MOGUĆNOSTI ZAGAĐENJA PODZEMNE VODE ŠTIPSKOG VODONOSNIKA S OBZIROM NA NJEGOVE HIDROGEOLOŠKE KARAKTERISTIKE

POSSIBILITIES FOR GROUNDWATER POLLUTION OF THE STIP AQUIFER REGARDING ITS HYDROGEOLOGICAL CHARACTERISTICS

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Key words: Stip aquifer, overlay sediments, contamination, ground water.

Sažetak

U radu je predstavljeno istraživanje filtracijskih značajki aluvijalnih sedimenata štipskog vodonosnika s ciljem utvrđivanja stupnja zaštite podzemne vode od zagađenja. Prethodna istraživanja utvrdila su da se aluvijalni sedimenti štipskog vodonosnika sastoje od dva sloja različitih granulometrijskih i filtracijskih značajki. Vodonosni sloj je krupnozrnata porozna sredina građena od pijeska i šljunka s hidrauličkom vodljivosti u rasponu od 40 do 280 m/dan. Ovaj sloj u krovini ima sitnozrne sedimente slabih filtracijskih značajki. Sastoje se od prašnjavih i glinovito prasnjavih pijesaka hidrauličke vodljivosti u rasponu od

2×10^0 – 1.5×10^{-3} m/dan. Ovo istraživanje je pokazalo da pokrovne naslage ne osiguravaju dovoljnu prirodnu zaštitu podzemne vode štipskog vodonosnika i da pripadaju osjetljivom geološkom okolišu.

Abstract

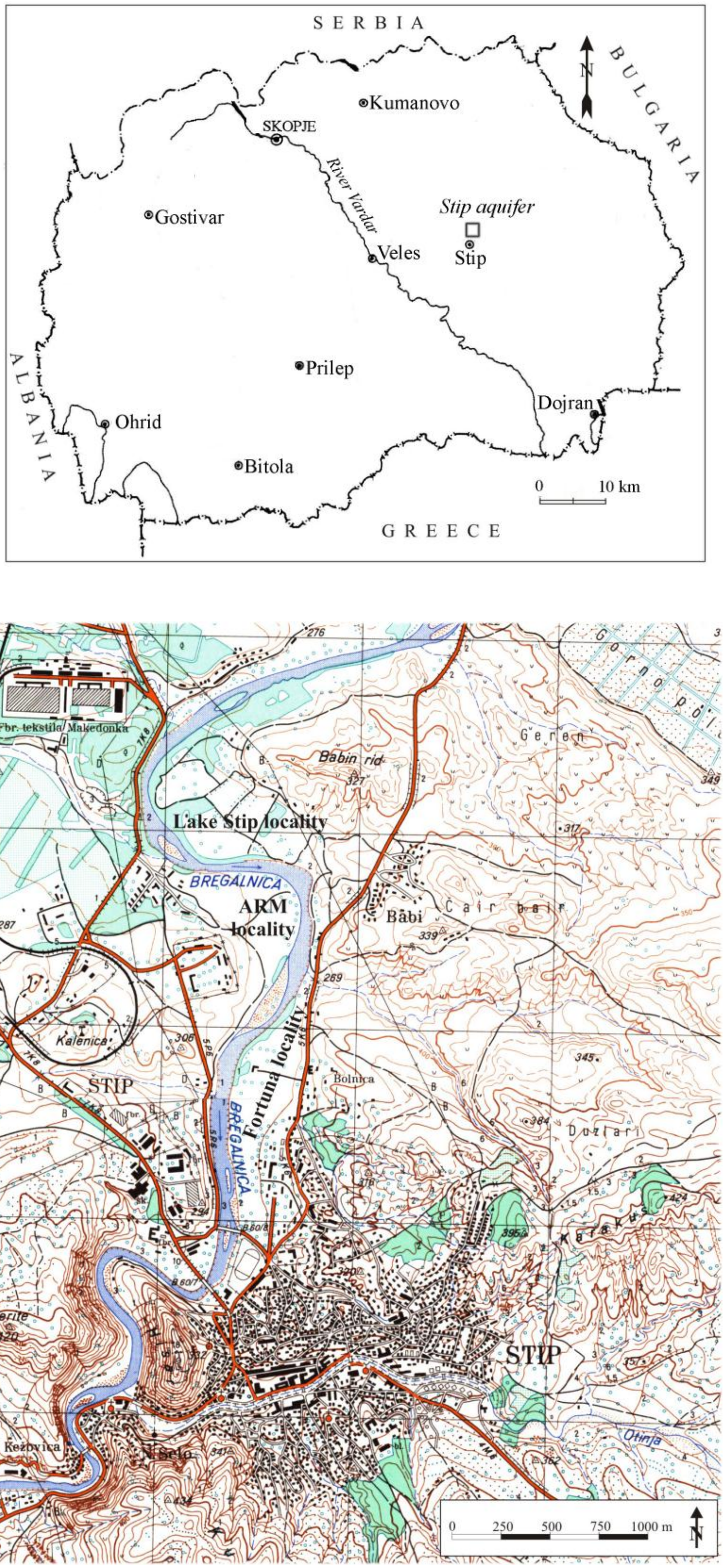
The paper presents research on filtration characteristics of the alluvial sediments of the Stip aquifer in order to determine the degree of protection from ground water pollution.

