Features of the formation and use of groundwater in the Novgorod region

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Abstract. The article discusses the problem of providing fresh water to residents of the Novgorod region, which is linked to the possibilities of expanded use of groundwater. The authors characterize the features of occurrence and distribution of the aquifer in the region. Special attention is paid to the mineralized waters of the region, the features of their modern use in the resort industry and the food industry, for domestic needs of the population.

1. Introduction
The problem of providing consumers with clean water is very relevant for the Novgorod region. According to the Office of the Federal Service for Supervision of Consumer Rights Protection and Human Well-Being in the Novgorod Region, the number of unsatisfactory samples of drinking water in the region in terms of sanitary and chemical indicators amounted to 34.2\% (38.2\% in 2018) in the distribution network. The most unsatisfactory water quality in terms of sanitary-chemical indicators (significantly higher than the regional indicator) is in Batetsk (87.5\%), Starorussky (85.5\%), Kholmsky (90.4\%) districts. Basically, the discrepancy is due to such indicators as color, turbidity, iron. According to microbiological indicators, 4.9\% of the studied samples did not meet hygienic standards (2018–4.0\%). The most unsatisfactory water quality according to microbiological indicators (significantly higher than the regional indicator) is in the water pipelines of Batetsky (33.3\%), Kholmsky (18.7\%), Chudovsky (11.2\%) districts.

2. Objects and methods of research
The object of research is the underground fresh and mineral waters of artesian basins located within the Novgorod region.

The characteristics of underground waters were carried out using the analysis of cartographic material and scientific literature.

3. Results and discussion
The region uses mainly surface water resources for water abstraction and further provision of the population with clean drinking water. The second important source of both fresh and mineral water is groundwater. In the region, groundwater permeates almost the entire thickness of sedimentary rocks, forming a powerful basin of artesian waters. In structurally hydrological terms, the region is located within the Leningrad groundwater basin, and only its extreme eastern part belongs to the Moscow basin.
The upper part of this basin, which combines quaternary, carboniferous, Devonian aquiferous complexes and horizons, is best studied. It is that is of the greatest interest for water use. The lower part of the basin, consisting of the Ordovician, Cambrian, and Proterozoic aquifers, is poorly studied.

Groundwater is associated with all genetic types in quaternary sediments. They are confined to the sandy and loamy strata of lacustrine, alluvial, lacustrine-glacial, fluvio-glacial and glacial deposits. The swamp waters of modern peat bogs are also widespread in the region. A common feature for quaternary groundwater is:

- shallow occurrence—from 0.5–1m to 8m;
- circulation pattern—pore water with a free surface;
- powersource—precipitation;
- drainage of aquifers carried out by the entire river network of the region;
- insignificant water mobility of deposits—the maximum flow rate of wells does not exceed 1 l/s;
- level mode, subject to seasonal fluctuations and depending on the amount of precipitation.

The underground waters of the quaternary sediments are widely used by the population of small villages for domestic and drinking water supply. As a rule, the source of water abstraction is dug wells 1–10 m deep. However, due to the shallow occurrence of groundwater and the good filtration ability of sandy rocks, which favors the penetration of wastewater, conditions are created for surface water pollution [1]. This circumstance, as well as the low water availability of the quaternary horizons, does not allow us to consider quaternary sediment water as a reliable source of water supply for settlements. The waters of deeper aquifers are of greatest interest from this point of view.

The Devonian deposits lie directly under the quaternary deposits in most of the Novgorod Region, and only along the eastern border of the region the deposits of the carboniferous system stretch, forming the so-called carbonic plateau. In the section of coal deposits, there are aquifers, which belong to:

1. Limestone-dolomite stratum of middle carboniferous. Water circulates in limestones, dolomites and dolomitic limestones, highly fractured and karst. The latter is evidenced by the presence of a large number of karst voids developed from the surface—from saucer-shaped funnels to large karst basins, as well as the presence of large karst springs and periodically disappearing karst lakes. The water mobility of the horizon is generally high, however, the flow rate of the wells varies widely, which depends on the degree of fracturing and karst rocks.

