

Some Aspects of Groundwater Resources Management in Transboundary Areas

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ABSTRACT

According to UN experts, by 2030, about half of the world's population will suffer from a shortage of fresh water, which may cause future hostilities and conflicts. In this regard, extraction of such a valuable mineral as groundwater must be rationally managed. However, practice has shown that managing and protecting the groundwater resources is a very challenging task. As part of the analysis pertaining to 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 agreements of the Russian Federation were identified; a methodology for managing groundwater extraction in the territory of a transboundary aquifer was developed, dimensions, parameters and factors affecting the formation of a transboundary zone were determined (using the example of research and analysis of water intake activities in the border territories of the Russian Federation and the Republic of Estonia).

Keywords: groundwater, transboundary zone, transboundary aquifer, water intake, water extraction, management, regulation, hydrogeological calculations.

INTRODUCTION

Groundwater is one of water supply sources and the most important minerals. In the context of increasing deterioration in the quality of surface waters, fresh groundwater is often the only source providing the population with high quality drinking water, protected from pollution [Pugach 2015].

According to the UN experts, in the 21st century, water will become a more important strategic resource than oil and gas, since a ton of clean water in arid climate is already more expensive than oil (Sahara Desert and North Africa, center of Australia, South Africa, Arabian Peninsula, Central Asia). The lack of clean fresh surface water is forcing many countries to use groundwater more actively. In the European Union, already 70% of all water used by consumers is taken

from underground aquifers. Groundwater is the only source of fresh water for public consumption in Denmark, Lithuania and Austria. In arid countries, water is almost entirely taken from the underground sources (Morocco – 75%, Tunisia – 95%, Saudi Arabia and Malta – 100%) [World fresh water market].

In accordance to the leading UN experts, by 2025 Russia, together with Scandinavia, South America and Canada, will remain the countries which are most abundant in fresh water – more than 20 thousand m³/year per person (inhabitant) [Stroykov et al. 2020]. In future, Russia will be assigned a special role in solving the problems of rational water use not only on its territory, but also in the international arena [Improvement of the legal regulation 2012]. This determines the strategic importance of water resources for the Russian Federation. The questions regarding sufficiency

of fresh water reserves do not arise in the Russian Federation, at the same time, in some neighboring countries, the problems of using fresh water are quite acute, which may also affect the fresh-water objects shared with Russia. In this regard, it seems relevant to study the bilateral treaties of the Russian Federation on the use and protection of transboundary fresh water sources in order to establish their compliance with modern trends in development of international legal regulation of relations in this area and ensuring the interests of the Russian state [Teymurov 2017].

Many aquifers and complexes existing in the world are transboundary, that is, they lie on the territory of two or more administrative units within a country or two or more countries. Obviously, 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 the groundwater issues, based on mutual trust and transparency. Unfortunately, at present there are not many examples of such cooperation in the world [GGRETA Project 2015].

Very few international boundaries match the natural physical features, and water resources can cross them unhindered. In order to effectively manage and distribute these resources fairly, scientists assess the resources that cross these boundaries. In hydrogeological terms, these crossing resources can only be estimated through observations and measurements of selected hydraulic parameters, similar to the process of estimating other transboundary resources. In many cases, an aquifer can have a recharge area in the territory of one state, and a discharge area in the territory of other border states. For Russia, the topic is very relevant due to the presence of 16 land-based neighboring states.

The analysis of the current state of exploration maturity and use of groundwater shows that under the new socio-economic conditions, the effectiveness of research significantly depends not only on the degree of knowledge of the hydrogeological conditions, but also on the compliance of their results with the requirements of the regulatory framework. The issues of normative legal regulation of the study and extraction of groundwater have not yet received sufficient scientific substantiation, which significantly affects the information security of the work performed and their efficiency [Yazvin 2015].

By its nature, beneficial and rational use of groundwater is more dependent on socio-economic, institutional, legal, cultural, ethical and political considerations than surface waters. Their national development is hampered by weak social and institutional capacities, as well as weak legal and policy frameworks. In a transboundary context, this can be further enhanced by contrasting levels of knowledge, capabilities and institutional frameworks on both sides of many international borders [UNESCO, ISARM 2001].

