power supply facilities, and ore mining plants); (4) the rationalization of water use, e.g., the increase in the share of recycling water supply.

The situation most widespread in the Siberian part of the AZR is the freezing or even freezing through of a surface water source; the absence of acceptable groundwater (in territories with a thick and continuous permafrost stratum, in particular, in the plains of the Arctic Yakutia), and the forced conversion to pre-stored and melted river and lake ice for the heat and water supply in winter, even in populated localities with centralized water supply. The situation with water shortage and low levels in summer and autumn is also possible here, and it even has taken place in the Noril'sk urban district (in 2013 and 2016), in the eastern Taimyr Dolgano-Nenets district. However, the water demand being still not large, along with measures, efficient enough – the prompt construction of a backwater dam on the Norilka river – make this restriction still not serious nor widespread.

The restrictions of the 2nd type are typical of territories and water bodies with: (1) high background concentrations of chemicals limiting the water use, (2) anthropogenic pollution, (3) seasonal or short-time natural deterioration of water quality, for example, during spring flood, under low-water conditions, or because of seawater penetration to the water intakes within river mouths and on sea coasts. It has been found that in six rural settlements (with a total population of 3200), water supply can be occasionally interrupted because of seawater intrusion (during storm surges or low-water periods in rivers). As is known, (Magritsky et al. 2017), the damage caused by seawater intrusion is largest in Arkhangel'sk City. Here, seawater in the Northern Dvina delta can disturb the water supply to the Arkhangel'sk Hydrolysis Plant, pulp and paper plant, TPP, and municipal water supply plant.

It is assumed that the share of polluted water in wastewater structure is not large (Table 1). In fact, however (Zaitseva and Koronkevich 2003), the system of wastewater treatment is far less effective than it is formally stated.

The restrictions associated with water failing to meet quality requirements can be eliminated by water pretreating and temporary or permanent change of water source, e.g., to groundwater. However, the population of the majority of the populated localities of Krasnoyarsk krai

and the Republic of Sakha, which consume water from rivers and have no water treatment stations, have no such opportunity. Moreover, each hydrological season has its own features in the context of water quality deterioration in rivers.

Restrictions of the 3rd type – i.e., caused by a direct effect of flood water on the infrastructure taking freshwater, its treating and distribution, as well as disposal – were identified in 26 populated localities, which lie, fully or partly, in an inundation zone, and in 4 populated localities in river reaches with erodible banks. The population of such areas is 42 thousand. The latest such important event took place in Ust'-Yansk Settlement (Yakutia) in the early June 2018. Overall in AZR, about 80 populated localities suffer inundations by river water and require protection measures. Inundations in sea coasts and at river mouths can be also caused by storm surges. The surge in November 2011, which lasted for less than 2 days, inundated up to 50 km of land at the Northern Dvina mouth with a maximum depth of 1–1.5 m and inflicted damage to the cities of Severodvinsk and Arkhangel'sk with damage of \$1.5–2.0 million (Magritsky et al. 2017).

Clearly, several types of hydrological restrictions can be applicable to some water users and municipalities.

CONCLUSIONS

The Arctic zone of Russia (with islands taken into account) occupies ~18% of its territory. Even greater area (~71%) belong to the drainage basins of Arctic seas. Nevertheless, the volumes of water consumption in these areas, sparsely populated and weakly developed as they are, have been shown in this study to be relatively low. It has no effect on the water resources of Arctic rivers and river water inflow into the seas of the Russian Arctic. Moreover, the water withdrawal has dropped considerably compared with the situation in the 1980s, in particular, by about 30% in the Pechora, Lena river basins, and from the rivers of Murmansk oblast, and by 50% in the Northern Dvina, Yenisei, and Kolyma river basins. It has increased in the Nenets and Yamalo-Nenets AO because of the intense development of the local oil-and-gas complex.

Nowadays, according to the authors' estimates, 21.28 km³/year (Table 2) is being withdrawn in the drainage basins of RF Arctic seas and 2.58 km³/year, within the AZR, or 28.8 and 3.5% of the total volume in Russia. The largest contribution to this value is due to the water-management complexes in the basins of the Ob (14.7 km³/year with 60.5% being the share of RF; 19.0% that of Kazakhstan; and 20.5% that of China), Yenisei (2.77 km³/year), Northern Dvina (0.64 km³/year), and Murmansk oblast (1.72 km³/year). The major water users are the industry (with a high proportion of mining plants), thermal power engineering, and municipal economy. Their contributions vary from one basin to another and within the AZR territory. Many districts and rivers in AZR are not involved in the water management activity. This conclusion is illustrated by the original Map of Anthropogenic Withdrawal of Natural Water in the Basins of Arctic Rivers and in AZR Areas (Fig. 3).

The volumes of water discharges back into water bodies at the drainage basins of Russian Arctic seas are comparable with the volumes of freshwater withdrawal – 71% of water intake. Even lesser is the difference within AZR. That is why the irrecoverable anthropogenic losses of runoff are lower than those either in the country or in the world.

Therefore, the regional deficit of water resources is out of question. However, the economic use of runoff in

the southern part of the Ob–Irtysch basin and in the Ural Economic Region has been classified as critical since the 1970–1980s. Conversely, considerable and diverse hydrological restrictions exist at the municipal level and for some water users in AZR. These conclusions were derived from the data in the Electronic Catalogue of Water Users in AZR. It had been created by the authors, mostly, using the open publications of municipal units, such as «Schemes of Water Supply and Disposal and Heat Supply», «The Program of Integrated Development of Municipal Infrastructure Systems,» as well as SIUPWB. The analysis of these materials has shown that they can be an alternative source of reliable and diverse water-management data.

The features and seriousness of hydrological restrictions depend on many factors, including the economic sector type and the scale of water user, its location, the type of natural water used, and the yield and the hydrological

regime of a water source. Many factors vary over the area, within a year, and from year to year. The restrictions can be combined into three groups. The first is associated with problems relating the supply to a water user of the required amount of fresh water; the second relates to the restrictions because of the withdrawn water failing to meet the standards, and the restrictions of the third group are due to inundation, damage, destruction, or silting of water intake or discharge structures, the systems of heat and water supply during ice drift, high water discharges or levels, as well as water freezing in pipes. Several types of hydrological restrictions can be applicable to some water users and territorial units. These are considered in detail and generalized, in particular, in the form of various maps and diagrams, for water users of Chukotskii AO, Arctic regions of the Republic of Sakha, and Krasnoyarskii Krai. ■

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