HYDROLOGICAL INVESTIGATIONS ON THE GROUND WATERS IN THE GLADNICA SITE, KUMANOVO

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A b s t r a c t: The paper presents data obtained during the detailed hydrogeological investigations carried out on the Gladnica site, Kumanovo.
Drilling 10 to 132 m to depth determined fracture type of aquifer formed in neogene volcanogenic sediments. Data obtained made it possible to dig a well with exploitable reserves of 4.17 l/s.
Based on the chemical features the water can be classified as hydrocarbonate, magnesian-calcic low mineral water with characteristic amounts of strontium and fluor.

Key words: fracture type of aquifer, volcanogene sediments, Gladnica, neogene.

INTRODUCTION

The Gladica site is situated in the vicinity of Dragomance, some 20 km north-east of Kumanovo.
The area is composed of alluvial terrace sediments of the Pcinja River with boundary type of aquifer. The alluvial sediments overlie volcanic tuffogenous Pliocene and Ologomiocene sediments in which fracture type of aquifer is located. The aquifer was subject matter of hydrogeological investigations for the discovery of ground water that can be used for bottling.

GEOLOGICAL COMPOSITION OF THE WIDER REGION

From geotectonic-regional aspect Gladica is part of the boundary area that separates the Vardar zone and the Serbo-Macedonian mass (Arsovski, 1997).
The geology of the region is made up of Precambrian, Paleozoic, Paleocene, Neogene and Quaternary age (Karajanovic and Hristov, 1972)(fig. 1).
The oldest rocks are those of Precambrian age present as micaschists (Sm.) and various schists with the predominance of quartz-chlorite and muscovite-chlorite schists (Sse).
The Paleozoic rocks include marbles (M) present as large elongated masses and tracks in association with sandstones (Sca) and phyllites (F).
Paleogene is present as Upper Eocene flysch sediments (E^3_3) made up of fine-grained carbonate sandstones, clay carbonate alevrolites and marly limestones and slates.
Neogene is present as trachyandesites (τα), andesite tuffs (Θα), a sandy-clayey series (PL_3), volcanic breccia (ω), ignimbrites (Θα), andesites (α), dacites (αq), opal.. breccias (ω`op) , kayanite (τβ`) .
Quaternary is made up of limnic sediments (j), upper river terraces (t_2), lower river terraces (t_1), deluvial (d) and alluvial layers (al).