The contemporary research in minerals processing aims to improve the environmental economic and energy efficiency of technological processes, as energy and water requirements are very important [Litvinenko 2019]. The balance of economic interests between the country's constituent regions is a required condition for improving the efficiency of the mineral resource sector at all management levels [Vasilenko et al. 2019, Kirsanova 2017, Lenkovets 2020, Stroykov et al. 2020, Kirsanova et al. 2017, Baranova et al. 2020, Luebeck 2019].

The problems of transboundary regulation of mineral resources extraction are analyzed in the works of different scientists [Eckstein 2017, Jarvis 2017, Smirnova et al. 2019]. Allocating shared water resources of transboundary character according to international law is one of the key factors of security in the region [Janusz-Pawletta et al. 2015].

The main goal of this article was to improve the legal framework in the field of state regulation of groundwater resources in transboundary territories by amending the laws and regulations governing the procedure for groundwater extraction for various purposes from transboundary aquifers and complexes. The work assumes the use of foreign experience in this area, preparation of materials for interaction with UNESCO, exchange of methods at the international level, amendments to the basic laws and by-laws governing extraction of groundwater from common aquifers.

MATERIALS AND METHODS

The search for ways to resolve interstate disagreements on the use of water bodies located on the territory of two or more states is increasingly relevant in the international community [Nikanorova et al. 2019]. In this regard, it is paramount to

establish the concepts and definitions in the field of transboundary water resources.

Transboundary waters are understood as the reservoirs and watercourses, which either cross the state border of two adjacent states, or along which state borders pass [Bolgov et al. 2016]. This concept was adopted in 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” [Convention Helsinki, 1992]. Article 19 of the Water Code of the Russian Federation of 1995 defined 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”. Unfortunately, in the Water Code of the Russian Federation, approved in 2006, and in the amendments to it, there is no such article [Bolgov et al. 2016, Water Code 2006].

Attention should be paid to transboundary sources of fresh water, relations on the use and protection of which are the subject of relevant bilateral agreements. 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 [Agreements], while the other half of the treaties excludes the use and protection of transboundary sources of groundwater [Antipov et al. 2019].

At the same time, the existing international treaties and other acts in order to ensure the rational use and protection of transboundary fresh water sources are increasingly calling on states to implement integrated water resources management (hereinafter – IWRM), which, first of all, involves coordinated management of various types of water resources – surface, underground, etc. Unfortunately, this part of IWRM remains the most unenforceable, since the peculiarity of groundwater and the resulting need for special legal regulation, are not taken into account.

This problem continues to be relevant for Russia. Thus, the use and protection of surface fresh water resources is regulated by the provisions of

the 2006 Water Code of the Russian Federation [Water Code 2006]. As for groundwater, although they are partially subject to the norms of the Water Code, the issues of their use and protection are mainly regulated by the legislation on subsoil, in particular, the Law of the Russian Federation “About mineral resources” No. 2395–1 dated February 21, 1992 [Law of the Russian Federation “About mineral resources” 2020]. In addition to the fact that both legislative documents need to be modernized, the correct delimitation and interconnection of these regulatory documents is necessary [Golovina, 2013]. Thus, after numerous amendments to water legislation, the concept of continuity “in relation to legal regulation of groundwater bodies has disappeared. Thus, while the earlier existing Water Code of the Russian Federation contained the concept of “underground water body”, in the new Water Code of the Russian Federation there is no such concept. To date, it is unclear what is meant by a groundwater body as an object of legal regulation of water legislation and how it differs from the groundwater regulated by mining law. The lack of uniformity in terminology creates confusion in the choice of the branch of natural resource law, which is designed to regulate the use and protection of groundwater” [Mukhina 2011]. Having analyzed many provisions of the Water Code, we can conclude that it only regulates the relations in the field of the use of surface water bodies. Almost every chapter of the Code regulates the operation of underground water intakes, referring to the Law of the Russian Federation “About mineral resources” [2020].

The current Water Code stipulates that the right to use groundwater bodies arises on the grounds 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 detailing and legal regulation of relations” in the legislation on subsoil” [Yazvin 2014]. The 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 [Mukhina 2011].

The foregoing leads the majority of researchers to a reasonable conclusion about the fragmented nature of legal regulation of the use and protection of water resources and ignoring the ecosystem approach in Russian legislation [Relationship 2020].

It should also be noted that the bilateral treaties of the Russian Federation are based on the applicability of the same rules to surface and underground transboundary freshwater bodies.

