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Management of groundwater resources in transboundary territories (on the example of the Russian Federation and the Republic of Estonia)

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Abstract. Groundwater, as a source of water supply, the most important mineral and geopolitical resource, is often the only source of high-quality drinking water that is protected from pollution under conditions of increasing deterioration of surface water quality. Transboundary groundwaters are the focus of hydrogeological researchers for a number of reasons, including the reduction and pollution of water resources as a result of economic activities. The increased controversy between states over transboundary water issues has necessitated the development of international legal documents on issues related to water conflict prevention and the sustainable use of fresh water. As part of the analysis of the problem of legal regulation of groundwater extraction from transboundary aquifers and complexes, it is proposed to consider this aspect on the example of Russia. The problems of regulation of rational use and protection of fresh water in the bilateral treaties of the Russian Federation were revealed; a methodology for the management of groundwater extraction in the territory of the transboundary aquifer was developed, the size, parameters, and factors influencing the formation of the transboundary zone have been determined (based on research and analysis of water intake activities in the border areas of the Russian Federation and the Republic of Estonia) were determined.

***Key words*:** transboundary aquifer; water resources; legal regulation; extraction of groundwater; the “big well” method; bilateral agreement

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Introduction. According to the UN, by 2025 Russia with Scandinavia, South America and Canada will remain the most abundant in fresh water – more than 20 thousand m^3/year per person (inhabitant) [3]. In the future, Russia is assigned a special role in solving the problems of rational water use not only on its territory, but also in the international arena, which determines the strategic importance of water resources for the Russian Federation. At the same time, even if in Russia questions regarding the sufficiency of fresh water reserves do not arise, then in some neighboring countries the problems of fresh water usage are quite acute, which may affect the water bodies shared with Russia. In this regard, it is important to study intergovernmental agreements, bilateral treaties of the Russian Federation on the use and protection of transboundary sources of fresh water in order to establish their compliance with modern trends in the development of international legal regulation of relations in this area and ensuring the interests of Russia [10].

Many aquifers and complexes are transboundary, i.e. they lie on the territory of two or more administrative units within a country or two or more countries. In the second case, the administrative and operational management of groundwater resources faces additional challenges and requires harmonization of rules and establishment of transboundary cooperation between different bodies dealing with groundwater issues, based on mutual trust and transparency. There are few examples of such cooperation [11].

As practice shows, the need for joint groundwater exploitation from transboundary aquifers and complexes almost always leads to the emergence of certain tensions in the societies that they unite. This is due to various factors, which, in addition to relations between countries, include issues of national security, development of economic potential, openness and environmental stability. Transboundary water resources management can be both a unifying factor and a cause of conflict; orientation is largely due to political will [2].

Few international boundaries match natural physical features and water resources can cross them unhindered. For effective governance and fair distribution, scientists assess the resources that cross these boundaries. In hydrogeological terms, they can only be assessed through observations and measurements of selected hydraulic parameters, similar to the process of assessing other transboundary resources. In many cases, an aquifer can have a recharge area on the territory of one state, and a discharge area on the territory of other border states. For Russia, the topic is relevant due to the presence of 16 land-based neighboring states.

Analysis of the current state of knowledge and use of groundwater shows that in the new socio-economic conditions, the effectiveness of research depends not only on the degree of study of hydrogeological conditions, but also on the compliance of their results with the requirements of the regulatory framework. The issues of legal regulation of the study and extraction of groundwater have not received sufficient scientific substantiation, which significantly affects the information support of the work performed and their efficiency [5].

The beneficial and rational use of groundwater largely depends on socio-economic, institutional, legal, cultural, ethical and political considerations. Their national development is hampered by weak social and institutional capacities, legal and policy frameworks. In a transboundary context, this can be reinforced by contrasting levels of knowledge and capabilities on both sides of many international borders [4].

Modern research on the processing of minerals is aimed at increasing the environmental, economic and energy efficiency of technological processes due to the high demand for energy and water [26]. The balance of economic interests of the subjects that are part of the country is a necessary condition for increasing the efficiency of the mineral resource industry at all levels of government [21, 24]. Therefore, issues related to the state management of groundwater resources are relevant.

The problems of transboundary regulation of mining are analyzed in [16, 20, 27]. The distribution of shared water resources of a transboundary nature in accordance with international law is one of the key security factors in the region [19].

The main goal of the article is to improve the legal framework in the field of state regulation of the groundwater resources extraction in transboundary territories by amending the laws and regulations governing the procedure for the extraction of groundwater for various purposes from transboundary aquifers and complexes.

Methodology. The search for ways to resolve interstate disagreements on the use of water bodies located on the territory of two or more states is becoming more relevant in the international community [6]. First, it is necessary to establish definitions and concepts in the field of transboundary water resources, as well as to carry out an analysis of the current norms of Russian and international legislation.

Transboundary waters are understood as reservoirs and watercourses or waters that cross the state border of two adjacent states or along which state borders pass. This concept was adopted in

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the "UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes" in 1992, it is largely identical to the concept of "boundary waters" [17]. Article 19 of the Water Code of the Russian Federation of 1995 defines transboundary water bodies as "... surface and ground water bodies that designate, cross the border between two or more foreign states or along which the State border of the Russian Federation runs, are transboundary (border) water bodies", and further "The procedure for the use and protection of transboundary (border) water bodies is established by this Code, the legislation of the Russian Federation on the State Border of the Russian Federation and international treaties of the Russian Federation" [5]. However, in the Water Code of the Russian Federation, approved in 2006, and in the amendments adopted to it there is no such article [2, 19].

Analysis of bilateral agreements between Russia and neighboring states shows that in half of the treaties under consideration, transboundary freshwater objects are understood as "rivers, lakes, streams, swamps, as well as groundwater located or crossing the borders of two contracting states" [1, 6], while the use and protection of transboundary groundwater sources is eliminated from the other half of the treaties [10].