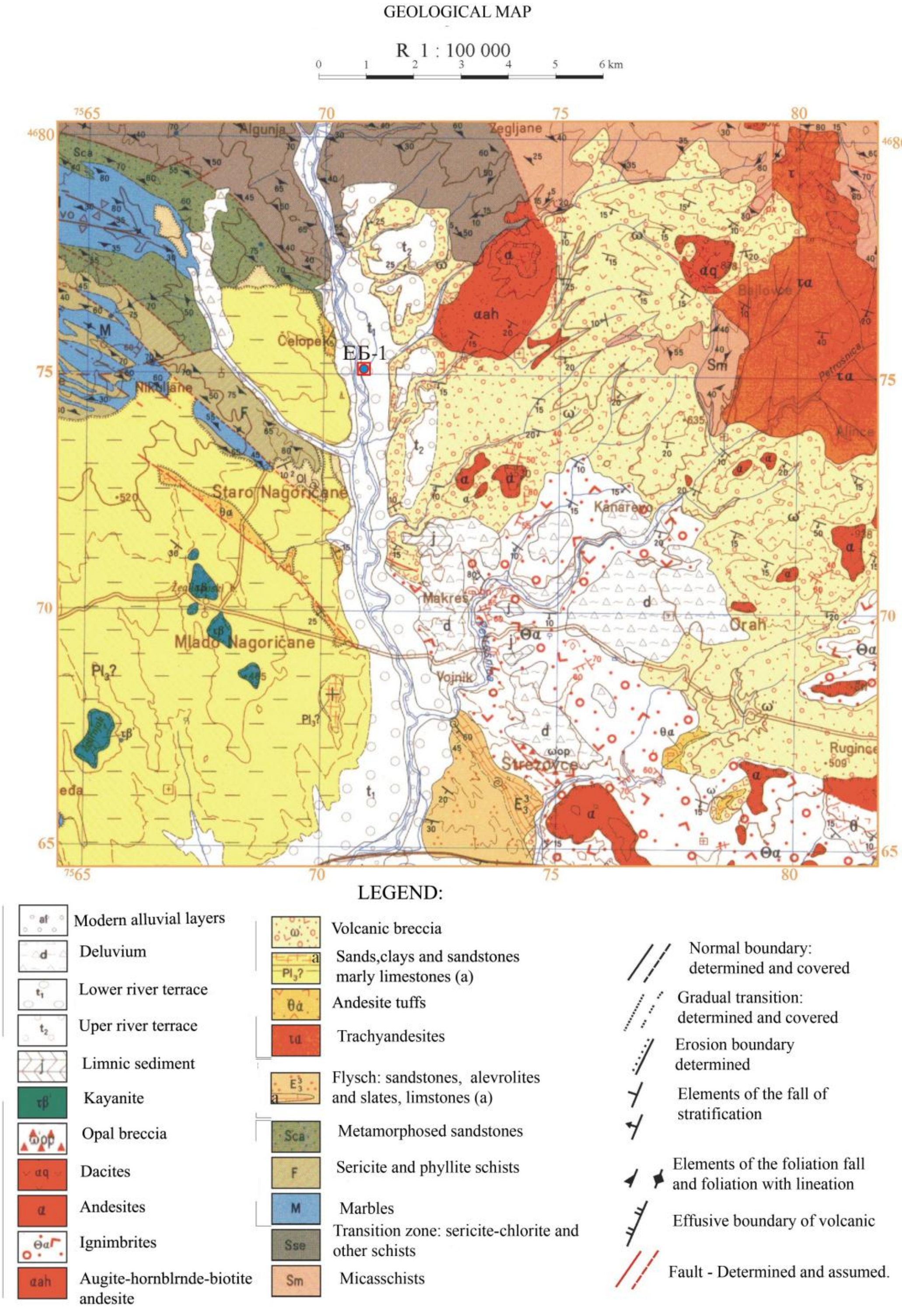

Fig. 1 Geological map of the region of Gladnica

HYDROGEOLOGICAL CHARACTERISTICS OF THE WIDER REGION

Based on results obtained during regional and detailed hydro-geologic investigations and those carried out on the structural type of porosity of rocks the following types of aquifers were distinguished:

- boundary type,
- and fracture type.

Boundary type of aquifers

Boundary type of aquifers occur in the Neogene-Quaternary age rock in which intergranular porosity is present.

The type formed in Pliocene sands, clays and sandstones as well as in alluvial and terrace sandy gravel like sediments distributed along the River Pcinja valley. The sediments are 6 - 10 m thick, the coefficient of filtration 20 to 150 m per day, the specific yield being 2 - 6 l/s/m. Recharge of aquifers is done by water infiltration from surface river flows and atmospheric rainfalls. The aquifers are of free level and totally open without significant top layer that allows various effects of external pollution. Along faults and fractures in the deep parts waters of volcanogene and metamorphic rocks lying in the floor also infiltrate. In such places the water in the alluvial- terrace sediments receives different chemistry that increases the minerlisation.

Several occurrences and structures have been found with mineral waters in the vicinity of Dragomance. They are all characterized by low total mineralization below 700 mg/l and free CO_2. This indicates that in the alluvial terrace waters of the deep fracture and shallow boundary type of aquifer mix.

Fracture type of aquifers

Fracture type of aquifers formed in neogene-volcanogene sediments that, on the surface, occur in the margin of the river valley above the village of Dragomance. The composition of rocks is predominated by tuffs, a material of volcanic origin settled in water medium. The rocks are layered to a variable degree. Pronounced neotectonic movements contributed to form, in such environment, local conditions for circulation and accumulation of ground waters. The process is also supported by young faults and fissure direction formed around them, that make possible water infiltration from the surface and the deeper parts of aquifers (penetration of mineralized waters with gas mechanism).

Volcanogene sediments are to 10 per cent porous and mostly poor to medium water porosity, K= 1 - 60 m/per day (locally over 100 to 200 m/per day). The quality of the ground water is estimated as very good with balanced hydrochemical composition and safe to drink.

Aquifers of thermomineral waters have been found in the nearby sites, downstream the River Pcinja valley with same or similar geochemical conditions. In Strnovec situated 2.5 km south of the area of investigation, thermomineral springs were found (T=39 C M=2.2 g/l) with artesian spring mechanism. The waters are secondarily accumulated in karstified Oligocene limestones, being drilled under the site beneath the volcanogene sediments 80 to 100 m in depth. Water occurrences have been noticed in several places down Strnovec as far as Katlanovo. It is realistic to predict the presence of the type of aquifers in the area, to greater depth - probably 200 to 250 meters in depth.