Indeed, the State practice regarding the use of groundwater freshwater resources is based on the provisions applicable to surface waters. As F. Zacharia (Romania) notes, the issues of the use of aquifers are ignored in state practice not intentionally, but in connection with the opinion that the same rules apply to them as to surface waters [Teymurov 2017].

The practice of applying the norms on the regulation of the use and protection of surface waters to groundwater was also reflected in the process of codification activities of the UN International Law Commission. In particular, the concept of a watercourse given in Article 2 of the 1997 Convention on the Law of the Non-navigational Uses of International Watercourses (hereinafter referred to as the 1997 Convention) includes both surface and ground waters. However, in this case, we are talking about the groundwater associated with surface waters. Confined, unbound groundwaters have been excluded from the scope of the 1997 Convention [Teymurov 2017].

Water resources, in accordance with the Constitution of Russian Federation, are the subject of state protection. The basic principles of water resources protection are detailed in the political documents of the Russian Federation: “Concept of National Security”, “Ecological Doctrine”, “National Security Strategy of the Russian Federation until 2020” [Bolgov et al. 2016]. The issues of water resources protection are reflected in the water law of the Russian Federation, which is the most important component of the state water resources management in Russia. The national water legislation consists of the Water Code of Russia and federal laws and regulations of the Russian Federation adopted in accordance with it, as well as the regulations of the constituent entities of the Russian Federation [Law of the Russian Federation “About mineral resources” 2020]. State regulation in the field of water law in the Russian Federation is carried out taking into account the political norms and principles of international water legislation.

Currently, the Russian Federation has 9 bilateral intergovernmental agreements with the neighboring states on the joint use and protection of transboundary objects: with Abkhazia – 2011, with Azerbaijan – 2010, with Belarus – 2002,

with Kazakhstan – 2010, with China in 2008, with Mongolia in 1995, with Ukraine in 1992, with Finland in 1964, with Estonia in 1997, and one trilateral agreement with Finland and Norway in 1959 [Law of the Russian Federation “About mineral resources” 2020].

Among the intergovernmental agreements concluded by the Russian Federation and providing for the creation of joint commissions include the Agreement on cross-border (transboundary) cooperation with Finland, Estonia, Belarus, China, Kazakhstan, Azerbaijan and Abkhazia. In turn, the agreements, the implementation bodies of which are the institute of commissioners, – a trilateral agreement of the Russian Federation with Finland and Norway and bilateral agreements with Ukraine and Mongolia [Bolgov et al. 2016].

The international practice of using transboundary water bodies, based on the principles of sustainable development, presupposes concerted actions of states on the territory of the basins of transboundary watercourses in implementation of water supply works, use and protection of water bodies on the basis of international treaties and agreements. Russia has ratified a number of international acts regulating the protection and use of transboundary waters.

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 transboundary zone (further TZ) along the state borders. The authors were the first to define the concept of “territory of a transboundary aquifer” as a strip of land located on two sides from the state border of neighboring countries, with certain geometric dimensions according to the hydrogeological calculations based on the filtration parameters of jointly exploited aquifers.

Limiting the width of transboundary zone (TZ) along the state borders means, first of all, the limitation of areas of responsibility for groundwater extraction, construction of mining enterprises, land reclamation works, as well as extraction of shale oil. TZ must meet the following requirements (factors):

1. A specially controlled subsoil use regime (groundwater resource management) within the width of TZ.
2. Restrictions on the development of reserves in transboundary territory (border). This clause is determined by mutual agreements and

settlements, i.e. parties agree on the maximum possible (permissible) reduction of the groundwater level at the specified monitoring points for the billing period.

3. Mutual bi-directional monitoring system for all exploited aquifers with functions of periodic measurement of levels as well as production of chemical, radiological, and microbiological analyses.
4. A special regime for control over groundwater extraction, expressed in a 100% licensing system for water intakes, including low-flow single water intakes with a production volume of up to 100 m³/day and mandatory approval of reserves by categories with exploration [Borevsky 2018]. Each water intake falling 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.
5. It should be noted that drinking, technical and mineral waters are undoubtedly “minerals”, if their reserves are considered by the State Commission on Reserves. If it is a mineral, then it is a “commodity”. Any product must have a value [Borevsky 2018, Khaustov 2017, Lange et al. 2020, Leonteva et al. 2018–2019]. It is advisable to introduce a transition to a new system of taxation of groundwater extraction on the TZ, i.e. introduction of mineral extraction tax, the rate of which may vary depending on the quality of groundwater, intended use, category of reserves. On the basis of the works of Borevsky B.V., the cost of groundwater acquires a function of the cost of water treatment; intended use; transportation; category of reserves (A, B, C1, C2).

