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HYDROGEOLOGICAL TESTING OF WELLS IN GROUP OPERATION AT THE BARICE WATER SOURCE; ŽIVINICE MUNICIPALITY

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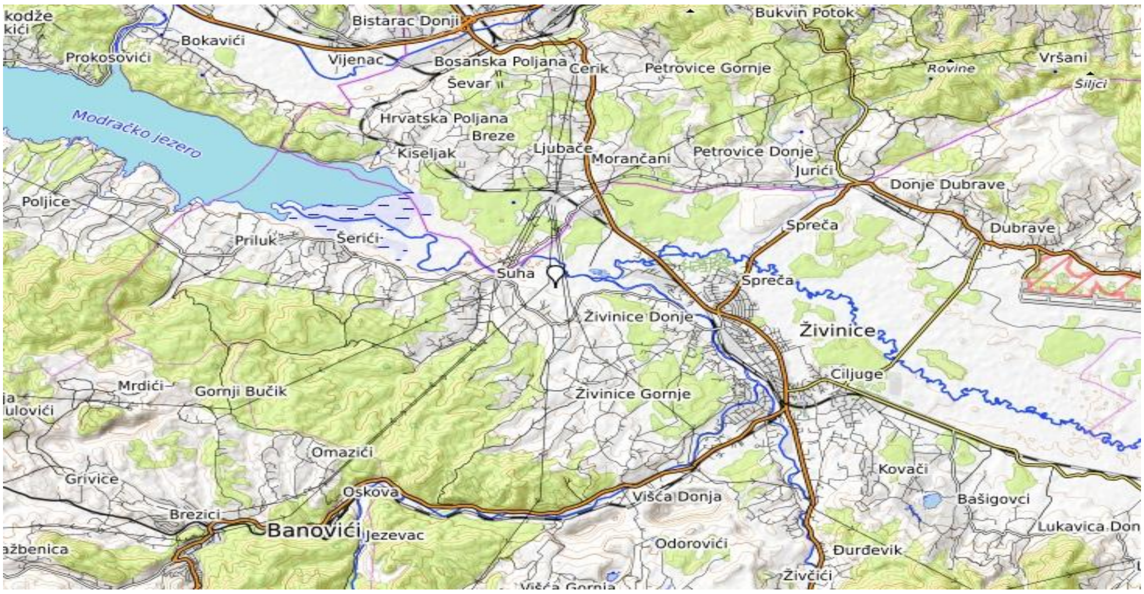
Abstract

For a long period, the drinking water supply for the population of the city of Živinice has not been at a satisfactory level. Larger settlements have local water supply systems, while the city of Živinice, along with suburban settlements and the Dubrave settlement, is supplied with drinking water from the joint water supply system of Tuzla and Lukavac, originating from the "Spreča" pumping station (Toplica water source).
The main issues in the drinking water supply relate to insufficient water quantities, limited reservoir capacity, and low network pressure, all of which result in frequent water supply restrictions. To improve the drinking water supply in this area, hydrogeological investigations were conducted to capture new water quantities from the "Barice" water source, located in the Živinice Municipality.
Hydrogeological and geological mapping of the research area was carried out, along with the drilling of piezometric boreholes and wells. Considering that both piezometers and wells are replenished from the same aquifers, measurements of groundwater levels during the construction of new wells indicated a decrease in water levels in surrounding hydrogeological structures during test pumping. Consequently, well testing in group operation was conducted.
Keywords: hydrogeological testing, water intake structures, test pumping of wells, source capacity, water supply