2. Lower carbon deposits:

   a) Limestone-dolomite strata. Water-bearing rocks are pure and dolomitic limestones, and dolomites with rare and unstable clay interlayers up to 1–5 m thick. Limestones and dolomites are broken by a system of various cracks, and karst voids, channels and lakes are also developed in them. Large karst springs with very large flow rates, up to tens of l/sec, are confined to these limestones. However, the degree of water availability of the limestone-dolomite sequence of the lower carboniferous in the vertical section is not uniform. Along with well-watered reservoirs, there are also anhydrous ones; this is due to the presence of unstable interlayers of clay rocks, which are relative water resistance;

   b) Thickness of intercalation of limestones with sandy clay rocks.

   Groundwater circulation in various layers occurs in a peculiar way. In limestone, water circulates through cracks, in sand-through pores; in general, the waters of this horizon can be attributed to fissure-pore. The degree of watering is not uniform due to the variegated lithological composition of the stratum. Layers of limestone, the least-sand are the most waterlogged. Interlayers of clay are an impermeability for them. The water availability of this stratum is significantly lower than the water availability of the above calcareous strata.

   c) Sandy-clay thickness (Tula horizon). The water content of this stratum is very diverse due to the variegated lithological composition of the rocks composing it and the unstable stretching of individual layers.

   Coal seams. Contain groundwater of crack type. Bauxite rocks. Groundwater circulation also occurs along cracks in them.
d) Dolomites occurring at the base of the carboniferous sequence. Water-bearing rocks are strata of dolomites, less commonly limestones, dissected by cracks, along which groundwater circulates. The water mobility of the stratum is quite high. The aquifers of coal deposits are a good source of water supply for settlements located in the development zone of these horizons, which is ensured by high water inflows into the wells and fresh calcium-carbonate groundwater composition.

The Devonian system deposits are the most developed in the Novgorod region. Three aquifers are clearly distinguished here:

1. The aquifer complex of the variegated sandy-clay stratum of the upper Devonian is developed almost everywhere. An independent aquifer in limestone (Buregsky) stands out in the south of the region, near the city of Staraya Russa, in the lower part of this complex. In lithological terms, the variegated stratum is a complex stratification of sand and clay rocks with thin limestone layers of subordinate importance. The thickness of sand and clay layers varies from 0.1 to 20 m, mainly from 0.5 to 10 m. Due to the peculiar mottled structure of the stratum, its hydrogeological conditions are notable for their inconsistency, lenticular bedding of aquifers, often divided into a series of aquifers, with differences in levels and flow rates. The predominant type of groundwater is reservoir. Water has a head. The specific production rates of the wells for the most part are very insignificant – 0.01 – 0.1 l/sec. In drilling practice, waterless wells were often encountered, and separate wells were also noted with a specific water flow rate of up to 1 l/s. The underground waters of the complex under consideration are fresh, and have mainly hydrocarbon-calcium composition.

The Buregsky aquifer is noted, as already indicated, in the southern part of the region, in a strip adjacent to Lake Ilmen. Water-bearing rocks are dolomitic limestones, brecciated in the upper part, broken by a system of cracks. Water of this horizon is fractured-stratal, ascending according to the type of circulation. The water mobility of the horizon as a whole is significant, although uneven, due to the uneven fracturing of limestones. The specific production rates of wells are mainly from 1 to 10 l/s. The waters of the Buregsky horizon are fresh, bicarbonate-calcium and are widely used for water supply in a number of settlements and the town of Staraya Russa.

2. The aquifer complex of the carbonate sequence of the upper Devonian. In hydrogeological terms, the carbonate stratum, despite the diversity of the lithological composition of the rocks along strike and depth, is a single aquifer, consisting of a series of aquifers interspersed with water-resistant interlayers of clays. Groundwater is contained by fractured limestones and marls and, according to the type of circulation, refers to reservoir-fractured, ascending waters.

The water mobility of the carbonate stratum is uneven and generally small. In most wells, the specific flow rate is 0.01 – 0.1 l/s. Individual wells during drilling were anhydrous. The waters of the carbonate stratum are predominantly fresh, bicarbonate-calcium. However, some wells in the northern part of the region have slightly saline waters with a salinity of up to 3 g/l, hydrocarbonate-chloride and chloride waters. Water with a salinity of up to 10 g/l was found in a carbonate aquifer complex in the southern part of the region, near Lake Ilmen and the city of Staraya Russa. Groundwater of the carbonate complex is used for water supply in a number of small settlements, however, as a source of centralized water supply to cities, it cannot be recommended due to poor water mobility and increased sites of water mineralization.