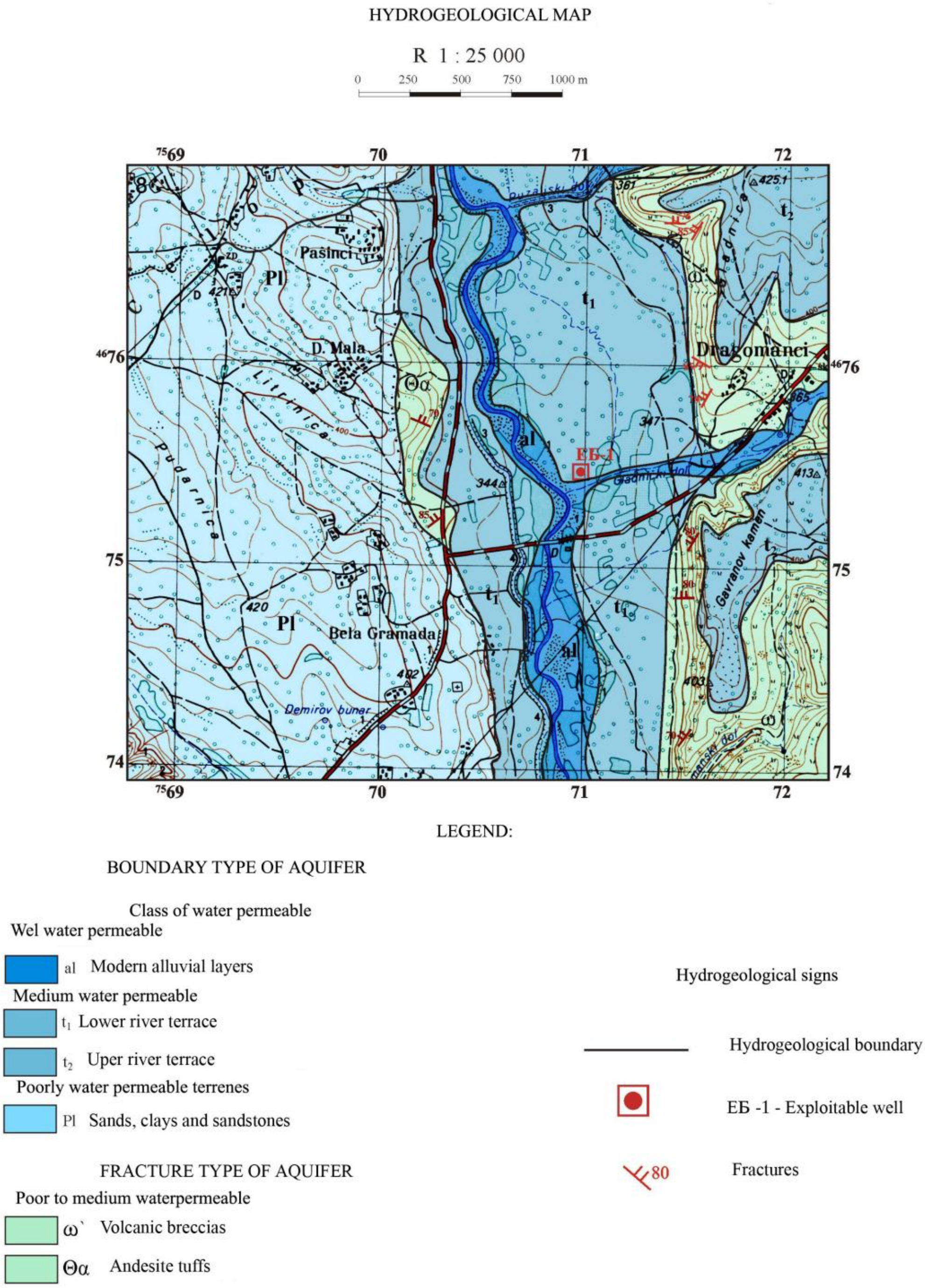

Fig. 2. Hydrogeological map of the wider region of Gladnica

HYDROGEOLOGICAL INVESTIGATIONS

Two exploration drill holes were made for the determination of the qualitative-quantitative parameters of aquifer.

The first drill hole is shallow, of 6 m in depth. It was drilled in order to determine the position and characteristics of the boundary type of the river terrace with alluvial sediments.