INTRODUCTION

The research area covers a surface of 15 km² and is located approximately 2 km from the city of Živinice. The terrain is predominantly flat and includes a part of the Spreča field, with absolute elevations ranging from 203 to 209 meters above sea level. This type of relief, characterized by steep slopes in the southern part, has resulted in a well-developed hydrographic network of intermittent or permanent watercourses, mostly oriented in a south–north direction. In the central part of the area, within Pliocene-Quaternary deposits, where the terrain transitions from steep to gently undulating, several parallel river valleys have formed, cutting almost down to Jurassic deposits. The research area belongs to the watershed of the Spreča River, which is the main recipient of the Tuzla Canton.
According to measurements taken downstream from the research area (Modrac), the lowest average monthly flow of the Spreča River occurs in September (6.69 m³/s), while the highest is in February (30.5 m³/s), with an average annual flow of 16.3 m³/s. Short-term groundwater level

observations conducted on installed piezometers during investigations between 1989 and 2019 indicate the presence of four distinct aquifer layers.



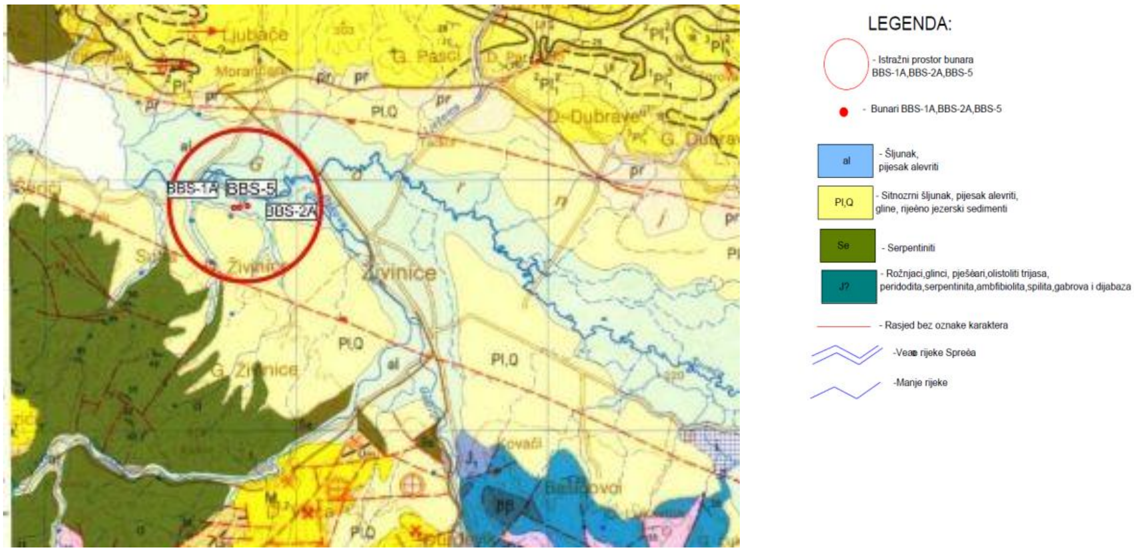
Picture 1. Geographical location of BBS-1A, BBS-2A, BBS-5

The constructed wells are replenished from the same aquifer layers, and during test pumping, mutual influence and a decrease in water levels were observed. When pumping at higher capacities exceeding 24.00 l/s, the dynamic water level dropped and was unable to reach a stable condition. During the same time period, water levels were monitored in other available hydrogeological structures.

A dug well by the road, located near the wells supplying the Barice local community, was identified as an artesian aquifer with a capacity of 2.48 l/s. However, during group well pumping at capacities exceeding 15 l/s, this well completely dried up. Wells operating under unfavorable conditions suffer damage to the near-well zone, as well as to the well pumps, which function at full power and capacity. Given the described well operation regime, well clogging and damage to the near-well zone can occur rapidly. Additionally, exceeding the permissible inflow velocities can lead to a turbulent flow regime, resulting in reduced yield and accelerated "aging" of the wells.

GENERAL GEOLOGICAL CHARACTERISTICS OF THE AREA

The Barice research area belongs to the central ophiolitic zone geotectonic unit, characterized by diverse ultrabasic rocks of the Konjuh massif, dating back to the Jurassic period. These formations are predominantly covered by Pliocene-Quaternary and alluvial deposits.