The authors have developed a methodology for substantiating the width of the territory of a transboundary aquifer, taking into account specific geological conditions. The materials of geological research in the territory of the Leningrad region and Estonia were used as an example. The object of the study was the Lomonosov aquifer, which is operated for the purposes of 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 covered in detail in the work of Mironova A.V., Rumanin V.G. and others in 2006 using modern methods of numerical modeling for two main aquifers in the area of the Russian-Estonian border [Mironova et al. 2006].

The study boundaries were taken in fact from the aquifer recharge area to the discharge area. The research work is of fundamental nature, a huge number of water intakes, the data from the monitoring network, both Russian and Estonian, have been analyzed, and the influence of individual water intakes, both from the Russian side to the Estonian side, and vice versa, have been calculated. The main conclusions of the work are that hydrodynamic situation in the transboundary territory 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, and early 2000s. The most important factor in this work is mutual participation of specialists from both Russia and Estonia. This concerns the development of a numerical model and analytical calculations. Our state continues to exchange the data from the groundwater monitoring systems, and also uses the developed numerical model to solve predictive epignosis tasks.

As mentioned earlier, the problems of transboundary groundwaters are of great relevance at the present time. The assessment of 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 [Mironova et al. 2006].

The work evaluates the joint exploitation of groundwater in the border zone between Russia and Estonia. In hydrogeological terms, the territory under consideration is located within the East European artesian basin [Sidorenko et al. 1967]. The most exploited aquifer in the border area is the Lomonosov (Lower Cambrian) Aquifer (LA), which are under the influence of joint exploitation of groundwater for drinking water supply, mine and quarry drainage in the Russian Federation and the Republic of Estonia.

The freshwaters of the Lomonosov aquifer were drilled by wells in the Russian Federation on the territory of the Gatchinsky, Lomonosov, Volosovsky, Kingisepp and Slantsevsky districts

of the Leningrad region, as well as in the northern part of the Gdovsky district of the Pskov region. The Lower Cambrian aquifer is represented by the terrigenous deposits of the Lomonosov Formation. On the territory of the Republic of Estonia, the main water intakes are located in the settlements of Narva, Narva-Jõesuu, Toila, Sillamäe, Vaivara.

Water-bearing deposits are represented by fine-grained, weakly cemented sands with interlayers of clays. The aquifer thickness in the study area is on average 20 m. The water-resistant roof for the Lomonosov aquifer is the clays of the Lontovskaya formation. It is underlain by water-resistant Kotlin deposits of the Upper Proterozoic. The aquifer lies at a depth of 109 to 208 m from the earth's surface. The filtration coefficient is 0.11–5.2 m/day, in the study area – on average 3 m/day. Water transmissibility varies from 50 to 150 m²/day in the study area 60 m²/day [Information note Russia-Estonia) 2018]. Delivery lift of the Lomonosov aquifer in some places reaches 180 m and more. The depth of the water level varies from 34.4 to 72 m. The chemical composition of groundwater is mainly hydrocarbonate-sodium chloride with mineralization of 0.5–0.6 mg/dm³. Water hardness does not exceed 1 mg-eq/dm³. In some places, there is an increased content of bromine up to 4.1 mg/dm³ and fluorine up to 0.5 mg/dm³ [Information note Russia-Estonia 2018].

The aquifer has been sufficiently studied; monitoring observations are carried out on it both on the territory of Russia and from the Estonian side. The process of 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. Total water withdrawal from the Lomonosov aquifer for 2015–2017 in the border area of Russia and Estonia is presented in Table 1 [Information note Russia-Estonia 2018]. Thus, the influence on the piezometric surface of the Lomonosov aquifer of the two states is almost equal (53–57% Russia, 43–47% Estonia).

On the territory of Russia, exploitation of the aquifer and observations of the hydrodynamic situation are carried out at three large group water intake centers: in the cities of Ivangorod, Kingisepp, Slantsy. On the territory of the Republic of Estonia, water intakes are operated and changes in the aquifer are monitored at five water intakes located near the following settlements: Vaivara, Narva, Toila, Sillamäe, Narva-Jõesuu.