3. The aquiferous complex of sand deposits of the upper and middle Devonian is developed in a wide (about 100 m) thickness. In the North-West of the European part of Russia, this complex is called the Sventoisko-Staroskokolskiy. This complex underlies the thickness of marls with interbeds of dolomites and clay of the middle Devonian. Marls are a monolithic rock, almost devoid of cracks. On the whole, this is a water separation that separates the Devonian aquifers from the underlying Ordovician. In the northwestern part of the region, the aquiferous complex of sand deposits of the upper and middle Devonian contains pressureless or low ascending water; in the rest of the territory, groundwater everywhere has a large head, all wells flow out. The water availability of the complex is very high, increasing in a southerly direction. The greatest inflow of water was recorded in the region of Lake Ilmen, where the flow rate of the well at a spill amounted to 80 l/sec (well on the lake Ilmen) and 55

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The waters of the described complex in the northwestern part of the region are fresh, bicarbonate-calcium, saline in the rest of the area, very hard, sodium chloride with salinity varying southward from 1.3 g/l (Zapolye village) to 20 g/l (StarayaRussa) and 44 g/l (Valdai city). The aquiferous complex of sand deposits of the Upper and Middle Devonian is of practical interest in the northern half of the region, where water salinity does not exceed 3 g/l. Here, due to this complex, the water demand of the previously existing large livestock farms was satisfied, since the indicated mineralization is within the limits acceptable for watering livestock. Water of this complex is not suitable for drinking water supply.

In the region of the city of Veliky Novgorod, an aquiferous complex with mineralized waters was discovered at a depth of 65–70 m. The Upper Devonian carbonate aquiferous complex with fresh waters lies above; however, insignificant water inflows into the wells here cannot provide the city’s water demand, therefore drinking and household water supply have to be based on surface waters.

The deepest part of the artesian basin is filled with the waters of the Ordovician, Cambrian and Proterozoic formations, which were discovered and tested by Starorusskiy, Krestetsk and Valdai support wells. The Starorusskiy well in the range of 820–920 m opened water in the formations of the Proterozoic sodium chloride composition with a mineralization of 73.3 g/l. The Krestetsk key well in the sediments of the Ordovician, Cambrian, and Proterozoic tested seven intervals. The waters had a sodium chloride composition, and their mineralization gradually increased from 84.15 g/l (interval 565–580 m) to 180.24 g/l (interval 996.5–1795 m). The Valdai key well in the same sediments tested four intervals. The composition of the water is also sodium chloride, water mineralization at a depth interval of 1447 m–1453 m (Proterozoic aquifer) is 180 g/l.

The peculiarity of groundwater in the territory of Novgorod region is the laws of their dynamics and chemistry, determined by the position of the major lakeside depression—the Priilmen depression in the central part of the region. The presence of this cavity causes the flowing of wells located over a large area around it. A comparison of the piezometric levels of various Devonian aquifers shows a certain pattern in their distribution. A concentric smooth decrease in piezometric levels occurs toward Lake Ilmen, which indicates the movement of the underground flow in this direction and is confirmed by numerous ascending groundwater sources and the presence of salt-chloride-type salt water in the area of Lake Ilmen in aquifers, which usually contain fresh hydrocarbonate calcium waters. An illustration of the latter is provided by data from a well drilled on Lake Ilmen, where sodium chloride composition with a salinity of 2.67 was discovered in a carbonate-bearing aquiferous complex of the Upper Devonian in the range of 18.6–26.9 m. The waters were opened immediately under lake-glacial clays with mineralization of 2.67 g/l, and in the range 43.6–62.9 m in the same complex, mineralization increased to 8.7 g/l.

Diagrams of hydroisopiezic of various Devonian aquifers are drawn in the form of contours that are closed around Lake Ilmen, in a leveled form resembling a diagram of a modern surface, thereby emphasizing the dependence of the piezometric surfaces of aquifers on a modern relief.

A certain regularity is also observed in the chemical composition of groundwater in a vertical geological section, namely, a change in the chemical composition and salinity of groundwater with depth. In the hydrogeological section, three hydrochemical zones are clearly distinguished: a freshwater zone with a thickness of 100–120 m, and in the area of Velikiy Novgorod — up to 75 m, in which calcium-carbonate waters are noted; the zone of brackish and salty waters, presumably distributed in the intervals of depths of 100–300 m and containing sodium chloride waters with a salinity of up to 20 g/l and a zone of sodium chloride brines, opened by Starorusskiy, Krestetskiiy and Valdai key wells with a salinity of up to 180 g/l [1].