Picture 2. Geological map on a wider scale 1: 100,000 made on the basis of OGK list Tuzla.

JURASSIC PERIOD

A portion of the Lower Jurassic and the diabase–hornstone formation, likely corresponding to the Middle and Upper Jurassic, are developed in this area. The research area belongs to the central ophiolitic zone, which includes various ultrabasic rocks of the Konjuh and Ozren massifs (in the wider Banovići area) at its southwesternmost part. Within the Jurassic formations in this study area, the dominant rocks are peridotites, with a minor presence of serpentinites.

Peridotites (P)

Peridotites appear south of Banovići as the northwestern ultramafic Konjuh massif. The relationship between peridotites and other magmatic members and sediments is tectonic, with cataclastic and more or less mylonitized zones. According to J. Pamić (1964), peridotites and other ultramafic rocks were intruded as solid and cold bodies into Jurassic sediments, which explains the lack of structural conformity with the surrounding rocks and the absence of contact metamorphism effects.

Serpentinites (Se)

Serpentinites consist mainly of serpentine minerals, along with numerous secondary minerals such as chlorite, talc, limonite, and occasionally carbonates, quartz, opal, and chalcedony. Relict primary minerals, such as olivine and pyroxenes, are also frequently present. In the study area, serpentinites are found only in the Upper Živinice region, specifically in the settlements of Šabanovići and Rahmanovići.

PLIOCENE–QUATERNARY (Pl,Q)

Pliocene deposits in the Tuzla–Živinice area are represented by the Pontian stage, which is further divided into the Lower Pontian (Novorossian stage) and the Upper Pontian (Portoferian stage). Significant sedimentation occurs only in the Spreča tectonic depression. The edge of this tectonic trench, uplifted by neotectonic movements, has become a distribution area for terrigenous material, which has formed thick layers of clastic rocks of aquatic–fluvial–lacustrine origin. The composition is dominated by clayey–sandy sediments, siltstones, marl and marl–sandy clays, sand, and gravel.

QUATERNARY PERIOD

River Sediments (al)

These deposits are found in the valley of the Spreča River and its tributaries. Along the course of the Spreča River in the Spreča field, river deposits are differentiated at a single level as channel-proximal alluvium (floodplain terrace). Due to the geological structure of the river basin and the energy of the flow, these deposits are dominated by fine-grained sediments of floodplain facies, consisting of silt–clay and sandy material, overlying gravelly–sandy channel facies. A significant presence of gravel and sand is observed at the confluences of larger left-bank tributaries such as the Oskova River. Compared to river deposits from other streams, the Oskova's deposits differ significantly in granulometric and mineralogical–petrological composition due to differences in the geological background of its basin and a steeper flow gradient.

HYDROGEOLOGICAL CHARACTERISTICS

The Spreča field is a vast enclosed depression, approximately 40 km long and with an average width of five kilometers, located in the southern part of the Tuzla Neogene Basin. This depression is conditioned by the well-known Spreča fault, which extends in a northwest–southeast direction between the Eocene horsts of Majevica and Trebovac in the north and the ophiolitic zone in the south.