Previous studies determined that alluvial sediments of the Stip aquifer are built of two layers of different granulometric and filtration characteristics.

The water-bearing layer is a coarse-grained porous media built of sand and gravel with hydraulic conductivity ranging from 48 to 280 m/day. This layer is overlaid with fine-grained sediments having low filtration characteristics. Overburden consists of dusty and clayey dusty sands with hydraulic conductivity ranging from 2×10^0 - 1.5×10^{-3} m/day. This research showed that overlay sediments don't provide sufficient natural protection for ground water of the Stip aquifer and that they pertain to susceptible geological environment.

Introduction

The water supply system of the City of Stip, Macedonia, relies on ground water from aquifers with intergranular porosity formed in alluvial sediments of the first terrace of the River Bregalnica. The aquifers are located in the northern periphery of the Stip City (Fig 1). It is an urban area and the high risk of pollution is due to potential surface anthropogenic pollutants.



Slika 1. Lokacija štipskog vodonosnika

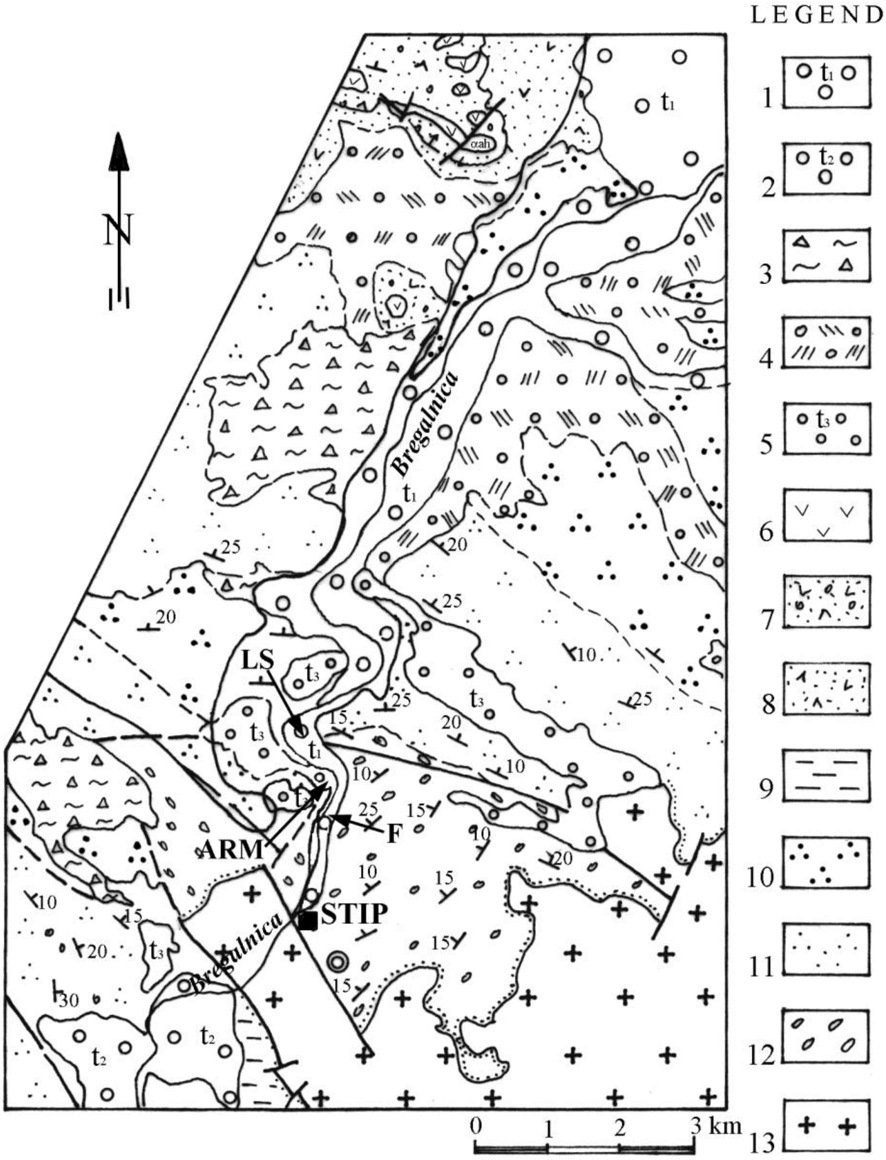
Figure 1 The location of the Stip aquifer