On the basis of the available data, we will assess the change in the piezometric surface of the 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 operation of water intakes on the territory of the Russian Federation and on the territory of the Republic of Estonia; calculating the lowering of the piezometric level within the radius of influence, determining the amount of “taken” groundwater resources from the territories of neighboring states for a service life of 25 years.

In order to assess the nature of change in the piezometric level of transboundary groundwaters of the Lomonosov aquifer during operation, standard calculation schemes are used to assess the groundwater reserves with the hydrodynamic method. The main task of the hydrodynamic method is to determine the calculated lowering during the operation of the 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 allowable decrease is determined by the arithmetic mean value, which is $S_{pr} = 136$ m. Due to the lack of information from Estonia, we accept the filtration parameters and the allowable decrease by analogy with the fields located in Russia. In order to select a typical design scheme, we schematize the natural geological and hydrogeological conditions of the study area. The following formula can be used:

$$S = \frac{Q_t}{2\pi km} \cdot \ln \frac{R}{R_0} \quad (1)$$

Table 1. Total water withdrawal from the Lomonosov aquifer in the Border Territory (Russia-Estonia)

Year	Water extraction, thousand m ³ /day		Percentage impact on aquifer	
	Russia	Estonia	Russia	Estonia
2015	3,85	2,883	57	43
2016	3,26	2,735	54	46
2017	3,344	2,923	53	47

where: Qt – total water consumption, thousand m^3/day ;
 km – water transmissibility, m^2/day ;
 t – estimated life of the water intake – 104 days;
 R – radius of influence, calculated, according to the formula:

$$R = 1,5\sqrt{at} \quad (2)$$

where a – piezoconductivity, m^2/day ;
 R_0 – radius of “big well”, for a real well location $R_0=0,1P$; P – perimeter, m.

Complementary degradation at the well (S_0):

$$S_0 = \frac{Q_w}{2\pi km} \cdot \ln \frac{r}{r_f} \quad (3)$$

where: Q_w – project well flow rate, m^3/day ;
 r – radius of the area of influence of the design well, m,
 r_f – the radius of the well filter, m;

$$R_e = 0,47 \cdot \sqrt{\frac{F_0}{\pi}} \quad (4)$$

where: R_e – equivalent radius
 F_0 – the area of the area bounded by lines running in the middle between adjacent wells, m^2 .

The Lomonosov aquifer is pressure water horizon, overlain by Lontov’s water-resistant sediments of folded silty clays, the filtration coefficient of which is 0.02 m/day. 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 exploited jointly, as a result of which there is a hydraulic connection between them. Since the Lomonosov aquifer is isolated by aquicludes, unlimited in plan, and pressure head, the Theis scheme is used for lowering calculations. On the territory of the works, water intakes will be considered as compact groups of wells; therefore, it is advisable to make hydrogeological calculations using the “big well” method [Dashko et al., Directive 2000, Lange et al. 2019, Leonteva et al. 2018, 2019, Ustyugov et al. 2015]. The distance between the intakes is taken from their center (Table 2).

The distances from the water intake sections to the Russia-Estonia border are presented in Table 3. For calculations, we will use distance from the center of the “big well” to the border, which from the Russian Federation is about 15,000 m, and from Estonia about 15,750 m. Changes in the piezometric surface from operation of the water intakes for the service life of the water intakes 10^4 days (Table 4) are shown below.

Calculation of the total decrease (S_t) according to the “big well” method includes: the decrease on the external contour (S_{ext}), which is determined in accordance with the schematization and is adopted – the Theis-Jacob scheme, the decrease inside the “Big well” system in the well itself (S_0). In addition, the calculation takes into account depressions from the interaction of water intakes located in the adjacent territory (S_{at}). The results are shown in Table 4.