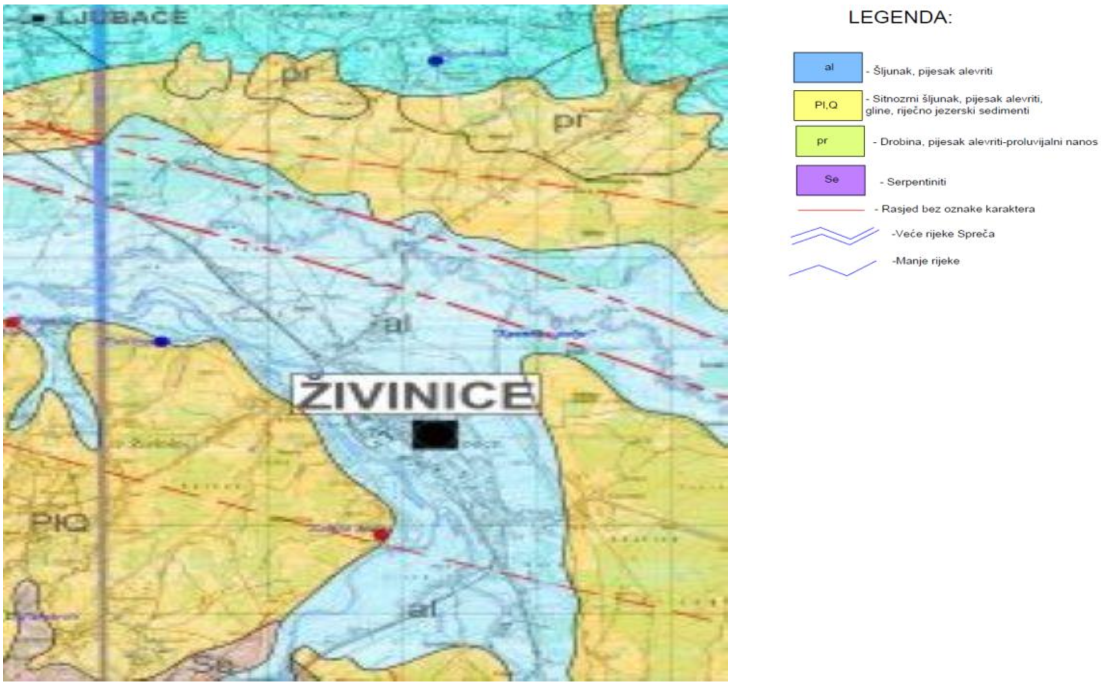
The narrower area of the Spreča field, designated as a water supply source for Tuzla, is limited to the section from the confluence of the Spreča River into Modrac Lake (Maline) to the confluence of the Gribaja River into the Spreča, spanning approximately 10 km. The deep depression has resulted in thick accumulations of alluvial deposits from the Spreča River, whose composition reflects fluctuations in sedimentation intensity, deposition characteristics, and material transport directions.

In the gravel-rich sections, material of hornstone origin (diabase–hornstone formation from the ophiolitic complex in the south) is predominant, while in the sandy–clayey sections, quartz-rich materials and clay minerals are more common, originating from the Neogene basin clastics in the north.

The "Barice" water source is located along the left bank of the Spreča River, downstream from the Oskova confluence, and forms part of the southern boundary of the alluvial hydrogeological complex of the Spreča field. It is bordered to the north by the meandering Spreča riverbed and to the south by a Pliocene–Quaternary terrace.

According to previous research, the core area of "Barice–Maline" is primarily composed of:

- Pliocene–Quaternary terrace deposits of clayey–sandy–gravelly composition, and
- Gravelly–sandy–clayey alluvial deposits of the Spreča and Oskova River valleys.



Picture 3. Hydrogeological map with the legend of the source of Barica

Filtration Characteristics

Previous research has primarily determined filtration characteristics based on pumping tests conducted on piezometric boreholes. These boreholes were constructed at different times, with varying structural and technical characteristics, and pumped using different methods, contributing to inconsistencies in the results.
The following average values of filtration parameters have been obtained from these studies: transmissivity (T), filtration coefficient (k), specific yield (μ), and piezoconductivity coefficient (a).

$$T = 2.8 \times 10^{-3}\ m^2/s$$
$$k = 1.7 \times 10^{-4}\ m/s$$
$$\mu = 0.044$$
$$a = 3.11 \times 10^{-1}$$

It is observed that the filtration parameter values obtained for the Barice area fall within the range of values for the broader region (except for the Maline area). Therefore, their average values can be used for orientation calculations.