The ground water abstraction occurs on three wellfields: the Fortuna (Q=65-70 l/sec), ARM (Q=60 l/sec) and The Lake Stip (Q=120 l/sec) where 250 l/s are obtained for the water supply system of the City of Stip.

Geological setting

The geological composition of the surrounding of the Stip aquifer (Fig. 2) is shown using the data of Rakicevic et al., (1969), It consists of:

- Mesozoic granites,
- Tertiary sediments,
- Pliocen-quaternary sediments and
- Quaternary sediments.



Slika2. Geoloska karta sire okolice stipskog vodonosnika i lokacije istrazivanog podrucja.

Kvarter: 1. niska recna terasa (aluvijalne sedimente), 2. visoka recna terasa, 3. deluvium, 4. proluvium, 5. stara recna terasa, Pliocen-kvarter: 6. augit-hornblenda-biotitske andezite, 7.andezitske tufove, 8. andezitske brece, ***Tercier:*** 9. Pliocen: pjescenjaci, sugline i slunkove, 10. Eocen: gorna flisna zona, glince, pjescenjaci, 11. Eocen: lapori, vapnenci i glince, 12.Eocenska bazalna serija: pjescenjaci, lapori, i konglomerati. ***Mezozoik:*** 13. Jurske granite. LS – lokalitet Stipsko jezero; ARM- lokalitet ARM; F-Fortuna lokalitet.

Figure. 2. Geologic map of wider environment of the Stip aquifer and locations of the investigated area. ***Quarter:*** 1. lower river terrace (alluvial sediments), 2.higher river terrace 3. deluvium, 4. proluvium, 5. old river terrace, ***Pliocen-quarter:*** 6. augit-hornblende-biotitic andesites 7. 5. Pliocene, 6. upper flysch zone. Eocene: slates, sandstones, 7. andesitic tufs 8. andesitic brecia ***Tertiary****:* 9. Pliocene: sandstones, loams and gravels. 10. Eocene: upper flysch zone slates, sandstones 11. Eocene marls, limestones, slates, 12. Eocene basal series: sandstones, marls and conglomerates, ***Mesozoic:***13. Jurassic granites. LS – Lake Stip locality; ARM- locality; F-Fortuna locality.