The permissible decrease of 136 m does not exceed the calculated one for a service life of 10^4 days. In order to identify the changes in the natural conditions of the Lomonosov aquifer from the operation of water intakes in the transboundary territory of Russia – Estonia, let us trace the dynamics of the change in pumping depression over time. According to the data obtained in the study of the Lomonosov aquifer,

Table 2. Distance between the observation points

№	Russian Federation		Republic of Estonia	
	Location	Distance, m	Location	Distance, m
1	Kingisepp-Slantsy	40900	Toila – Sillamae	16700
2	Kingisepp – Ivangorod	19000	Sillamae-Narva-Joesuu	19800
3	Ivangorod – Slantsy	33800	Narva-Joesuu – Narva	11500
4			Narva – Vaivara	23100
5			Vaivara – Toila	17000
6	Totally	93700	Totally	88100

Table 3. General information about water intakes located on the territory of the Russian Federation

Location of the well field	Number of wells	Total flow rate m ³ /day	Distance to the border with Republic of Estonia, m	Location of the well field	Number of wells	Total flow rate m ³ /day	Distance to the border with Russian Federation, m
Ivangorod	2	1931	3740	Vaivara	2	2923	15100
Slantsy	5	270	17700	Toila	1		30200
Kingisepp	5	1140	19600	Sillamae	1		30000
				Narva-Joesuu	1		3007
				Narva	1		367
in all	12	3341	15000	in all	6	2923	15750

Table 4. Results of calculations of changes in the piezometric level

Indicators	Water intakes on the territory	Water intakes on the territory
Sext, m	14,35	13,06
S0, m	9,86	6,12
Sat, m	5,67	4,96
St, m	29,88	24,14

we determine the radius of influence, the value of which is $R_e = 47434$ m. We take the value of the radius of influence equal to the aquifer in Russia and Estonia.

On the basis of this magnitude of the radius of influence, it can be concluded that the influence from the operation of water intakes at 31684 m will go beyond the borders of the Republic of Estonia and by 32434 m outside the borders of the Russian Federation. Further, it is advisable to determine the dynamics of the spread of the depression

funnel (pumping depression) for different periods of time on both sides of the transboundary zone. The calculations are shown in Table 5. The assessment of the dynamics of the pumping depression spread was considered by calculating the radius of influence for 5 points in time 450, 500, 1000, 1103, 2000, 5000 days. The calculation shows a systematic change in the pumping depression, which will reach the border from the Republic of Estonia in 1103 days, and from the Russian Federation in 1000 days (Figure 1).

Using the obtained radius of influence, we will calculate the decrease. The results are presented in Table 5 and Figures 1, 2. Taking into account the calculated depressions obtained, let us determine the amount of “withdrawn” groundwater resources from the territory of the Republic of Estonia and from the territory of the Russian Federation. The calculation is made according to the converted Theis scheme:

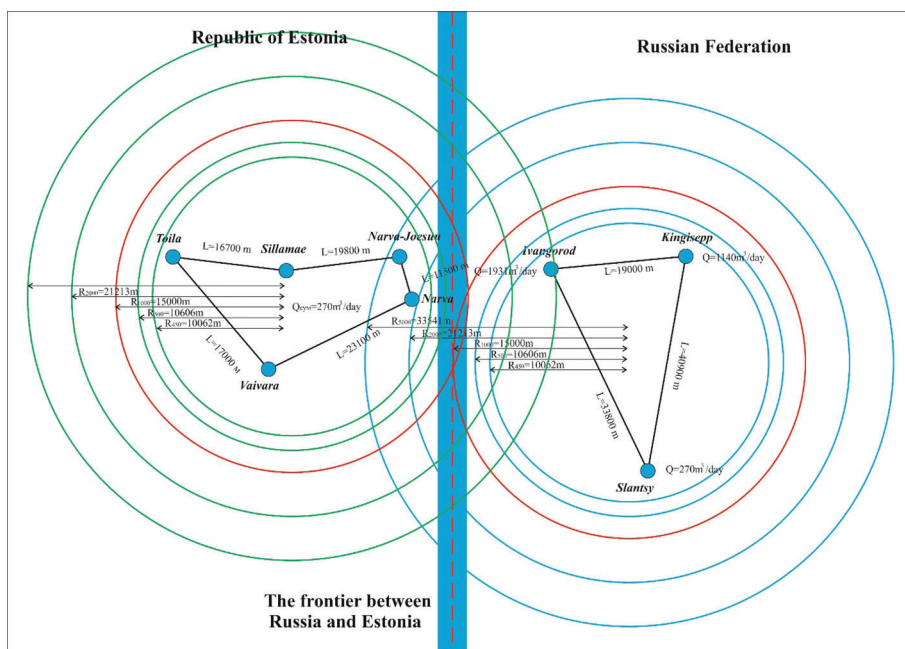


Figure 1. The dynamics of the pumping depression spread during the operation of water intakes