Hydrodynamic Characteristics

In the narrower "Barice" area, the hydrodynamic conditions are likely still undisturbed due to both the distance (approximately 5 km) and the probable hydraulic separation by the Spreča River, which acts as a hydrogeological boundary with a constant water level.
Short-term observations of groundwater levels in the piezometers during the research period from 1989 to 2019 indicate four distinct aquifer layers:

- First aquifer layer (shallow phreatic aquifer with a free water level) down to a depth of 6.0 meters

- Second aquifer layer (first artesian aquifer under pressure) at depths from 8.0 m to 21.5 meters
- Third aquifer layer (second artesian aquifer under pressure) at depths from 15.0 to 30.0 meters
- Fourth aquifer layer (third artesian aquifer under pressure) at depths exceeding 53.0 meters

This indicates complex recharge and drainage conditions. Recharge occurs through underground inflow from the broader surroundings and from older Pliocene-Quaternary sediments laterally and at depth. The weak artesian level suggests a lower hypsometric position of the recharge area. The higher artesian pressure in the elevated area (at an elevation of 207 meters) and lower pressure in the Spreča riverbed area (approximately 203 meters) indicate indirect drainage into the Spreča and Oskova rivers. The lack of continuous groundwater level monitoring for these aquifers prevents a more detailed interpretation of hydrodynamic relationships.

Drilling of Piezometric Boreholes

Following the interpretation of previous research results and detailed hydrogeological mapping, the locations for exploratory boreholes PBBS-3, PBBS-5, PBBS-1A, and PBBS-2A were determined.
When selecting borehole locations, consideration was given to the existing water supply infrastructure in the Barice water source area. Two wells were already present in the study area: one at the Mišići site, constructed in 1989, and another (marked as PB-3) at the Ravan site, used for the water supply of the Suha settlement. In addition, the locations were chosen considering three existing wells within the Barice water source area, which already had an established water supply infrastructure. After agreement, the most favorable locations for drilling exploratory boreholes were defined as parcels in K.O. Živinice Donje (PBBS-5, PBBS-1A, PBBS-2A).

Construction of Wells BBS-4, BBS-5, BBS-1A, BBS-2A

After drilling the piezometers and conducting the aforementioned works, a Preliminary Report was prepared, recommending the construction of three wells, each with a depth of 35 meters.
The wells were constructed as exploratory wells with standard profiles, but they were also designed for permanent exploitation. The concept was based on tapping the third aquifer layer. The well depth was uniform, at 35 meters. The wells were drilled using the rotary method with direct flushing using clean water. Drilling began with a Φ 600 mm diameter down to a depth of 10.0 meters, after which a protective casing Φ 508/495 mm (standard steel pipe) was installed. The casing was sealed with clay along the entire annular space of the borehole to isolate the upper aquifer layers. After installing the protective casing, drilling continued with a Φ 400 mm diameter bit down to a depth of 35 meters.
Upon reaching the depth of 35.00 meters:

- For wells BBS-4 and BBS-1A, a well structure was installed consisting of a Φ 273/260 mm protective-exploitation casing with inline Φ 250/202 mm wound-wire filters and a sediment trap. The filter slot width was approximately 1.0 mm, and the pipes were joined using standard welded rings.

- For wells BBS-5 and BBS-2A, a well structure was installed consisting of a PVC exploitation casing Φ 225/200 mm with inline Φ 225/200 mm slotted filters and a sediment trap. The filter slot width was approximately 2.0 mm, and the pipes were connected with threaded joints. After installing the protective-exploitation and filter structures, the annular space of the borehole was backfilled with granulated filter material (grain size Φ 4-8 mm) down to a depth of about 10 meters, while the remaining annular space up to the top was sealed with clay.

Well development and stabilization were carried out using the airlift method, ensuring the necessary flushing time to achieve water clarity and remove unwanted particles.