At the same time, existing international treaties and other acts to ensure the rational use and protection of transboundary fresh water sources are increasingly calling on states to implement integrated water resources management, which involves the coordinated management of various types of water resources – surface, underground, etc. In this part, integrated water resources management remains the most unenforceable, since it does not take into account the peculiarity of groundwater and the resulting need for special legal regulation [10]. This problem remains relevant for Russia. The use and protection of surface fresh water resources is regulated by the provisions of the 2006 Water Code of the Russian Federation. Groundwater is partially subject to the norms of the Water Code, however, mainly the issues of its use and protection are regulated by the legislation on subsoil, in particular the Law of the Russian Federation "About mineral resources" N 2395-1 dated February, 21 in 1992. In addition to the fact that both documents need modernization, it is also necessary to correctly delineate and interconnect these regulatory documents in terms of adjustment and regulation of groundwater extraction. Thus, after numerous amendments to the water legislation, the concept of continuity "in relation to the legal regulation of groundwater bodies" has disappeared. If the earlier existing Water Code of the Russian Federation contained the concept of "underground water body", then in the new code there is no such concept. It is not yet clear what is meant by a groundwater body as an object of legal regulation of water legislation, and how it differs from groundwater regulated by mining law. The lack of unity in terminology creates contradictions in the choice of the branch of natural resource law, which should regulate the use and protection of groundwater [4, 5].

The current Water Code provides that the right to use groundwater bodies arises on the basis and in the manner established by the legislation on subsoil. However, "the referential nature of the norms of water legislation seems to be insufficient in the absence of detail and legal regulation of relations" in the legislation on subsoil [14, 15]. Disunity of legal regulation in several branches of natural resource law exacerbates the problem of the implementation of legal norms in this area, since it leads to collisions and contradictions [5]. Therefore, most researchers tend to the fragmented nature of the legal regulation of the use and protection of water resources and ignore the ecosystem approach in the Russian legislation [8].

Russia has created a regulatory and methodological framework for nine bilateral agreements of the Russian Federation in the field of protection and rational use of transboundary water bodies with Belarus, Kazakhstan, China, Mongolia, Ukraine, Finland, Estonia, Azerbaijan, Abkhazia and a trilateral agreement on the river Paz (Paatsojoki) with Finland and Norway [6, 7, 13]. Bilateral treaties of the Russian Federation proceed from the applicability of the same rules to surface and underground transboundary freshwater bodies, like most countries exploiting common aquifers. In both national and international legislation, there are practically no regulations for determining the size of the transboundary zone (TZ), rules and restrictions on the operation of groundwater intakes located along state borders.

One of the most important points missed in the current international legislation on the regulation of groundwater extraction in transboundary territories is the lack of a definition and methodology for calculating the width of TZ along the state border. For the first time, the concept of the territory of a transboundary aquifer (TTA) is defined as a strip of land located on both sides of the state border of neighboring countries, which has certain geometric dimensions that were calculated by hydrogeological methods based on filtration parameters of jointly exploited aquifers.

Limiting the width of the TZ along the state border means limiting the zones of responsibility for groundwater extraction, construction of mining enterprises, land reclamation and extraction of shale oil. The transboundary area should meet the following requirements (factors):

• especially controlled regime of subsoil use (management of groundwater resources) within the boundaries of the width of the TZ;

• mutual two-way monitoring system for all exploited aquifers with functions of periodic measurement of levels and carrying out chemical, radiological, microbiological analyzes;

• limitation on depletion of reserves at TTA, which is determined by mutual agreements and settlements, i.e. the parties agree on the maximum permissible decrease in the level of groundwater at the specified monitoring points for the billing period;

• a special regime for monitoring groundwater production, expressed in a 100 % licensing system for water intakes, including low-flow single water intakes with a production volume of up to 100 m^3/day and the obligatory approval of reserves by categories with the production of geological exploration work (geological exploration) [2]. Each water intake that falls into the TZ must be equipped with a system for monitoring production volumes (water meters, systems for measuring groundwater levels), as well as periodic reporting on the state of the chemical and microbiological situation for the water samples taken;

• extraction of drinking, technical and mineral groundwater is to a varying degree related to the assessment of reserves, respectively, from this point of view, groundwater is a mineral. Consequently, groundwater is a “commodity” that must have a value [2]. It seems expedient to transfer TZ to a new system of taxation of groundwater extraction, i.e. introduction of a tax on the extraction of minerals, the rate of which may vary depending on the quality of groundwater, intended use, category of reserves. The cost of groundwater acquires a function of the cost of water treatment, intended use, transportation, category of reserves (A, B, C1, C2) [2].

A method to substantiate the width of the TTA has been developed, taking into account specific geological conditions. As an example, the materials of geological research in the territory of the Leningrad region and Estonia were used. The object of the study is the Lomonosov aquifer, which is used for domestic and drinking water supply and is of strategic importance; the calculation period is 25 years.

Results and discussion. Hydrogeological studies on the issue of groundwater extraction from a transboundary aquifer are described in detail in [4, 9] using modern methods of numerical modeling for the two main aquifers in the area of the Russian-Estonian border.

The study boundaries were taken from the aquifer recharge area to the discharge area. The research work was of a fundamental nature, a large number of water intakes, data from the Russian and Estonian monitoring networks were analyzed, and the impact of individual water intakes both from the Russian side on the Estonian side and vice versa was calculated. The main conclusions of the work were that the hydrodynamic situation at the TZ is close to neutral, despite the significant capacity of the water intake facilities in the border area. The work was carried out on the analysis of materials from the late 1990s – early 2000s.