The second drill hole is 132 m deep that helped define the composition of, the position and the nature of the fracture type of aquifer formed in the volcanogene and the older sediments. Lithostratgraphic and hydrogeological characteristics of the terrain obtained based on drillings are given in the hydrogeological cross-section (fig. 3). Th technical features are given in fig. 4.

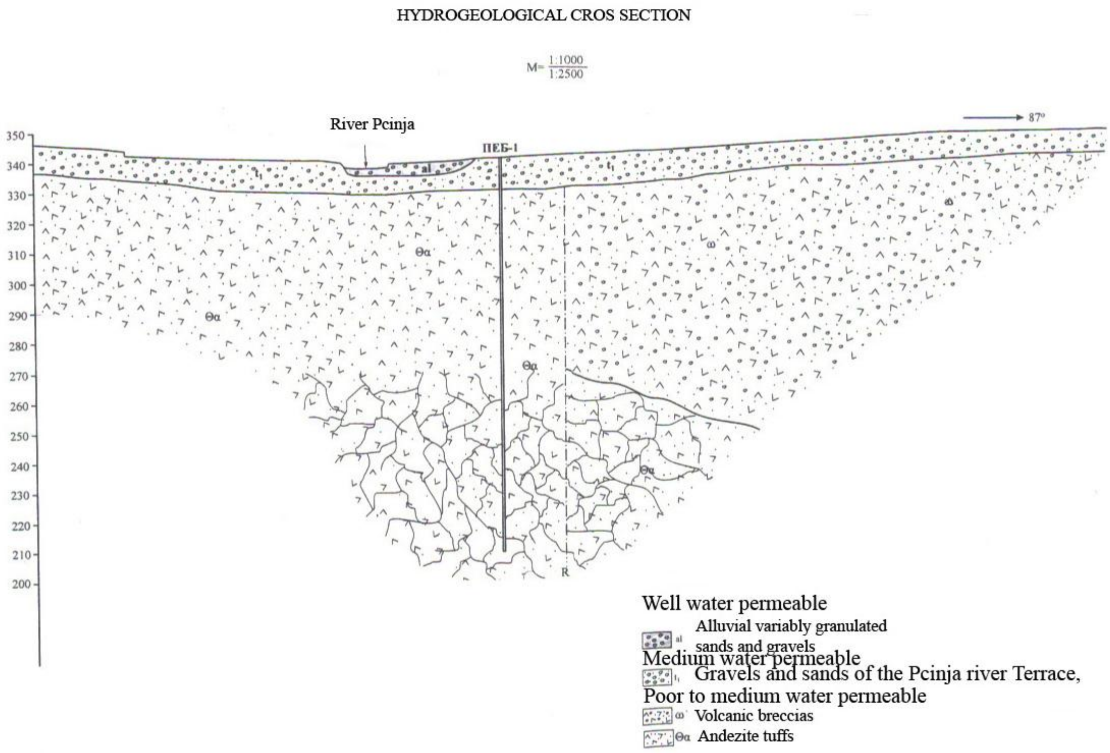

Fig. 3 Hydrogeological cross-section of Gladnica

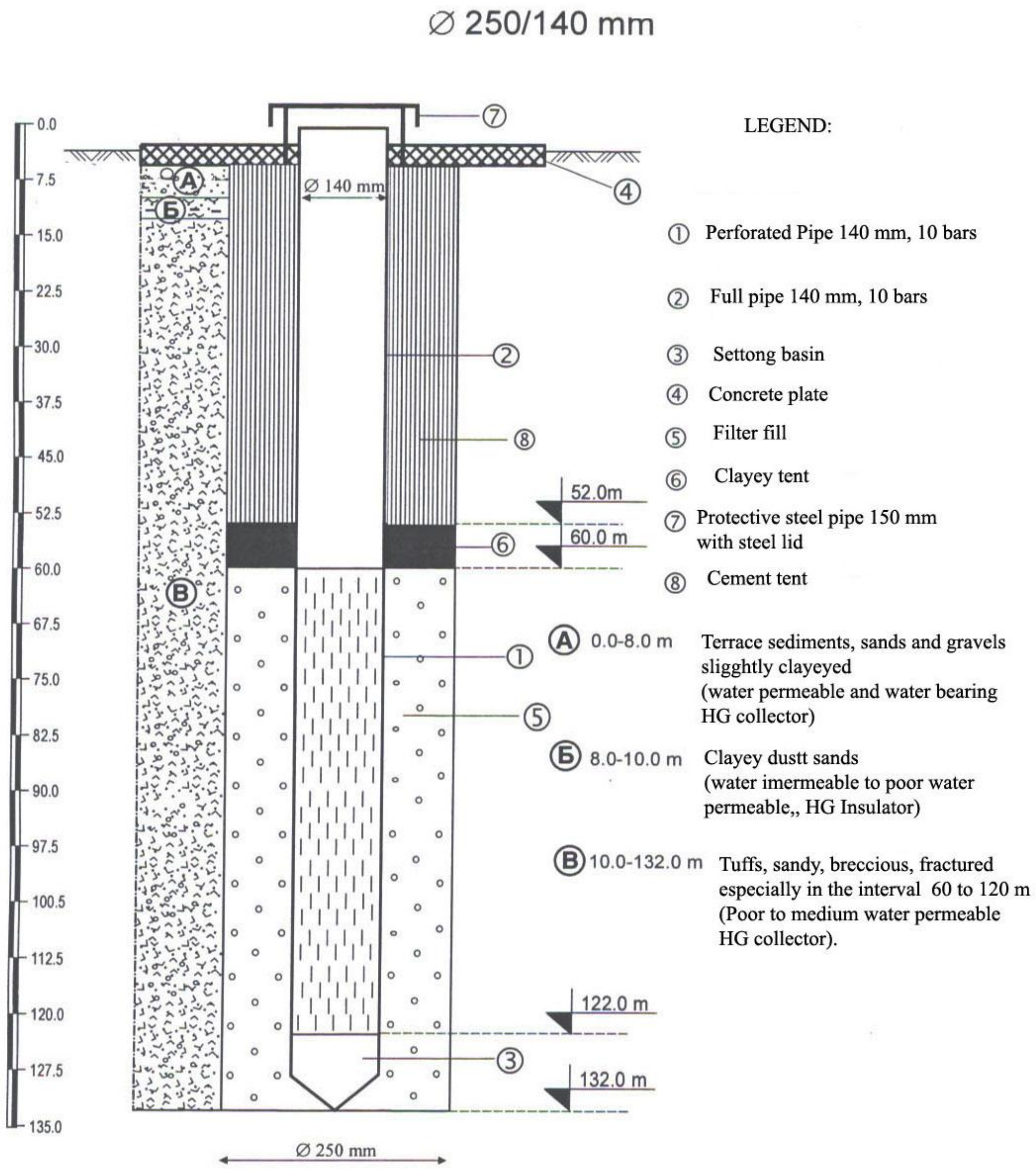

Fig. 4 Lithostratigraphic-hydrogeologica and technical characteristics of the well.

Litostratigraphic composition of the terrain

Humus-mill occurs on the terrain cover as a 0.5 m thick cover. 10 meters beneath this, alluvial-terrace sediments were found. They are made up of unsorted coarse-grained gravels and sands, well rounded with boulders, the grains being mainly those of quartz, gneisses, schists, seldom marbles and effusives that corresponds with the petrographic composition of rock masses down the water catchment area.

From 10 to 132 m the terrain is built of volcanic sedimentary rocks present as andesite tuffs, ignimbrites and breccias, sandy clayey tuffs (tuffaceous sands and clays) and similar transition varieties. The rocks are mostly well layers that can be seen from surrounding open cross-sections, poorly fissured with meter to decameter tight fractures. The rocks are of similar physical-mechanical characteristics, being fresh and hard, except for the tuffaceous sands and clays which are soft and breakable.

Sudden slump of drilling tools occurs 120 m in depth with occurrence of mineral water. This can be explained with possible presence of a fracture zone along with distribution of mineral water done from the Paleozoic floor marble masses and the main collectors within the Pcinja trench.