Well Testing

Well testing was conducted through experimental pumping using the STEP TEST method with three pumping rates, a Test Constant, and Recovery Test measurements with short interruptions. The preliminary testing established the following well capacities:

- Well BBS-4 – Q = 1.20 l/s
- Well BBS-1A – Q = 6.20 l/s
- Well BBS-5 – Q = 6.80 l/s
- Well BBS-2A – Q = 6.50 l/s

PRELIMINARY INDIVIDUAL PUMPING TESTS AT WELLS BBS-5, BBS-1A, BBS-2A

Pumping Test at Well BBS-5

Due to the specific location characteristics, which include a subartesian water pressure, the pumping test was conducted using a combined method with a submersible pump of 5.5 kW power, installed on galvanized pipes with a diameter of Ø 2 inches, at a depth of 10 meters. As part of the pumping test, the step-drawdown method (STEP-TEST) was applied with three pumping rates:

- Q1 = 4.00 l/s
- Q2 = 6.00 l/s
- Q3 = 6.80 l/s

The following parameters were obtained:

- Static water level before pumping: 0.2 meters
- Pumping capacity: 6.80 l/s
- Dynamic water level in the well: 4.50 meters
- Drawdown in the well: 4.30 meters
- Specific capacity: 1.58 l/s/m

After the step test, a recovery test was conducted to observe the return to the static water level over the required time period.
Following the recovery observation, a Constant-rate test was performed with Qmax = 6.80 l/s,

as well as recovery monitoring after completing the constant-rate test.

Pumping Test at Well BBS-1A

Due to the subartesian water pressure, the pumping test was conducted using a combined method with a submersible pump of 5.5 kW power, installed on galvanized pipes with a diameter of Ø 2 inches, at a depth of 10 meters.
As part of the pumping test, the step-drawdown method (STEP-TEST) was applied with three pumping rates:

- Q1 = 4.00 l/s
- Q2 = 6.00 l/s
- Q3 = 6.20 l/s

The following parameters were obtained:

- Static water level before pumping: 0.2 meters
- Pumping capacity: 6.20 l/s
- Dynamic water level in the well: 7.80 meters
- Drawdown in the well: 7.60 meters
- Specific capacity: 0.81 l/s/m

After the step test, a recovery test was conducted to observe the return to the static water level over the required time period.
Following the recovery observation, a Constant-rate test was performed with Qmax = 6.20 l/s, as well as recovery monitoring after completing the constant-rate test.

Pumping Test at Well BBS-2A

The subartesian water pressure required the pumping test to be conducted using a combined method with a submersible pump of 5.5 kW power, installed on galvanized pipes with a diameter of Ø 2 inches, at a depth of 17 meters.
As part of the pumping test, the step-drawdown method (STEP-TEST) was applied with three pumping rates:

- Q1 = 4.00 l/s
- Q2 = 6.00 l/s
- Q3 = 6.50 l/s

The following parameters were obtained:

- Static water level before pumping: 0.2 meters
- Pumping capacity: 6.50 l/s
- Dynamic water level in the well: 9.00 meters
- Drawdown in the well: 8.80 meters
- Specific capacity: 0.73 l/s/m

After the step test, a recovery test was conducted to observe the return to the static water level over the required time period.

Following the recovery observation, a Constant-rate test was performed with Qmax = 6.50 **l/s**, as well as recovery monitoring after completing the constant-rate test.

PUMPING TEST OF WELLS IN GROUP OPERATION

The objective of the group pumping test was to determine the hydraulic characteristics and operational parameters of the wells through their mutual influence (capacity, drawdown, hydraulic losses) using standard methods. Since these wells are designed for long-term operation and are all recharged from the same aquifers, the test was conducted in two phases.
The first phase, using a single pumping rate, lasted until the water levels in the wells approximately stabilized (±3 cm). The test began with the initial pumping rate **Q1**, followed by a second rate **Q2** = 1.5 to 2 times **Q1**, and finally, the third rate **Q3**, which ensured the maximum allowable drawdown—2.0 meters above the pump intake level in the wells. Once stabilization was achieved at the third pumping rate, the pumping was stopped, and the recovery of groundwater levels to the static level was observed.
After obtaining preliminary results from this test, an extended pumping test was conducted with a constant discharge rate. The individual well pumping capacities were:

- Q1 = 5.0 l/s
- Q2 = 6.50 l/s
- Q3 = 8.00 l/s

During the pumping test, continuous monitoring of groundwater levels was carried out in both the pumping wells and nearby piezometers. The observation of groundwater level recovery to the static level was performed only after the final pumping rate. Existing wells (at least two) were used as observation points.
Following the step-drawdown test lasting 36 hours, a discharge rate was determined for the extended pumping test with a constant flow. During this phase, continuous groundwater level measurements were taken at the pumping well and observation points.
Throughout the pumping test, all relevant data were recorded, particularly:

- Pumping capacity at the well (measured with a flow meter or calibrated orifice plate)
- Static groundwater level before pumping at both the pumping well and observation points
- Dynamic groundwater level during pumping, along with the time of data collection
- Operational condition of the pumping system (pump, power supply controls, etc.)

During the group pumping test, water levels in surrounding piezometers and wells were measured. When all three wells were pumped at a rate of 5 l/s, the water levels failed to stabilize, and a continuous decline was observed in both the wells and piezometers. Over a three-hour measurement period, the water level dropped by approximately 20 cm per hour.
Due to this, the pumping rate at Well BBS-2A was reduced to 4.50 l/s, as this well exhibited the highest drawdown, reaching -7.70 meters.
After reducing the pumping rate at Well BBS-2A to 4.50 l/s, the group pumping test continued with pumping rates of 5.0 l/s at Wells BBS-5 and BBS-1A.

ASSESSMENT OF THE WELL CAPACITY

Following the group pumping test at the Barice-Maline wellfield, it is necessary to apply an appropriate hydrogeological schematization and make certain assumptions common to analytical solutions for groundwater filtration processes.

Based on the hydrogeological conditions in the wellfield area and the adopted concept of abstraction structures, the wellfield can be considered a two-layer homogeneous and isotropic porous medium, operating under confined conditions, with two conditionally parallel boundaries (strip layer model).

The southern boundary consists of low-permeability Pliocene-Quaternary gravel-sand terraces, which, for simplification, is assumed to be an impermeable boundary with the condition Q = 0.

The northern boundary can be treated in two ways:

- If the Spreča and Oskova riverbeds are hydraulically connected to the aquifer, the boundary condition is h = constant.
- If this hydraulic connection is absent (due to a clay isolation layer), the filtration field is considered unbounded.

This uncertainty requires further investigation, but for now, the second boundary condition (h = ∞) has been applied for the calculation.

Capacity Calculation

The capacity estimation was conducted under non-steady-state filtration conditions over a period of t = 4 days.

Since this involves an extended pumping period (i.e., continuous operation), where the parameter:

$$\mu = r^2/4at \ \leq \ 0{,}05$$

The exponential form of the "well function" W(u) can be approximated logarithmically with sufficient accuracy (error <10%):

$$W\,(u) = Ei\,\left(-\frac{r^2}{4\,a\,t}\right) \cong \ln\frac{2{,}25\,T\,t}{r^2\,\mu}$$

Thus, for the capacity of a single fully penetrating well under the given hydrogeological conditions and for the specified drawdown, the following formula is applied:

$$Q = \frac{4\,\pi\,T}{S}\left[\frac{2{,}25\,T\,t}{r^2\,\mu} - \ln\frac{2{,}25\,T\,t}{4a^2\mu} + \ln\frac{2{,}25\,T\,t}{4b^2\mu}\right]$$

Applying the boundary condition h = ∞, the simplified formula for calculation is:

$$Q = \frac{4\,\pi\,T}{S}\left[\ln\frac{2{,}25\,T\,t}{r^2\,\mu} + \ln\frac{2{,}25\,T\,t}{4\,b^2\,\mu}\right]$$

Input Parameter Values:

Ssr= 5,88 m, $T = 2{,}8 \times 10^{-3}\ m^2/s = 241{,}9\ m^2/day$, r = 0,10 meters