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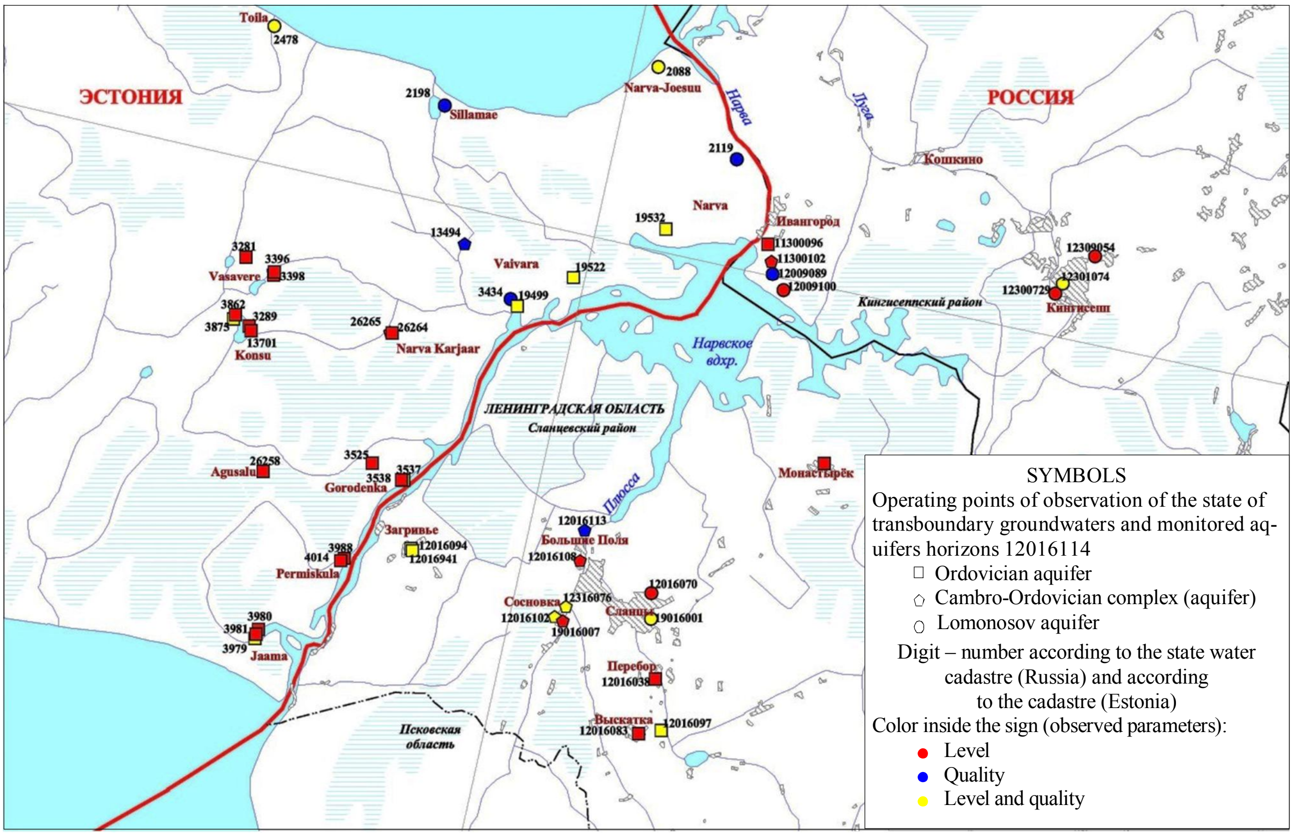

Fig.1. Layout of observation points and observed indicators for the state of transboundary groundwater bodies in Russia and Estonia*

Experts from Russia and Estonia took part in the work; a numerical model was developed and analytical calculations were carried out. Russia continues to exchange data from groundwater monitoring systems, and also uses the developed numerical model to solve predictive epignosis problems.

Assessment of the mutual hydrodynamic influence during the joint exploitation of aquifers makes it possible to assess the "attraction" of water resources from the territory of a neighboring state [4].

The joint exploitation of groundwater in the border area of Russia – Estonia is analyzed. In hydrogeological terms, the territory under consideration is located in the East European artesian basin, within which the following objects are distinguished: the Lomonosov (Lower Cambrian) aquifer, the Cambrian-Ordovician aquifer and the Ordovician aquifer complex. The most exploited aquifer in the border area is Lomonosov (Lower Cambrian), which is under the influence of joint exploitation of groundwater for drinking water supply, mine and quarry drainage in the territory of the Russian Federation and the Republic of Estonia. The layout of observation points is shown in Fig.1.

The object of research is the Lomonosov aquifer, which is widely distributed in the Leningrad region in Gatchinsky, Lomonosovsky, Volosovsky, Kingiseppsky and Slantsevsky districts, as well as in the northern part of the Gdovsky district and the Pskov region. It is composed of fine-grained, weakly cemented sands, interbedded with interlayers of siltstones and clays. The thickness of the aquifer in the study area is, on average, 20 m. The water-resistant roof for the Lomonosov aquifer is the clays of the Lontovaskaya suite. It is underlain by water-resistant kotlin deposits of the upper proterozoic; the aquifer lies at a depth of 109-208 m from the earth surface. The filtration coefficient is 0.11-5.2 m/day, in the study area on average – 3 m/day. The head height in some places reaches 180 m and more; the depth of the water level varies from 34.4 to 72 m.

*Information Note on the State of Transboundary Groundwater Bodies (Russia – Estonia) for 2018. North-West Regional Center of the HMSN, 2018.

Transboundary consumers of groundwater in this area are: the Russian Federation, the main group water intakes in the border zone – Ivangorod, Kingisepp, Slantsy (total water withdrawal – 3.341 thousand m^3/day); the Republic of Estonia – Vaivara, Vasasvere, Konsu, Agusalu, Permisküla and Gorodenka (total water withdrawal – 2.923 thousand m^3/day).

Joint exploitation of the Lower Cambrian aquifer by water intakes located on the territory of the Leningrad region and the Republic of Estonia, formed a disturbed groundwater level regime. Change in the groundwater level at water intakes in the border area of Russia in 2018 (Ivangorod/Kingisepp): groundwater production – 1.93/1.14 thousand m^3/day; actual lowering of the groundwater level S_f – 32.5/24.2 m; level change – +1.3/–0.9 m; permissible decrease S_p – 83.2/81 m; operating mode – steady state.