Based on the spatial location of the volcanics, which occur as monocline structure, the depth of the rocks is estimated at 200 to 250 meters.

Boundary of aquifer and manner of water formation

The fracture aquifer determined is part of a regional hydrogeological unit that occupies a large discontinuous area. It consists of smaller water permeable regions in volcanic environment connected with faults and fractures.
The main strikes and water permeable zones are the fault of NW-SE strike that cut the River Pcinja valley and the fault zones of NS strike related to the formation of the river valley. These tectonic events made the tuffs and other volcanic rocks become rather fractured. Fractures are partially open, especially at the surface that allows rapid infiltration of atmospheric waters to depth. This is also supported by permanent water flows.
In this manner, the formation of aquifers in volcanogenic sediments in Gladica receives a mixed type with ion content that classifies the ground water as poorly mineralized and oligomineral.
This means that the main zones of recharge of fracture aquifer are the uncovered volcanic rocks in the Gladnicki Dol that come across steep fractures, open for atmospheric water infiltration and those of deeper aquifers that mix with the waters that come from the surface. This is indicated by several wells and aquifers of gas and water in the wider region.
The extension of the aquifer to depth was determined with a drill hole of 132 meters deep. The lower boundary of older paleogene and Paleozoic rocks is expected to be 200 to 250 meters in depth.