Table 5. The calculated value of the decrease at different points in time

Water intake operating time, days	Influence radius Re, m	Lowering on the external circuit of the «Big well», Sext, m	Additional lowering, S ₀ , m	Cutting off the level from the work of neighboring groups of water intakes, m	Total decrease, St, m	Water intake operating time, days	Influence radius Re, m	Lowering on the external circuit of the «Big well», Sext, m	Additional lowering, S ₀ , m	Cutting off the level from the work of neighboring groups of water intakes, m	Total decrease, St, m
Russian Federation						Republic of Estonia					
450	10062	13,73	9,86	5,67	29,26	450	10062	12,03	6,12	4,96	23,11
500	10606	13,26	9,86	5,67	28,79	500	10606	11,62	6,12	4,96	22,70
1000	15000	10,19	9,86	5,67	25,72	1000	15000	8,92	6,12	4,96	20,00
1103	15750	9,75	9,86	5,67	25,28	1103	15750	8,53	6,12	4,96	19,61
2000	21213	7,13	9,86	5,67	22,66	2000	21213	6,25	6,12	4,96	17,33
5000	33541	3,10	9,86	5,67	18,63	5000	33541	2,72	6,12	4,96	13,80

$$Q = \frac{2 \cdot \pi \cdot T \cdot S_{ext}}{\ln \frac{R_e}{R_0}} \quad (5)$$

where: *T* – water permeability m²/day;
S – lowering on the external circuit of the “big well”.

The calculation results are presented in Table 6 and in Figure 2.

Calculations have shown that the pumping depression created by the operation of water intakes located on the territory of Russia and Estonia operating the (Lower Cambrian) Lomonosov aquifer will be *R_e* = 47434 m during the operation of the water intakes 10⁴ days.

The radius of influence from the operation of the water intakes will reach the border after 1000 days of operation from the Russian side and after 1103 days from the Estonian side, and the decrease in it will not exceed 25.72 m and 19.61 m, respectively.

Calculation of water consumption from the operation of water intake sites in different currents of the pumping depression showed that from the center of the “big well” to the border with the Republic of Estonia, the amount of resources operated by water intakes is 2372.4 m³/day, out of the required 3341 m³/day. This difference suggests that the groundwater resources in the amount of 968.6 m³/day, extracted from the water intakes located on the territory of Russia are “taken” from the territory of Estonia, which in terms of

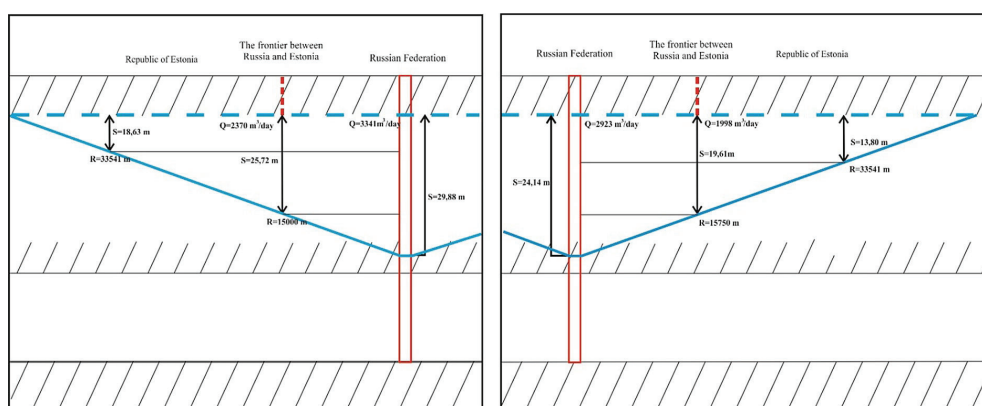


Figure 2. Changes in piezometric level during the operation of water intakes in Russia.

Table 6. Amount of “withdrawn” groundwater resources from the territory of the Republic of Estonia

Water intake operating time, days	Influence radius Re, m	Lowering on the external circuit of the «Big well», Sext, m	Percentage of «withdrawn» water	Water intake operating time, days	Influence radius Re, m	Lowering on the external circuit of the «Big well», Sext, m	Percentage of «withdrawn» water
Russian Federation				Republic of Estonia			
15000	10,2	2372	29	10606	8,91	1998	32

percentage is 29%. Up to the border with the Russian Federation, the amount of resources operated by water intakes is 1998 m³/day, out of the required 2923 m³/day. This difference suggests that the groundwater resources in the amount of 925 m³/day, extracted from the water intakes located on the territory of Russia “are taken” from the territory of Estonia, which in terms of percentage is 32%.