Based on the available data, it is expedient to assess changes in the piezometric surface of transboundary waters of the Lomonosov aquifer at the Russia – Estonia border.

The assessment will consist of determining the value of the radius of influence from the operation of water intakes at the Russian Federation and the Republic of Estonia; calculations of lowering the piezometric level within the radius of influence, determination of the amount of "withdrawn" groundwater resources from the territories of neighboring states for the service life of 25 years.

To assess the nature of changes in the piezometric level of transboundary groundwaters of the Lomonosov aquifer during operation, standard design schemes are used to assess reserves by the hydrodynamic method, the main task of which is to determine the design decrease during the operation of water intake structures. The calculation of the predicted decrease in the level is carried out for a period of $t = 10^4$ days. The value of the allowable decrease is taken from the experience of operating the group water intakes of Ivangorod and Kingisepp. To solve this problem, the arithmetic mean of the permissible decrease from the operation of water intakes will be used, which will be S_p = 136 m. Due to the lack of information, the Estonian side adopted filtration parameters and the permissible decrease by analogy with fields located in Russia.

For the selection of a typical design scheme, a schematization of the natural geological and hydrogeological conditions of the study area was carried out.

The Lomonosov aquifer is confined, overlapped by Lontovaskiy water-resistant sediments, composed of silty clays, the filtration coefficient of which is 0.02 m/day. According to the assumptions of Myatiev – Girinsky $k_{max} / k_{min} = 3 / 0.02 = 150 > 100$, the Lontovaskiy sediments layer is an aquiclude, and the Lomonosovskiy sediments layer is assumed to be homogeneous permeable. The hydrogeological system is single-layer, the feeding is concentrated, the flow structure is radial, the dimension is one-dimensional, the type of water exchange is horizontal.

The aquifer recharge area is far beyond the study area. In the northern part of the Leningrad region. and within the Estonian shale basin, the Gdov and Lomonosov aquifers are operated jointly, which is why there is a hydraulic connection between them.

Since the Lomonosov aquifer is isolated by aquicludes, is unlimited in plan and is a pressure head, the Theis scheme is used to calculate the depression [22, 23]. On the territory of work, water intakes will be considered as compact groups of wells, therefore, it is advisable to calculate using the "big well" method.

For an unbounded reservoir, a decrease in is determined on the outer contour of the "big well"

$$S_{ext} = \frac{Q_{tot}}{2\pi km} \ln \frac{R_r}{R_0}, \quad (1)$$

where Q_{tot} is the total water intake flow rate, m^3/day; km – formation water permeability, m^2/day; R_0 is the radius of the "big well", for the areal system it is determined by the dependence $R_0 = 0.1P$, where P is the perimeter of the area where the wells are located, m; R_r – reduced range radius of well

$$R_{\mathrm{r}} = 1.5\sqrt{at}; \tag{2}$$

a – reservoir conductivity, m^2/day; t is the estimated service life of the water intake – 10^4 days.

An additional reduction in the well is calculated using the formula:

$$S_0 = \frac{Q_c}{2\pi km}\ln\frac{r_r}{r_w}, \tag{3}$$

where Q_c is the design flow rate of the estimated well in the worst operating conditions, m^3/day; r_w – well filter radius, m; r_r is the reduced radius of the conditional area of influence of the design well [12, 25], which is calculated for the areal system according to the dependence:

$$r_r = 0.47\sqrt{\frac{F_0}{\pi}}; \tag{4}$$

F_0 – area of the site bounded by the lines passing in the middle between adjacent wells, m^2.

The calculation of the assessment of the impact of water intakes in the study area was carried out using the "big well" method with an areal system of location of water intakes, the distance between which is taken from their center (Table 1).

Table 1

Distance between observation points

The Russian Federation		The Republic of Estonia	
Settlements	Distance	Settlements	Distance
Kingisepp – Slantsy	40900	Vaivara – Vazavere	15600
Kingisepp – Ivangorod	19000	Vazavere – Konsu	7200
Ivangorod – Slantsy	33800	Konsu – Agusalu	15300
		Agusalu – Permisküla	7200
		Permiskula – Gorodenka	6400
		Gorodenka – Vaivara	25900
Total	93700	Total	77600

Distances from the water intake sites to the Russia – Estonia border are presented in Table 2. For the calculations, the distance from the center of the "big well" to the border was used, which from the RF side is about 15000 m, and from the Estonian side – about 11110 m. Calculation of the change in the piezometric surface from the operation of the water intakes for the service life of the water intakes of 10^4 days (Table 3).

Table 2

General information about water intakes located on the territory of the Russian Federation and the Republic of Estonia

The Russian Federation				The Republic of Estonia			
Cities with operational water intakes	Number of water intakes	Total debit, m^3/day	Average distance to the border with Estonia, km	Cities with operational water intakes	Number of water intakes	Total debit, m^3/day	Average distance to the border with Russia, km
Ivangorod	2	1931	3.74	Vaivara	2	2923	17.4
Slantsy	5	270	17.7	Vazavere	3		20.8
Kingisepp	5	1140	19.6	Konsu	4		18.5
				Agusalu	1		7.67
				Permisküla	2		1.00
				Gorodenka	3		1.30
Total	12	3341	15.00	Total	15	2923	11.11