Characteristics of exploitation well

Based the drill hole a pipe like well was constructed. The technical and lithostartigraphic characteristics are shown in fig. 4.

The main technical characteristics of the well EB- 1 are:
Depth 132 m
Drilling diameter 250 m
Pipe diameter 250
Filter length 60 m

The well confirmed the hydrogeological profile as follows:

0,0 8 0 terrace clayeyed gravels and sands,
1.00 10.00 m clayey sandy boulder
1.01 10.00 132 m tuffs: sandy, breccious, fractures in the 60 - 120 m interval.

In this water bearing part of the profile were noticed pronounced fractures 90.110 and 120 m in depth where loss of technical water was noticed.

Ground water regime

The basic characteristics of the fracture aquifer regime are as follows:
- Ground water movement is non-stationary,
- The level of ground water of the aquifer is of poorly pronounced subartesian pressure,
- Water temperature is mainly stable and under strong influence of external effects,
- The relation to external surface flows is poor to medium pronounced depending on the lithological composition of the uncovered portions,
- The effects of river water of the Pcinja are practically excluded due to the geological and litostratigraphic position.

It was determined that season changes of some chemical elements and materials occur in the aquifer. It was especially noticeable by the changes of Fe, Mn, Na, K and F contents. Repeated studies are necessary in order to confirm this.

Testing of the well

Test drawdowns were done for capacities of 2 l/s, 2.7 l/s and 3 l/s. the parameters calculated and results obtained are shown in Table 1.

Table 1. Results obtained from testing of the well.

LGW Static m	Q (l/s)	LGW Dinamic. (m)	S (m)	t (h)	q (l/s/m)
0.00	2.0	14.50	14.50	1	0.14
0.00	2.7	33.50	33.50	1	0.08
0.00	3.0	39.50	39.50	2	0.075

Parameters obtained made possible the construction of a diagram of yield dependence and specific lowering yield Q = f(S), I q = f (S) = (fig. 5), diagram of yield dependence on time Q = f(t) (fig. 6) and a diagram of dependence on lowering from time S = f (t) (fig. 7).

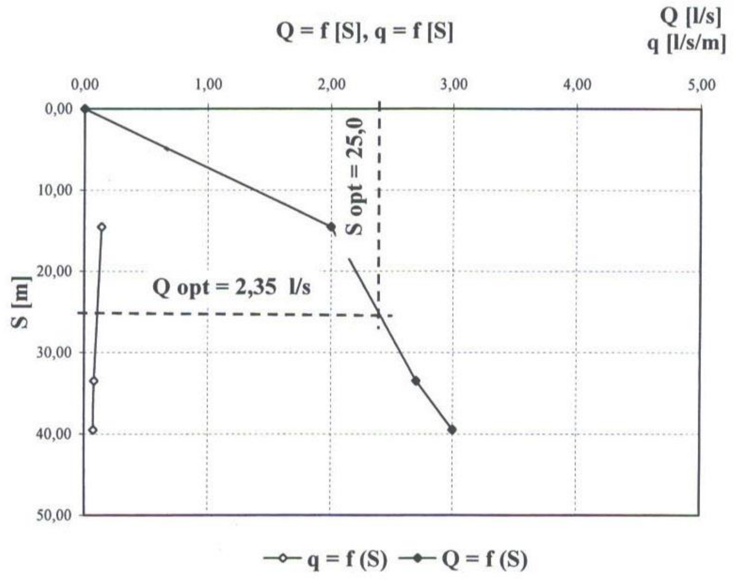

Fig. 5 Diagram of yield dependence and specific yield after lowering Q = f(S) I q = f (S)