μ = 0,044, t = 4 days, b = 300 meters

Where:

- Q – Well capacity (m^3/s)
- T – Transmissivity coefficient (m^2/s)
- S – Drawdown in the well (given)
- r – Well radius
- μ – Specific yield
- b – Distance from the well to the impermeable boundary (Q = 0)
- t – Pumping duration

The filtration parameters T and μ were taken as average values for the filtration area, resulting in:

$$Q = 15{,}07 \ l/s$$

The calculation was performed based on test pumping; however, it is important to consider that there are already seven wells at the source, which influence each other. The fact remains that the wells cannot pump more than 5 l/s per well, as they were designed and adapted to the conditions prevailing in the Barice area.

Based on an assessment, the Barice source can provide 30-40 l/s of water across all wells. Therefore, the adopted source capacity is:

$$Q_{izv.} = 30 \ l/s$$

The obtained data indicate that further investigative work is necessary to confirm the adopted assumptions, more precisely define the spatial and filtration parameters of the filtration area, and ensure that new water intake wells are technically and hydraulically correctly constructed.

CONCLUSION

The "Barice" water source is located along the left bank of the Spreča River, downstream from the confluence of the Oskova River, and is part of the southern boundary of the alluvial hydrogeological complex of the Spreča field. It is bordered to the north by the meandering riverbed of the Spreča and to the south by a Pliocene-Quaternary terrace.

Based on the results of previous hydrogeological research, the "Barice" area is primarily composed of:

- Pliocene-Quaternary terrace deposits of clayey-sandy-gravelly composition, and
- Gravelly-sandy-clayey alluvial deposits of the Spreča and Oskova river valleys.

The groundwater at the "Barice" source is of the calcium-magnesium type, and physicochemical and bacteriological water analyses confirm its compliance with the Regulation on the Health Safety of Drinking Water (Official Gazette of BiH 40/10).

From a hydrogeological perspective, the source has favorable natural protection conditions. However, despite this, it is necessary to establish a special water quality control regime and to design new sanitary protection zones or redesign the existing ones, as defined in the 2011 study.

Since the constructed wells are recharged from the same aquifer layers, test pumping of the wells revealed a mutual influence in terms of water level reduction. When pumping at capacities exceeding 24.00 l/s, the dynamic water level dropped significantly and could not reach a stable state. At the same time, water levels in other available hydrogeological structures were monitored.

A dug well near the road, located next to the wells supplying water to the residents of the Barice local community, is characterized as an artesian source with a capacity of 2.48 l/s. However, when the wells were pumped in group operation at capacities exceeding 15 l/s, this artesian well completely dried up.

Under such conditions, the operational wells function under an unfavorable regime, which is harmful to both the wells and the surrounding well zones, as well as to the well pumps operating at full capacity.

This described operational regime can rapidly lead to well clogging and deterioration of the surrounding well zone due to exceeding the allowable inflow velocities and the resulting turbulent flow conditions. This, in turn, causes a decrease in well yield and accelerates the "aging" of the wells.

For this reason, it is recommended that the maximum pumping capacity (Qmax) for all three wells be set at 15.00 l/s.

Based on the conclusions drawn regarding the hydrogeological relationships in the water intake area and the adopted concept of water intake structures, it can be concluded that the study area represents a two-layered homogeneous and isotropic porous medium, with a confined flow regime and two conditionally parallel boundaries.

The southern boundary consists of a low-permeability Pliocene-Quaternary gravelly-sandy terrace, which, for the sake of simplifying calculations, is considered an impermeable boundary with a condition of Q=0. The northern boundary can be treated in two ways. In the first case, if the riverbeds of the Spreča and Oskova rivers are hydraulically connected to the aquifer layers, the boundary condition is h=const. If this hydraulic connection does not exist due to the presence of a clay layer acting as an insulator, then the filtration field is conditionally unlimited.

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