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Table 3

Results of calculating changes in the piezometric level

The Russian Federation	The Republic of Estonia
Calculation of lowering on the outer contour of the "big well"	
$R_r = 1.5\sqrt{10^5 \cdot 10^4} = 47434$ m.	$R_r = 1.5\sqrt{10^5 \cdot 10^4} = 47434$ m.
$R_0 = 0.1 \cdot 93700 = 9370$ m.	$R_0 = 0.1 \cdot 77600 = 7760$ m.
$S_{ext} = \frac{3341}{2 \cdot 3.14 \cdot 60} \ln \frac{47434}{9370} = 8.86 \cdot 1.62 = 14.35$ m.	$S_{ext} = \frac{2923}{2 \cdot 3.14 \cdot 60} \ln \frac{47434}{7760} = 7.76 \cdot 1.81 = 14.04$ m.
Calculation of an additional drawdown in a well with worse operating conditions	
$r_r = 0.47\sqrt{\frac{318295967.1}{3.14}} = 4732.04$ m.	$r_r = 0.47\sqrt{\frac{229652725.65}{3.14}} = 4019.5$ m.
$S_0 = \frac{386}{2 \cdot 3.14 \cdot 60} \ln \frac{4732.04}{0.3} = 1.02 \cdot 9.67 = 9.86$ m.	$S_0 = \frac{194.9}{2 \cdot 3.14 \cdot 60} \ln \frac{4019.5}{0.3} = 0.51 \cdot 9.50 = 4.84$ m.
Calculation of the decrease from the interaction of water intakes on the territory of the Russian Federation	
Total consumption of water intakes in the border area $Q_{tot} = 2923$ m³/day. Distance from the centers of the group water intake – 24890 m,	Total consumption of water intakes in the border area $Q_{tot} = 3341$ m³/day. Distance from the centers of the group water intake – 24890 m,
$S_{ext} = \frac{3341}{4 \cdot 3.14 \cdot 60} \ln \frac{2.25 \cdot 10^4 \cdot 10^5}{24890^2} = 4.43 \cdot 1.28 = 5.67$ m.	$S_{ext} = \frac{2923}{4 \cdot 3.14 \cdot 60} \ln \frac{2.25 \cdot 10^4 \cdot 10^5}{24890^2} = 3.87 \cdot 1.28 = 4.96$ m.
The total decrease will be: $S_{tot} = S_{ext} + S_0 = 14.35 + 9.86 + 5.67 = 29.17$ m.	The total decrease will be: $S_{tot} = S_{ext} + S_0 = 14.04 + 4.84 + 5.67 = 23.64$ m.

The permissible decrease of 136 m does not exceed the calculated one for a service life of 10^4 days.

Based on monitoring data for 2020, the depression funnel in the city of Slantsy was 26.4 m (14 %) of the permissible decrease, and in the territory of Ivangorod – 31.1 m (37 %) of the permissible decrease. In the Kingisepp industrial area, the depression funnel was 20.7 m (25 %) of the permissible decrease*. The results obtained are comparable with the actual data, which indicates the correctness of the calculation methodology.

To identify changes in the natural conditions of the Lomonosov aquifer from the operation of the water intakes of the TZ Russia – Estonia, the dynamics of the change in the depression funnel was monitored. According to the data obtained in the study of the Lomonosov aquifer, the radius of influence was determined, the value of which is $R_r = 47434$ m and is the same for both Russia and Estonia.

Based on the magnitude of the radius of influence, it can be concluded that the influence from the operation of water intakes at 37430 and 32434 m will go beyond the borders of the Republic of Estonia and the Russian Federation, respectively. Further, the dynamics of the propagation of the depression funnel at different time intervals on both sides of the TZ was determined (Table 4).

The assessment of the dynamics of the propagation of the depression funnel was considered by calculating the radius of influence (2) for five points in time – 450, 500, 1000, 2000, 5000 days:

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* Information bulletin on the state of the subsoil of the territory of the North-West Federal District of the Russian Federation in 2020. St. Petersburg, 2021.

$$R_r = 1.5\sqrt{10^5 \cdot 450} = 10062 \text{ m};$$

$$R_r = 1.5\sqrt{10^5 \cdot 500} = 10606 \text{ m};$$

$$R_r = 1.5\sqrt{10^5 \cdot 1000} = 15000 \text{ m};$$

$$R_r = 1.5\sqrt{10^5 \cdot 2000} = 21213 \text{ m};$$

$$R_r = 1.5\sqrt{10^5 \cdot 5000} = 33541 \text{ m}.$$

The calculation shows a systematic change in the depression funnel, which will reach the border from the Republic of Estonia in 450 days, and from the Russian Federation in 1000 days (Fig.2).

Based on the obtained radii of influence, the calculation of the decrease was carried out according to equations (1) and (3) (see Table 3, Fig.3).

Table 4

The calculated value of the decrease at different points in time

The Russian Federation						The Republic of Estonia					
Water Intake operating time, days	Influence radius R_r, m	Lowering on the external circuit of the “big well”, S_{ext}, m	Additional lowering, S_0, m	Cutting off the level from the work of neighboring groups of water intakes, m	Total decrease, S_{tot}, m	Water Intake operating time, days	Influence radius R_r, m	Lowering on the external circuit of the “big well”, S_{ext}, m	Additional lowering, S_0, m	Cutting off the level from the work of neighboring groups of water intakes, m	Total decrease, S_{tot}, m
450	10062	13.77	9.86	4.96	28.59	450	10062	12.02	4.84	4.96	21.82
500	10606	13.27	9.86	4.96	28.09	500	10606	11.55	4.84	4.96	21.35
1000	15000	10.20	9.86	4.96	25.02	1000	15000	8.91	4.84	4.96	18.71
2000	21213	7.12	9.86	4.96	21.94	2000	21213	6.20	4.84	4.96	16.00
5000	33541	3.07	9.86	4.96	17.89	5000	33541	2.71	4.84	4.96	12.51