The Mesozoic is present of Jurassic granites (155±5 m.y. by Rb/Sr method, (Soptrajanova, 1967). They are of heterogenous lithological composition and made up of biotite adamelites, biotitic granites and aplitoid granites crosscut by earlier phase dacite daykes.

The Tertiary is present as a basal series of Eocene sandstones, marls and conglomerates, and Upper Eocene flysch sediments made up of slates, sandstones, marls and limestones. The Pliocene sediments are present as sandstones, loams and gravels.

The Pliocen-quaternary is present of andesitic brecia, andesitic tufs and augit-hornblende-biotitic andesites.

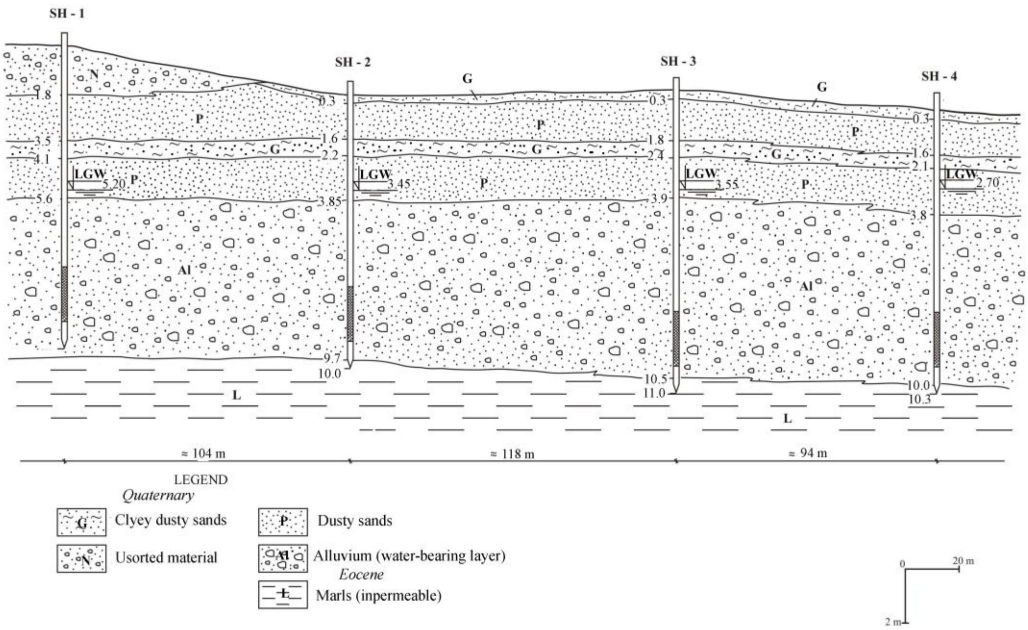
The Quaternary is present along the River Bregalnica as lower, higher and old river terraces made up of andesitic alluviums, seldom quartz and gneisses as well as alluvial sediments presents as gravels and sands, and of deluvium and proluvium sediments.

The alluvial sediments of the Stip aquifer represents continuous lithological-hydrogeological unit. The erosion of the River Bregalnica divided this unit into three river terraces: the Fortuna, ARM and the Lake Stip. River terraces appear in a 3 km long and 100 to 300 m wide belt. The alluvial sediments represent separate lithologic facies and hydrogeological unit where appreciable amounts of ground water have accumulated so far. They are separated from the surrounding Eocene sediments which represent the boundary of the aquifers (Fig. 3.).

Hydrogeological characteristics of the alluvial sediments

Hydrogeological explorations carried out for the water supply of the Stip City, determined the structural position of the alluvial sediments relative to the basal Eocene sediments and their lithologic-facial alterations (Terziovski, 1992).

Fig. 3 is a representative geological-hydrogeological cross-section for the Stip aquifer compiled with data obtained from bore-holes.