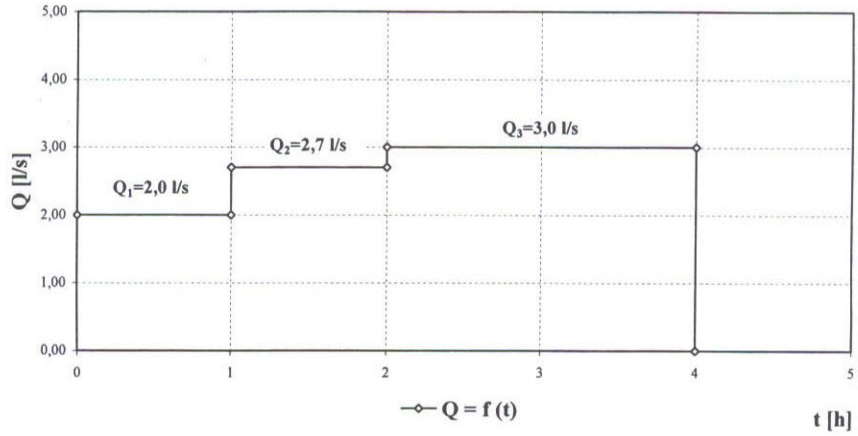

Fig. 6 Diagram of dependence of yield on time Q = f (t).

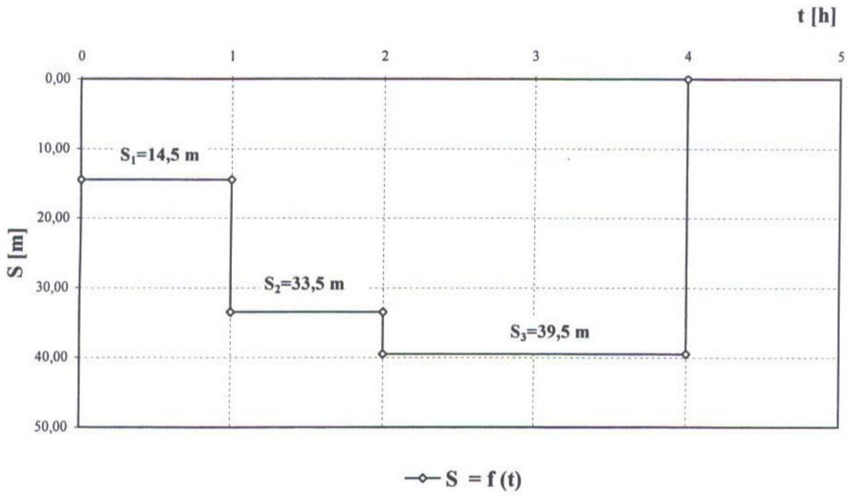

Fig. 7 Diagram of dependence of lowering on time S = f (t).

Hydrogeological parameters of aquifer

The results obtained from the testing were used to calculate the basic hydrogeological parameters.

Transmissivity coefficient (T) was determined with graphic analytic method JACOB using the formula:

$$T = (0.183 \text{ x } Q)/\Delta S$$

In the diagram S = F(lg t) the values for Q and S were introduced obtained with three step regime of draw down. Replacing the values for Q and S in the formula were obtained the values as follows:

$$T_1 = (0.183 \text{ x } Q_1)/\Delta S_1 = (0.183 \text{ x } 172.8)/1.80 = 17.57 m^2/den$$

$$T_2 = (0.183 \text{ x } Q_2)/\Delta S_2 = (0.183 \text{ x } 233.3)/2.90 = 14.72 m^2/den$$

$$T_3 = (0.183 \text{ x } Q_3)/\Delta S_3 = (0.183 \text{ x } 259.2)/2.80 = 16.94 m^2/den$$

$$T_{sr} = 16.41 m^2/dey$$

The filtration coefficient (K) was obtained from the same relationships so that the value T obtained was divided by the corrective thickness in the water-bearing horizont. The thickness of water-bearing horizont is H = 70 m.

$$\mathbf{K_1 = T_1/H = 17.57/70 = 0.25 m/den = 2.89 \times 10^{-4} cm/sek}$$
$$\mathbf{K_2 = T_2/H = 14.72/70 = 0.21 m/den = 2.43 \times 10^{-4} cm/sek}$$
$$\mathbf{K_3 = T_3/H = 16.94/70 = 0.24 m/den = 2.78 \times 10^{-4} cm/sek}$$

$$\mathbf{K_{sr} = 0.233\ m/den = 2.70 \times 10^{-4}\ cm/sek}$$

The values obtained for the basic filtration parameters point out the presence of water-bearing environment with medium water permeability.