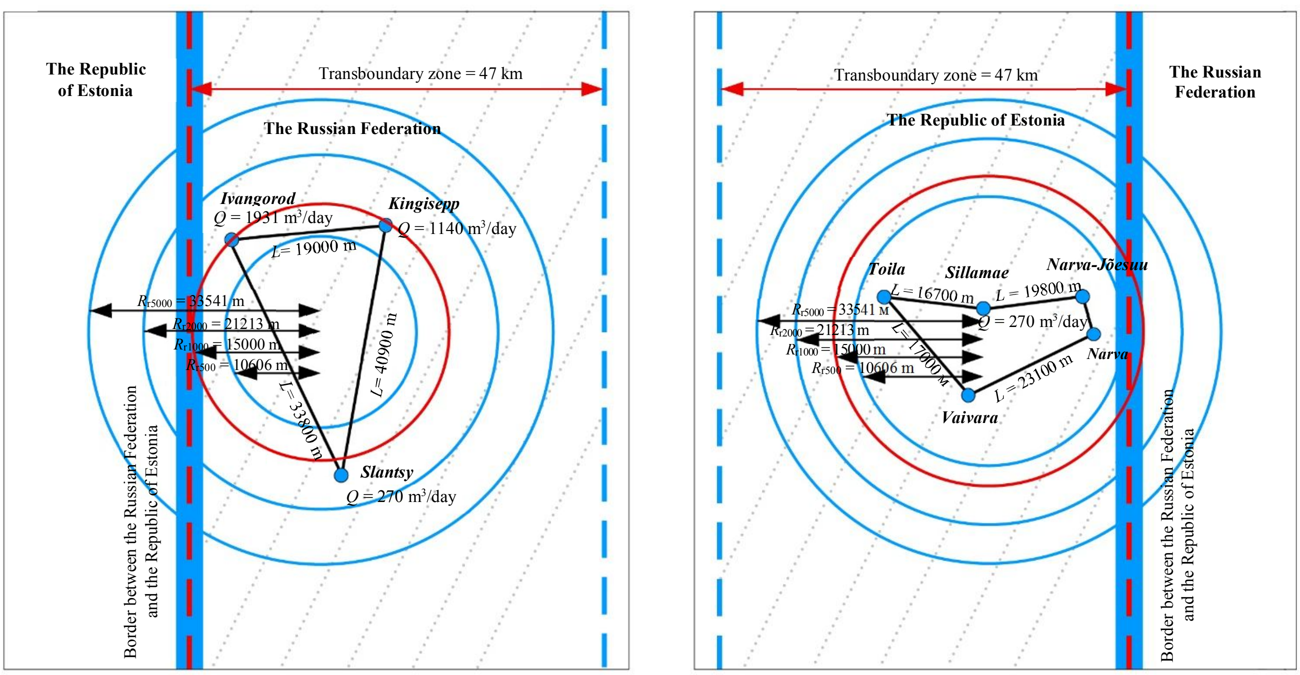

Fig.2. Dynamics of the spread of the depression funnel during the operation of water intakes on the territory of the Russian Federation (*a*) and the Republic of Estonia (*b*)

Taking into account the calculated depressions obtained, the amount of "withdrawn" groundwater resources from the TZ of the Republic of Estonia and the Russian Federation was determined. The calculation was carried out according to the converted Theis scheme:

$$Q = \frac{2\pi T S_{ext}}{\ln R_r / R_0}, \quad (5)$$

where T is water permeability, m^2/day; S – lowering on the external circuit of the "big well". The calculation results are shown in Fig.2.

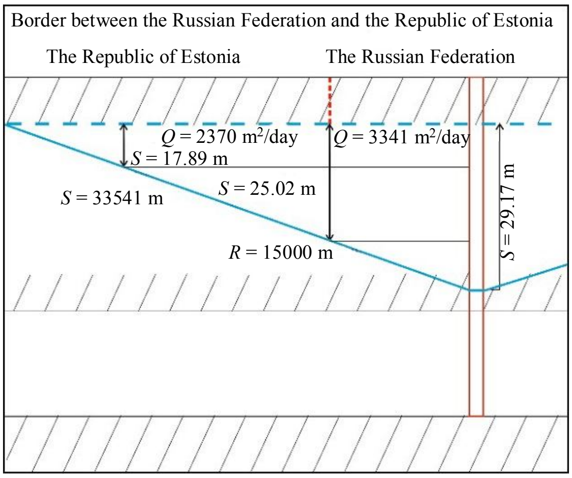

Fig.3. Changes in the piezometric level duringthe operation of water intakes on the territory of the Russian Federation

The amount of groundwater resources "taken" from the territory of the Republic of Estonia (Russian Federation/Republic of Estonia): radius of influence R_r – 15000/10606 m; lowering on the outer contour of the "big well" S_{ext} – 10.2/8.91 m; the amount of attracted resources at different points of the radius of influence – 2372/1998 m^3/day; the percentage of "taken" water – 29/32.

Calculations showed that the depression funnel created by the operation of water intakes located on the territory of Russia and Estonia, exploiting the (Lower Cambrian) Lomonosov aquifer, will be R_r = 47434 m during the operation of the water intakes 10^4 days.

The radius of influence from the operation of water intakes will reach the border after 1000 days of operation from Russia and after 500 days from Estonia, and the decrease will not exceed 14.35 and 14.04 m, respectively.

Based on the calculation of the groundwater discharge at different points of the depression funnel, it can be concluded that the distance from the center of the "big well" from the Russian side to the border with Estonia is 15,000 m; with a decrease equal to 10.2 m within this radius, the amount of resources exploited by water intakes is 2372.4 m^3/day out of the required 3341 m^3/day. This means that the missing 968.6 m^3/day are taken from the territory of Estonia, which is 29 % of the total declared demand. The distance from the center of the "big well" on the Estonian side to the border with Russia is 10606 m, with a decrease of 8.91 m within this radius, the amount of resources exploited by water intakes is 1998 m^3/day out of the required 2923 m^3/day. It follows from this that the missing 925 m^3/day are taken from the territory of Russia, which is 32 % of the total declared demand.

Thus, the Russian Federation takes 374 m^3/day more water from the Republic of Estonia. This value is conditional, since the calculations do not take into account the costs of the natural flow of groundwater. But since there is no excess of the maximum permissible level, the situation can be considered as neutral. More accurate calculations can be obtained using numerical modeling of subsoil use at TTA, which is based on a monitoring network and long-term observations of the groundwater regime. It is necessary to carry out an annual reconciliation of data on subsoil use on the TZ in order to control its mutual balance. The considered example of interaction between the two states is to a certain extent exemplary, as it shows the connection between the services for monitoring groundwater production in the two countries.