Slika 3. Geološko-hidrogeološki presjek kroz lokalitet Fortuna

Figure 3 Geologic-hydrogeological cross-section through the Fortuna locality

The Quaternary alluvial sediments transgressively and discordantly overlay the Eocene impermeable marls. The water-bearing layer is built of 5.5 to 9 m thick sands and gravels. The maximum depth of the water-bearing layer goes to 11 m. The water-bearing layer is overlaid with sediments of variable thickness built mainly from dusty and clayey dusty sands. The thickness varies from 3.8 to 5.6 m, increasing to the periphery of the river terrace where contact with the Eocene sediments occurs. Overlay sediments are thinner at the bank of the River Bregalnica with thickness ranging from 0.2 to 3 m. In some parts of the aquifer, gravel and sand deposits emerge to the surface.

Depth to water table is shallow, ranging from 3 to 5.4 m. Ground water table is connected to the river Bregalnica so there is a direct hydraulic connection between the river and water-bearing layers. Ground water recharge is mainly from river bank infiltration and from precipitation recharge through overlay sediments.

Filtration characteristics of the alluvial sediments

Water-bearing alluvial sediments represent a coarse porous environment consisting of a series of variously granulated gravels and sands with super capillary intergranular porosity. Dusty and clayey sediments of fine-grained porosity are transgressively and discordantly deposited above the coarse porous environment. In the regional scale, both alluvial and overlay sediments are of homogenous lithologic and granulometric composition and horizontal extension. Their thickness varies vertically.

Filtration characteristics of the overlay sediments

Filtration characteristics of the overlay sediments are important regarding ground water protection. They were determined based on data obtained from granulometric analyses. Hydraulic conductivity of the overlay sediments was calculated using the USBR and Slichter method. Samples for the granulometric analyses were collected from the Fortuna, ARM and the Lake Stip locality. The results for the calculated hydraulic conductivities are shown in (Table 1).

Tablica 1 Vrijednosti hidrauličke vodljivosti (K) izračunate za pokrovne naslage štipskog vodonosnika koristeći USBR i Slichter metodu.

Table 1 Hydraulic conductivity (K) values calculated for the overlay sediments of the Stip aquifer using the USBR and Slicher methods.

Probe	d_{10} (mm)	d_{20} (mm)	(USBR) K (m/den)	(Slichter) K (m/den)	The mean values K (m/den)
F – 1	0.07	0.25	1.18×10^{1}	4.32×10^{-1}	8.06×10^{-1}
F- 2	0.003	0.014	1.83×10^{-2}	8.50×10^{-4}	9.57×10^{-3}
F- 3	0.06	0.2	6.75×10^{0}	3.24×10^{-1}	3.54×10^{0}
St.E-1	0.002	0.006	2.52×10^{-3}	3.77×10^{-4}	1.45×10^{-3}
St.E -2	0.01	0.04	1.82×10^{-1}	9.42×10^{-3}	9.57×10^{-2}
St.E -3	0.003	0.006	2.29×10^{-3}	7.94×10^{-4}	1.54×10^{-3}
St.E -4	0.012	0.022	4.60×10^{-2}	1.24×10^{-2}	2.92×10^{-2}
ARM-1	0.02	0.06	5.11×10^{-1}	3.06×10^{-2}	2.70×10^{-1}
ARM-2	0.0065	0.016	2.03×10^{-2}	4.50×10^{-3}	1.24×10^{-2}

The mean K values for the overlay sediments were calculated using the two methods for each lithologic environment.

The Fortuna locality. The mean K values for samples F-1 and F-3 taken from the dusty sands in near vicinity of the River Bregalnica amounts up to 2×10^{0} m/day.

The mean K value for F-2, clayey dusty sands close to the periphery where the Eocene sediments occur, amounts up to 10×10^{-2} m/day.

The clayey dusty sands occur in the *Lake Stip locality*. The calculated K values for the St. E-1 and St.-3, located at the edge of the river terrace in close proximity of the Eocene sediments were $K = 1.5\times10^{-3}$ m/day, for the St.-E-2 and St.-E-4 located 50 meters from the river in an open cross-section where dusty sands occur, the calculated K values were 5.7×10^{-2} m/day.

In the *ARM locality,* ARM-1 and ARM-2, where dusty sands occur close to the river, the calculated K values were 1.4×10^{-1} m/day.