Ground water reserves

Statical reserves were calculated for the fracture aquifer within the surface catchment of the Gladnik stream which will have immediate effect on the exploitation of the aquifer.

$$Q_{st} = \mu \text{ x } V$$

μ – 0.02 (value adopted based on porosity)

$$V = P \text{ x } H$$
$$P_{st} = 2.1\ km^2,\ H = 70m.$$
$$Q_{st} = \mu x V = 3.2x10^6 m^2 x 70m = 2.94x10^6 m^3$$

Dynamic reserves were calculated based on one selected cross-section through a ground flow in the catchment area in Gladnicki Potok (stream) according to the formula:

$$Q_{din} = KxNxBxi$$

K- 0.233 m/per day is the coefficient of filtration,
N-70 m is the thickness of water-bearing horizon,
B-1600 m is the width of ground flow,
i -0.02 is the gradient of flow.

$$Q_{din} = 522\ m^3/\text{den}$$

Exploitation reserves were determined based on earlier calculated values for statistic and dynamic reserves and based on capacity of test-exploitation well.

$$Q_{st} = 2.94x10^6 m^3$$
$$Q_{din} = 522 m^3/dey \text{ or } 187.920\ m^3/year$$

$$Q_{bun} = 2 - 3lit / sek$$

or 62.208 m^3/per year - 93.312m^3/per year which is 33% of the dynamic reserves.
In practice it is common the maximum allowed capture recovery of aquifer waters to amount within the dynamic reserves available. In this case the exploitable reserves in the fracture aquifer in the Gladnicki potok drainage area to be estimated at:

Q $= Q_{eks} = \alpha x Q_{din} (\alpha -$corect od degre od ivestigations 0.60)

$Q_{eks} = 0.6x187.920 = 131.544m^3 / year$ or 4.17 l/s.

In the initial phase of exploitation it is necessary to monitor the basic hydrogeological parameters and correct possible deviations in the exploitation regime.

GROUND WATER QUALITY

The composition of ground water analysed after digging of the well, points out the rather complex hydrogeological pattern in the terrain. Due to the different rock composition in the drainage area and variable size of filtration parameters, differences appear in the ions of waters. This may be an indicator of the presence of more horizons in the vertical cross-section from which, during draw down, there is mixing of waters depending on the size of depression so that waters from one or more horizons come to the well. However, mistakes during analyses can not be excluded, either.
The analyses for water quality carried out by the State Institute for Heat Protection were used for the classification of ground water.
In that regard only the contents of essential anions and cations that define the water type have been given.
According to the basic anion-cation composition shown using the Kurlov formula it follows that:

Analysis 1**.** M- 664 (mg/l) $HCO_3 - 82$ $SO_4 - 9$ Cl-8 /Ca-36 Mg-52 Na-10 K-1

Water type: hydro-carbonate, magnesian-calcic with specific contents of flour and strontium.

Analysis 2. M-731 (mg/l) HCO_3-79 SO_4-11 Cl-10 / Ca-36 Mg-54 Na-46 K-4

Water type: hydrocarbonate-sulphate, sodium-calcic and magnesian with interesting strontium and fluorite contents.

Analysis 3. M-696 (mg/l) HCO_3-80 SO_4-13 Cl-6 / Ca-31 Mg-41 Na+K-27
Water type: hydro-carbonate-sulphate, sodium-calcic-magnesian with strontium and fluorite.
Analysis 4. M-696 (mg/l) HCO_3-82 SO_4-9 Cl-9 / Ca-37 Mg-51 Na+K-11

Water type: hydro-carbonate, magnesian-calcic with strontium and fluorite.

Significant differences in the content of some chemical indicators in the four analyses remain unclear. This applies especially to the great differences in the cation contents of

Na (19-93 mg/l), K(3-14 mg/l), Mg (15-50 mg/l)< Fe (0.5-2 mg/l). With the anion contents greater differences were noticed in SO4 (35-61 mg/l).
According to the total mineralization, the water analysed with about 696 mg/l dissolved mineral materials was defined as poorly mineralised oligomineral water.

CONCLUSION

In the area of the Gladnica site, beneath alluvial terrace sediments of the River Pcinja 10 to 132 m in depth there is fracture type of aquifer formed in tectonically fissured volcanogene neogene sediments.
The water level in the aquifer is of poor subartesian pressure.
Recharge is carried out with water infiltration from the surface, from atmospheric rainfalls through the fissures volcanogene sedimentary rocks and water flow from the deeper aquifers when mixing of waters occurs that results in specific chemical composition.
The chemical composition of water is classified as hydro-carbonate, magnesian-calcic low mineral with characteristic strontium and fluorite contents.
Exploitable reserves of the well, according to calculation amount to 4.17 l/s, but for the best results it is advisable to amount to 2 l/s.

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