CONCLUSIONS

Undoubtedly, such an approach to solving the hydrogeological problems in the transboundary territory can be an example of cooperation between neighboring states in the development of relations in the field of 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 Estonia, but within the framework of the allocated TZ. The calculations used the subsoil data for the main large water intakes that fall into the TZ.

From the calculations, it can be concluded that inevitably in the territory of one of the states the volume of water resource extraction will always be higher than in the territory of the neighboring country. A quantitative assessment of water resource taken from the aquifer of a neighboring state can be performed by calculation using the balance method. To date, the quantitative indicators of the extracted resource cannot have a monetary equivalent as a commercial product; therefore, mutual settlements between the states that operate the same aquifer cannot be carried out in value terms. The factors for limiting the excessive extraction of groundwater in the TZ should be the criteria for the position of the groundwater level, as well as their quality within the framework of the interstate agreements reached, which are controlled within the framework of the international groundwater monitoring system.

According to Mironova, Molsky, Romanin, one of the main problems of joint subsoil use in the transboundary territory is a quantitative assessment of the “attraction” of water resources during the exploitation of an aquifer from the territory of a neighboring state [Mironova et al. 2006]. 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 very limited recharge area. Nevertheless, the problem under consideration narrows the area of research, despite the fact that regional hydrogeology and the genesis of the main horizons itself must be taken into account in forecasting tasks and especially when creating a numerical model of transboundary areas.

Today, there are a lot of border areas, especially on the territory of the African continent, Central Asian states and the Middle East, where geological exploration is simply not even carried out, let alone a monitoring system. Examples include Botswana, Namibia [UNESCO ISARM 2001]. Therefore, when creating a limited research area (width of TZ), the task of the international concept of TZ can be solved without global costs. The financing of the organization of TZ should be undertaken by the state, the specific share of which in the issue of subsoil use is the largest.

At the same time, an unconditional factor in organizing TZ is the involvement of specialists from both bordering states. If there is a shortage of them, it is possible to attract 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 areas, it is advisable to use the data on the existing water intakes, as well as the local network of the local network of observation points, and if mining enterprises or hydraulic structures reach the TZ, the account of the hydrogeological situation must be analyzed first.

The transboundary territory should have a certain limitation on the area of distribution, which is determined by the hydrogeological parameters and characteristics. The relevant rules and regulations can be applied to this territory. According to preliminary calculations, the width of the TZ can be from several kilometers to the first tens of kilometers.

It has been established that groundwater is a special type of minerals, the reserves and resources of which are renewable and dynamic, and act simultaneously as the most important component of the environment, affecting ecosystems and man-made objects, and as a valuable

resource for drinking and domestic water supply, for medicinal purposes, extraction of mineral and biological resources, which determines their high economic and social significance and the need for their rational use as well as protection from pollution and depletion.

Moreover, it has been established that most of the large aquifers and aquifers are located on the territory of several states, and are the object of the development of groundwater resources for their own purposes, which creates the preconditions for the formation of mutual agreements, agreements, conventions governing obligations to limit production and maintain a control system

A methodology for managing groundwater extraction in the transboundary zone has been developed, dimensions, parameters and factors affecting the formation of a transboundary zone have been determined (using the example of research and analysis of water intake activities in the border territories of the Russian Federation and the Republic of Estonia).

According to the results of hydrogeological calculations, the width of the transboundary territory 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 other conditions and areas. The presence of mining enterprises, hydraulic structures, as well as the extraction of shale oil in cross-border areas is of particular importance. In future studies, it is planned to expand the geography of the selected for analysis aquifers lying on the border territory of Russia and neighboring countries.

The global groundwater resources are key to sustainable development. Taking full advantage of groundwater resources and effectively managing perennial groundwater problems such as overuse and pollution are very difficult challenges. The exchange of information and experience on the management of groundwater production around the world will be necessary and extremely useful in this regard [Directive EU 2000, IGRAC 2020].

Under the conditions where the situation in the global economy and raw materials sector is not stable, expansion and deepening of international economic cooperation are gaining special importance [Litvinenko et al. 2018, 2020]. Russia can be the initiator of the consolidation of the mentioned 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.

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