Filtration characteristics of the water-bearing layer

The filtration characteristics of the water-bearing layer of the Fortuna locality were determined based on granulometric analyses carried out on samples taken from bore-holes and exploitation wells (Terziovski 1992) and based on data obtained of pumping test from bore-holes of exploitation wells of the Fortuna and Lake Stip localities. (Terziovski 1990).

The USBR method was used to calculate the hydraulic conductivity according to data from granulometric analyses. The mean hydraulic conductivity value of the water-bearing layer calculated for the borehole SH-1 equals 120 m/day, for the borehole SH-2 equals 80 m/day, for the borehole SH-3 equals 44 m/day and for the borehole SH-4 equals 130 m/day. The mean hydraulic conductivity for the above boreholes equals 93 m/day.

The mean value of hydraulic conductivity for the water-bearing layer calculated for five exploitation wells after USBR method is as follows: for the exploitation well S-1 mean K = 85 m/day, for the exploitation well S-2 mean K = 110 m/day, for the exploitation well S-3 mean K = 100 m/day, for the exploitation well S-4- mean K = 47 m/day and for the exploitation well S-8- mean K = 86 m/day.

The mean value of hydraulic conductivity for the water-bearing layer according to above results for all exploitation wells is K = 90 m/day.

The hydraulic conductivity for the Fortuna and the Lake Stip localities was determined using pumping test data after Jacob's method. (Jacob 1950).

At the Fortuna locality the hydraulic conductivity of the water-bearing layer was calculated using data from pumping tests carried out in four exploitation wells. The results obtained were as follows: for the exploitation well DB-3 K = 760 m/day, for the exploitation well DB-4 K = 340 m/day, for the exploitation well DB-6 K= 200 m/day and for the exploitation well DB-5 K = 300 m/day. Greater deviations of hydraulic conductivity were found in exploitation well DB-3. The result obtained from this exploitation well wasn't taken into consideration for calculation of the mean hydraulic conductivity. The mean hydraulic conductivity of the water-bearing layer calculated from the results of the three remaining exploitation wells is K = 280 m/day.

The hydraulic conductivity of the water-bearing layer at the Lake Stip locality was calculated using data from pumping tests carried out in two exploitation wells. The results obtained were as follows: for the exploitation well B-6/2000 K = 15.206 m/day and for the exploitation well B-7/2000 K = 80 m/day. The mean hydraulic conductivity for the above two exploitation wells is K = 47 m/day.

Analyses of the calculated hydraulic conductivities indicate that the alluvial sediments of the Stip aquifer consist of a two-layer porous environment, having different granulometric and filtration characteristics.

The bottom layer is a coarse porous water-bearing environment with good filtration characteristics. It is overlaid with the layer of fine-grained porosity and poor filtration characteristics.

Protection potential of the overlay sediments

In order to define the level of protection potential of the overlay sediments, it is necessary to determine percolation velocity and the time necessary for potential pollutants to pass through the overlay sediments and reach the ground water.

Since the aquifer system consists of two lithologic environments having different filtration characteristics, calculations will be performed for each environment and locality separately.

Fortuna locality

The overlay sediments in the Fortuna locality are built of clayey dusty sands and dusty sands of variable thickness. They are thicker in the periphery of the river terrace and at the contact with the Eocene sediments with thickness averaging 3.9 meters. They are thinner towards the river where their thickness ranges from 0.2 to 3 meters.

Calculations of the percolation velocity were performed with the assumption that pollution travels with the same speed as the water.

Vertical flow (percolation) through the overlay sediments. The average thickness of the overlay sediments obtained from the boreholes is 2 m. About 0.2 m pertains to clayey dusty sands and 1.8 m to dusty sands.

Percolation velocity through the overlay sediments was calculated using Darcy's formula which was result of the Darcy's low, (Darcy 1856):

$$V_z = \frac{-k}{n_{ef}} i$$

where:

V_z - is effective vertical percolation velocity,

-*k*- is vertical hydraulic conductivity ,

n_{ef} - is effective porosity, mean value according to Domenico & Schwartz. 1998).

i - is hydraulic gradient.