Conclusion. Such an approach to solving hydrogeological problems at the TTA can become an example of cooperation between neighboring states in the development of relations in joint subsoil use. Nevertheless, in 2020, independent analytical calculations were carried out on the water balance and mutual influence of the largest water intakes of the Russian Federation and the Republic of Estonia, but within the framework of the allocated TZ.

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From the calculations, it can be concluded that inevitably, on the territory of one of the states, the volume of water resource extraction will always be higher. A quantitative assessment of the water resources taken from the aquifer of a neighboring state can be performed by calculation using the balance method. Quantitative indicators of the extracted resource cannot have a monetary equivalent as a marketable product, therefore, mutual settlements between states that exploit the same aquifer cannot be carried out in value terms. The factors for limiting the excessive production of groundwater at the TTA should be the criteria for the position of the groundwater level, as well as their quality within the framework of the interstate agreements reached, control over which is carried out within the framework of the international groundwater monitoring system.

One of the main problems of joint subsoil use in the transboundary territory was the quantitative assessment of the "attraction" of water resources during the exploitation of an aquifer from the territory of a neighboring state. The same problem is inextricably linked with the change in the quality of the extracted resource over time. Such changes, most often an increase in salinity, are characteristic of the southern regions, where the main aquifers have a limited recharge area. Nevertheless, the problem under consideration narrows the area of study, despite the fact that regional hydrogeology and the genesis of the main aquifers should be taken into account in forecasting tasks, especially when creating a numerical model of transboundary areas [4].

There are many border areas, mainly on the territory of the African continent, Central Asian states and the Middle East, where geological exploration is not carried out, not to mention the monitoring system (for example, Botswana, Namibia) [8, 28, 29]. Therefore, when creating a limited research area (TZ width), the task of the international concept on TTA can be solved not with such global costs. The organization of TZ should be financed by state, the specific share of which in the issue of subsoil use is the largest.

An unconditional factor in organizing TZ is the involvement of specialists from both border states, and if there is a shortage of them, the involvement of environmental specialists, hydrogeologists, experts from states with similar work experience. Russia, and earlier the USSR, paid great attention to the training of highly qualified specialists with work experience not only on the Eurasian continent, but also around the world. This also applies to setting up geological exploration, organizing monitoring, analytical and expert activities related to the most complex engineering problems. In most border TZ, it is advisable to use data on existing water intakes, as well as the local network of observation points. In the event that mining enterprises or hydraulic structures get into the TZ, the account of the hydrogeological situation should be analyzed first.

The transboundary zone should have a certain limitation in the area of distribution, which is determined by hydrogeological parameters and characteristics. It is to this area that the relevant rules and regulations can be applied. According to preliminary calculations, the width of the TTA can range from several kilometers to their first tens.

It has been established that most of the large aquifers and complexes located on the TZ of several states are the main sources of water supply for the purposes of domestic water supply, which creates the preconditions for the formation of mutual agreements, arrangements, conventions regulating obligations to limit production and maintain a control system.

Based on the example of research and analysis of water intake activities in the border areas of the Russian Federation and the Republic of Estonia, a methodology for managing groundwater production at the TTA has been developed, the dimensions, parameters and factors affecting the formation of TZ have been determined.

According to the results of hydrogeological calculations, the width of the TZ for this example was 47 km. This area requires a special environmentally balanced subsoil use regime. Such hydrogeological calculations can be carried out for any conditions and areas. Of particular importance is the presence of mining enterprises, hydraulic structures, as well as the extraction of shale oil in cross-border areas.

The world groundwater resources are key to sustainable development. Making full use of groundwater resources and effectively managing the perennial groundwater problems – overuse and pollution – are very difficult challenges. Therefore, the exchange of information and experience on the management of groundwater production around the world will be necessary and useful [18, 29].

In the future, it is planned to use foreign experience in this area, prepare materials for interaction with UNESCO, exchange methods at the international level, amend the basic laws and by-laws regulating the extraction of groundwater from common aquifers. Russia can become the initiator of the consolidation of these concepts and methods in international law. Many international conflicts can be prevented if the problems of subsoil use are approached on the basis of a general agreement.

REFERENCES

1. Bolgov M.V., Demin A.P., Shatalova K.Y. Institutional, regulatory, and managerial aspects of the development of transboundary water bodies and streams in Russia. *Water Resources*. 2016. Vol. 43. N 4, p. 711-717. DOI: 10.1134/S0097807816040047

2. Borevskii B.V., Yazvin A.L. Development of ideas about the exploration of exploitable reserves and groundwater resources and the principles of their categorization. Podzemnye vody Vostoka Rossii, 18-22 iyunya 2018, Novosibirsk, Rossiya. Novosibirskii natsionalnyi issledovatelskii gosudarstvennyi universitet, 2018, p. 21-27 (in Russian).

3. World fresh water market. URL: http://www.vigorconsult.ru/resources/mirovoy-ryinok-presnoy-vodyi/ (date of access 25.03.2021).

4. Mironova A.V., Molskii E.V., Rumynin V.G. Transboundary problems associated with groundwater exploitation near the Russian-Estonian state boundary: case study of the Lomonosovskii-Voronkovskii aquifer. *Water Resources*. 2006. Vol. 33. N 4, p. 386-395. DOI: 10.1134/S009780780604004X

5. Mukhina E.M. Legal regulation of the use and protection of groundwater: Avtoref. dis. ... kand. yur. nauk. Moscow: Institut zakonodatelstva i sravnitelnogo pravovedeniya pri Pravitelstve Rossiiskoi Federatsii, 2011, p. 30 (in Russian).