The thickness of the fresh water zone varies from 0–40–50 m in the west, to 100–200 m in the east. There are explored deposits of fresh and mineral water within the region, as well as one deposit of multicomponent waters with a high content of cesium. Forecasted operational groundwater reserves are many times higher than prospective needs. The utilization rate in the early 90s of the last century was 0.02%. Six deposits of the region for household and drinking purposes with total reserves of 83.64 thousand m³/day. account for 1% of regional reserves.
The most famous deposit of mineral medicinal and medicinal-table waters operates in StarayaRussa resort. Sources of StarayaRussa are known since ancient times as an object of salt production. They have been used for medicinal purposes from 1828 to the present day. From the report of the director of the resort in 1893 “… the number of patients is 1142 people … of this number 68% recovered, 20% received relief, 4% did not receive relief …”, which indicates a good therapeutic effect of mineral waters [2].

Currently, there are eleven mineral springs in the city of StarayaRussa – wells of salty chloride-sodium water. Six of them, namely: Novy-Direktorskiy, Klyuchevoiy, Tsaritsinsky, Ekatherininskiy, Staro-Direktorskiy and Muravyovskiy, have been known since the 18th, 19th and 20th centuries. The lake spring has been known since 1370, the other four were drilled in 1958–1962.

Four sources out of seven are not of clear nature. It is not sure if they are wells or natural groundwater outlets. Water in old spring wells rises from the Sventoisko-Starooskolskiy complex of the Upper and Middle Devonian and has a sodium chloride composition and mineralization of 18.7–20.7 g/l. Currently, these sources are used for bathtubs, for the formation of mud and for decorative purposes. Of the four wells drilled in recent years, one also supplies water from the Sventoisko-Starooskolskiy complex, the rest use water from the carbonate sequence of the Upper Devonian. The water composition in them is also sodium chloride, however, the salinity of the water is much lower, from 2.7 to 10.2 g/l. The water of these wells is used as drinking water.

Thus, there are currently three types of mineral water in the resort:

Type I is sodium chloride water, with a total salinity of 18.7–20.7 g/l from the Sventoisko-Starooskolskiy complex, well depth is 117.0–266.0 m. The water is bromine with a high content of strontium by microcomponent composition. Water is supplied to the bathtub and in combination with mud is used to treat joints, bones and muscles, gynaecological organs, circulatory organs, nervous system and urological diseases.

Type II is chloride, sodium water with a total mineralization of 9.2–10.2 g/l that is contained in the aquiferous complex of the carbonate sequence of the Upper Devonian at a depth of 56–80 m. According to the microcomponent composition, water, as well as type I water, is bromine, however, the bromine content is much lower, and the strontium content is slightly higher. Water of this type is used for drinking in balneological purposes. This water treats diseases of the stomach, intestines, liver and biliary tract, the consequences of inflammatory processes in the abdominal cavity.

Type III is brackish chloride, calcium-magnesium, hard water with total salinity of 2.73 g/l, total hardness is 40.25 mg-Eq/l. Water is also from the aquiferous complex of the carbonate sequence of the Upper Devonian, but the depth of its production is 68 m. This type of water differs from the previous two in the increased magnesium content, which makes it possible to use this water in case of spasmodic conditions of the gastrointestinal tract. The high calcium content is beneficial in the treatment of allergic diseases [3].

At the beginning of the twentieth century, another resort in the city of Solszy existed in the Novgorod region. Mineral water was used here, similar in composition to the North Caucasian narzans with a low salt content from 4.47 to 5.98 grams of sodium chloride per liter. One of the three sources, the “Strakhovik” is similar to the Kochbrunnen spring in Wiesbaden, Germany. Thus, the region has good prospects for the development of resort use of mineral waters.