Percolation time was determined using the formula

$$t = \frac{m}{V_z}$$

where:

t - is time in days,

m - is thickness of sediments (m), overlay sediments,

V_z - is effective vertical percolation velocity (m/day).

and

Obtained results by calculations of the percolation velocity and time through the overlay sediments is shown in the table 2.

Movement of fluid particles in vertical direction in the least favorable case can be approximated with the flow through unsaturated semi-permeable layer with hydraulic gradient equal to 1.

Table 2. Brzina i vrijeme procedjivanja kroz pokrovne naslage za lokalitet Fortuna.

Tablica 2. Percolation velocity and time of he overlay sediments of the Fortuna locality.

0.2 m thick clayey dusty sands.					
K (m/day)	m *(m)*	n_{ef}	*i*	V_z (m/day)	t (days)
0.00957	0.2	0.3	1	0.0139	6.27
1.8 m thick dusty sands.					
K (m/day)	m *(m)*	n_{ef}	*i*	V_z (m/day)	t (days)
2.173	1.8	0.3	1	7.24	0.25
0.9 m thick clayey dusty sands.					
K (m/day)	m *(m)*	n_{ef}	*i*	V_z (m/day)	t (days)
0.00957	0.9	0.3	1	0.00319	28.21
3 m thick dusty sands.					

K (m/day)	m *(m)*	n_{ef}	*i*	V_z (m/day)	t (days)
2.173	3	0.3	1	7.24	0.41

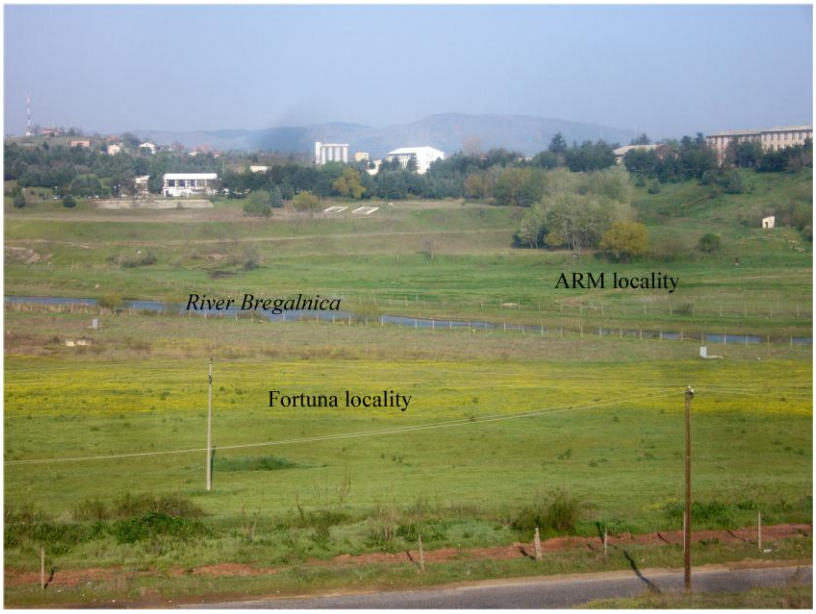
The total time necessary for the potential pollutant to pass through the overlay sediments built of 0.2 clayey dusty sands and 1.8 m of dusty sands is 6.27 days + 0.25 days = 6.52 days.

Overlay sediments in near vicinity of the contact with the Eocene sediments are 3.9 m thick . Of these, 0.9 m is built of clayey dusty sands and 3 m of dusty sands.

The calculated results show that pollutants will pass through overlay sediments built of 0.9 m clayey dusty sands and 3 m dusty sands in a time period of 28.21 days + 0.41 days = 28.62 days.

Furthermore, it can also be concluded that the natural ground water protection potential of the overlay sediments in the Fortuna locality is low. The ground water protection potential of the overlay sediments in the peripheral parts of the river terrace near contact with the Eocene sediments is higher since the time necessary for the pollutants to pass through is 28.21 days, whereas the protection that the overlay sediments provide at the River Bregalnica area is lower since pollutants need 6.52 days to pass through.