6. Nikanorova A.D., Egorov S.A. Development of principles and legal rules regulating the use of transboundary water resources by states. *Water Resources*. 2019. Vol. 46. N 1, p. 138-142. DOI: 10.1134/S0097807819010111

7. Orolbaeva L.E. Formation and geo-risk of transboundary groundwater flows in Kyrgyzstan. Ekologicheskaya i tekhnosfernaya bezopasnost gornopromyshlennykh regionov. Trudy IV Mezhdunarodnoi nauchno-prakticheskoi konferentsii, 7 aprelya 2016, Ekaterinburg, Rossiya. Uralskii gosudarstvennyi gornyi universitet, 2016, p. 219-225 (in Russian).

8. Parliamentary hearings in the State Duma (chronicle, annotations, review). URL: http://duma.gov.ru/media/files/s9GWpyC-NyMVLEVDwJ6g55w0ymVhcMqm5.pdf (date of access 25.03.2021).

9. Pugach S.L., Spektor S.V. Inferred resources, reserves, production and quality of groundwater by federal districts and main river basins of Russia. *Ispolzovanie i okhrana prirodnykh resursov v Rossii*. 2010. N 1, p. 8-11 (in Russian).

10. Teimurov E.S. Problems of regulation of rational use and protection of fresh water in bilateral treaties of the Russian Federation. Almanakh kafedry mezhdunarodnogo prava Ceteris Paribus. 2017, p. 78-86 (in Russian).

11. Management of groundwater resources in transboundary aquifers (GGRETA Project). Review and evaluation results (2013-2015). URL: https://groundwaterportal.net/sites/default/files/GGRETA%20Overview%20Brochure_RUSSIAN.pdf (date of access 12.04.2021).

12. Ustyugov D.L., Mironchuk D.P. Short-term pumping tests as an identification method of aquifer-surface interaction. *Journal of Mining Institute*. 2015. Vol. 212, p. 84-88.

13. Frumin G.T., Timofeyeva L.A. Transboundary waters and basins in Russia: problems and approaches to their solution. *Biosfera*. 2014. Vol. 6. N 2, p. 118-133 (in Russian).

14. Yazvin A.L. A review of regulatory and legal documents regulating the exploration and use of potable and industrial underground water sources. *Prospect and protection of mineral resources*. 2014. N 5, p. 3-10 (in Russian).

15. Yazvin A.L. Scientific substantiation of information support for the system of geological study of the resource potential of fresh groundwater: Avtoref. dis. … d-ra geol.-min. nauk. Moscow: Rossiiskii gosudarstvennyi geologorazvedoch-nyi universitet, 2015, p. 48 (in Russian).

16. Aureli A., Eckstein G. Strengthening cooperation on transboundary groundwater resources. *Water International*. 2011. Vol. 36. Iss. 5, p. 549-556. DOI:10.1080/02508060.2011.615137

17. Convention on the Protection and Use of Transboundary Watercourses and International Lakes. Helsinki, 17 March 1992. Elgar Encyclopedia of Environmental Law. Edward Elgar Publishing Limited, 2016, p. 257-268. DOI: 10.4337/9781785369520

18. IGRAC (International Groundwater Resources Assessment Centre). URL: https://www.un-igrac.org/ru (date of access 20.02.2021).

19. Janusz-Pawletta B., Gubaidullina M. Transboundary Water Management in Central Asia. Legal Framework to Strengthen Interstate Cooperation and Increase Regional Security. *Cahiers d'Asie centrale*. 2015. N 25, p. 195-215.

20. Jarvis T. The International Law of Transboundary Groundwater Resources. *Groundwater*. 2017. Vol. 56. Iss. 2, p. 247-247. DOI: 10.1111/gwat.12626

21. Kirsanova N.Yu., Lenkovets O.M. Future vision and possibilities of Russia's transition to "green" economy. Responsible Research and Innovation (RRI 2016), 7-10 November 2016, Tomsk, Russia. Future Academy, 2016, p. 514-521. DOI: 10.15405/epsbs.2017.07.02.66

DOI: 10.31897/PMI.2021.6.2

22. Lange I.Y., Lebedeva Y.A., Kotiukov P.V. A Study of Water Permeability of Coal Ash and Slag to Assess the Possibility of Their Use as Road Pavement Layers. *International Journal of Engineering Research and Technology*. 2020. Vol. 13. N 2, p. 374-378. DOI: 10.37624/IJERT/13.2.2020.374-378

23. Lebedeva Y.A., Kotiukov P.V., Lange I.Y. Study of the geo-ecological state of groundwater of metropolitan areas in the conditions of intensive contamination thereof. *Journal of Ecological Engineering*. 2020. Vol. 21. N 2, p. 157-165. DOI: 10.12911/22998993/116322

24. Lenkovets O.M. Housing renovation in Russia and engineering and environmental aspects of renovation programs. *Journal of Advanced Research in Dynamical and Control Systems*. 2020. Vol. 12. Iss. 4, p. 1060-1068. DOI: 10.5373/JARDCS/V12SP4/20201579

25. Leonteva E., Norova L. Anthropogenic impact on the resources and composition of groundwater in the North-Western slope of the Moscow Artesian Basin. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management SGEM*. 2018. Vol. 18. Iss. 1.2, p. 59-66. DOI: 10.5593/sgem2018/1.2/S02.008

26. Litvinenko V.S. Digital Economy as a Factor in the Technological Development of the Mineral Sector. *Natural Resources Research*. 2019. Vol. 29, p. 1521-1541. DOI: 10.1007/s11053-019-09568-4

27. Smirnova N.V., Cherepovitsyn A.E., Ilinova A.A. Application of Norwegian and Russian legislative basis during collaborative development of transboundary hydrocarbon fields. *European Research Studies Journal*. 2018. Vol. 21. Special iss. 2, p. 434-441.

28. UNESCO 2013-2015 GRGTA (Groundwater Resources Governance in Transboundary Aquifers). URL: https://unesdoc.unesco.org/images/0024/002430/243003r.pdf (date of access 29.04.2021).

29. UNESCO Internationally Shared (Transboundary) Aquifer Resources Management. A framework document – 2001. URL: http://www.fao.org/fileadmin/templates/legal/docs/Int_Shared_Aquifer_Resources_Management.pdf (date of access 25.03.2021).

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