Another important area is the use of groundwater in industrial production. Mineral water and soft drinks are produced in the region. 11 deposits have been explored in the region. Today in the region, the Elite I mineral drinking water is produced on the basis of table water from a well of 60 m deep in the village of Moika in the Batetskiy district. The chemical composition is hydrocarbonate-chloride calcium-sodium. Another well, on the basis of which production is organized, in the village of Uspolon, Shimsky district, belongs to the category of low-mineralized groundwater of chloride-magnesium-sodium-calcium composition. Mineral water “Mr. Veliky Novgorod” is spilt from a well located in the village of Sharok, Shimsky district. It is low-mineralized chloride magnesium-calcium-sodium water in terms of composition.

The total number of enterprises engaged in the use of underground fresh and mineral waters is 22, but all of them are at different levels of economic development. Appearing in the early 90s, some
continue to develop successfully (14), others are in the process of liquidation (2), others are in the process of reorganization (6) (table 1).

Table 1. Enterprises using groundwater for bottling*.  

| Enterprise | Status | Location |
|------------|--------|----------|
| OOO“Starorusskiypishchekombinat” | Operating | Veliki Novgorod |
| OOO“VodaVinogradova” | Operating | Veliki Novgorod |
| OOO“Zadornovipartner” | Operating | Pestovo |
| OOO“NovySvet” | Operating | StarayaRussa |
| ANO“NCSM –Novotest” | Operating | Veliki Novgorod |
| OOO“Rushanochka” | Operating | StarayaRussa |
| OOO“Buregi. SPA iKurort” | Operating | StarayaRussa |
| OOO“Nilolskievody” | Operating | Veliki Novgorod |
| AO“Altair VN” | Operating | Soltsy |
| AO“Deka” | Operating | Veliki Novgorod |
| OOO“Kapitalinvest” | Operating | Borovichskiy rayon, pos. Progress |
| OOO “Dobyvayushchaya kompaniyaSemiruch'ye” | Operating | Okulovka |
| OOO“Alina” | Operating | Veliki Novgorod |
| OOO“Vodokanal 53” | Operating | PoselokVolot |
| OOO“Viktoriya” | Under liquidation | Soltsy |
| OOO“Kofeisladosti” | Under liquidation | StarayaRussa |
| OOO“Borovichskayamineral'nayavoda” | Under reorganization | Borovichskiy rayon |
| OOO“Zhivayavoda” | Under reorganization | Veliki Novgorod |
| ZAO“Gamma Novgorod” | Under reorganization | Batetskiy rayon, derevnyaMoyka |
| OOO“Apeks” | Under reorganization | StarayaRussa |
| OOO“SvyatayaSofiya N” | Under reorganization | Novgorodskiy rayon, derevnyaVitka |
| OOO“Lignariya” | Under reorganization | Batetskiy rayon, derevnyaVeleshi |

*According to: Mineral water production in the region https://zachestnyibiznes.ru/category/okved-region?number=11071&region=53

In 2019, the state program “Pure Water in the Novgorod Region for 2019–2024” was approved in the Novgorod Region, which also emphasized the use of groundwater. More than twenty thousand people will be provided with groundwater for consumption during the implementation of the program. Groundwater water treatment plants will be built:

- in the Bogoslovsky rural settlement of the Pestovsky municipal district;
- in the village of Susolovo, Starorussky municipal district;
- In the village of Nagovo, Starorussky municipal district;
- in the village of Dubovitsy, Starorussky urban settlement, Starorussky municipal district;
- in the village of Zaluchye, Starorussky municipal district;
- in the village of Novoselsky, Starorussky municipal district;
- in the village of Melkovichi, Batetsky municipal district;
- in the village of Kositskoye, Batetskiy municipal district;
– in the village of Yaskovitsy of the Batetsky municipal district;
– in the Pestovsky rural settlement of the Pestovsky municipal region;
– in the Vyatka rural settlement of the Pestovsky municipal district;
– in the Bykovsky rural settlement of the Pestovsky municipal district.

Construction of an underground water supply within the mining allotment of an artesian well in the working village of Kulotino, Okulovsky municipal district. This is the first time, when so many stations using groundwater will be put into commission. Funds from both the federal and regional budgets are raised to carry out these works. But most importantly, the proportion of the population of the Novgorod region provided with high-quality drinking water from centralized water supply systems will increase significantly.

4. Conclusion
It follows from the above that currently the use of different types of groundwater is one of the priorities. This will be facilitated by the state program “Clean water...” developed and adopted for implementation. The use of fresh underground water will provide the population with high-quality water for domestic consumption. The mineral waters will be used for both bottling and recreational use.

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