There are no structural lithologic data for the ARM locality that may help to unravel the lithologic-hydrological structure better. The locality is situated on the right side of the Bregalnica opposite to the Fortuna locality (Fig. 4). The two localities are a lithologic-hydrological unit separated by the river. Bearing in mind the closeness of the localities and the small surface of the river terrace, it can be assumed that there are no major structural-lithologic differences between the two. Thus, the data obtained with hydraulic calculation for the Fortuna locality should correspond to those for the ARM locality.



Slika 4. Lokacija lokaliteta Fortuna i ARM

Figure 4. The location of the Fortuna and ARM locality

Horizontal flow through the water-bearing environment.The hydraulic conductivity obtained during pumping tests of exploitation wells was used to calculate the velocity of horizontal flow with which possible pollutants would travel when coming close to the water-bearing environment.

The velocity of horizontal flow was calculated according to the hydraylic gradient for the Fortuna locality based on the data from three wells.

i = 0.067- hydraylic gradient

n_{ef} = 0.3 -effective porosity (mean value for gravel and sand according to Domenico & Schwarz. 1998).

K = 280 m/day -mean hydraulic conductivity for Fortuna locality based on pumping test data from,

V_z – velocity of horizontal flow

V_z = 63 m/day.

Locality Lake Stip

According to the cross-section through the exploitation well B - 7/20000, the overlay sediments at the Lake Stip are built of 2.5 m thick clayey dusty sands. However, according to the data of exploitation well B-6/2000 they are built of 2.5 m dusty sands and 2.5 clayey dusty sands having the total thickness of 5 meters. Hydraulic calculations have been carried out on the overlay sediments for both cases. From the cross-sections it can be concluded that the cover sediments of the Lake Stip are of variable thickness built of two lithologic environments.

Vertical flow (percolation) through the overlay sediments. The following values were obtained for 2.5 thick overlay sediments built of clayey dusty sands:

m = 2.5 m, mean thickness of the overlay sediments built of clayey dusty sands,

K = 0.0015 m/day, clayey dusty sands - hydraulic conductivity obtained from granulometric analyses,

V_z = 0.0049 m/day; t = 510 days.

The following values were calculated for the 5 m thick overlay sediments built of 2.5 m dusty sands and 2.5 m clayey dusty sands:

m = 2.5 m thickness of the overlay sediments built of dusty sands,

K = 0.057 m/day, dusty sands - hydraulic conductivity obtained from granulometric analyses,

V_z = 0.19 m/day; t = 26 days.

Vertical percolation through the overlay sediments built of 2.5 m dusty sands would occur in 26 days, whereas percolation through 2.5 m thick clayey sands would occur in 510 days. Percolation through the overlay sediments built of 2.5 m thick dusty sands and 2.5 m clayey dusty sands would occur in 540 days. Calculation results indicate that protection potential of the overlay sediments built of dusty sediments is much lower than that of the overlay sediments built of clayey dusty sands.

Conclusion

The Stip aquifer is an unconfined to confined/unconfined aquifer. Hydrogeological calculations carried out indicate that the overlay sediments, particularly at the Fortuna locality, do not provide sufficient natural protection from possible pollution from the surface. Research carried out determined that the degree of protection of the overlay sediment in Lake Stip locality is higher than in the Fortuna locality.

There are also possibilities that ground water of the Stip aquifer could be polluted from the water of the River Bregalnica, since the aquifer is in direct hydraulic connection with the river. In such case pollution would affect the ground water quality since the velocity of the horizontal flow at which pollution would travel through the aquifer is high (amounting 63 m/day).

Researches carried out indicate that the alluvial sediments in the Stip aquifer are vulnerable to pollution.

In order to protect the ground water of the Stip aquifer from pollution, it is necessary to follow the measures envisaged in the project report where the sanitary protection zones around the wellfields are defined (Mircovski et al. 2009, Micevski et al 2007).

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