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CHANGES IN WATER QUALITY OF ZAGREB WATER-PUMPING SITES

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Abstract: The paper deals with changes of water quality of the aquifer in the valley of the Sava River at Zagreb, capital of Croatia, with respect to the depth of aquifer, laterally and temporally, during several years. The impact of water quality on the appearance of incrustation and corrosion in wells has also been analyzed. There are also presented procedures for preventing incrustation and corrosion. The basis for this paper are the results of analyses of the water samples taken from different wells, new piezometers and those previously carried out at water-pumping sites of different embedding depths.

INTRODUCTION

During the 125-year long tradition of the Zagreb water supply system, the underground water has been examined at numerous sites in the valley of the Sava River, from Bregana to Črnkovec, and also on the slopes of Medvednica and Samobor hills. Extensive and very complex research was conducted, the results of which have enabled the increase of retention and consumption of water from the initial small amounts (in 1878) to the current 150 mln m^3 of drinking water per year. A large number of exploration and observation boreholes and production wells have been done, and water-pumping sites with its safety zones arranged (Fig. 1). The goal of the water supply system is the safe supply of drinking water for about 850 000 citizens in the area of about 800 km^2.

Through complex and long lasting research, favorable natural hydro-geological features of the aquifer in the valley of the Sava for the Zagreb water supply have been determined. Because of the voluminous aquifer with the water quality that meets the criteria for potable water, the location of Zagreb is considerably more favorable than that of the majority of other cities in the world. Great financial means have been spent on researching the aquifer, building and equipping water-pumping sites and the aggregative water supply system, and it needs to be preserved, protected and conserved for permanent use. The consumption of water in Zagreb is increasing. Therefore, immaculate conservation of wells and control and protection of the quality of intake water is necessary in order to

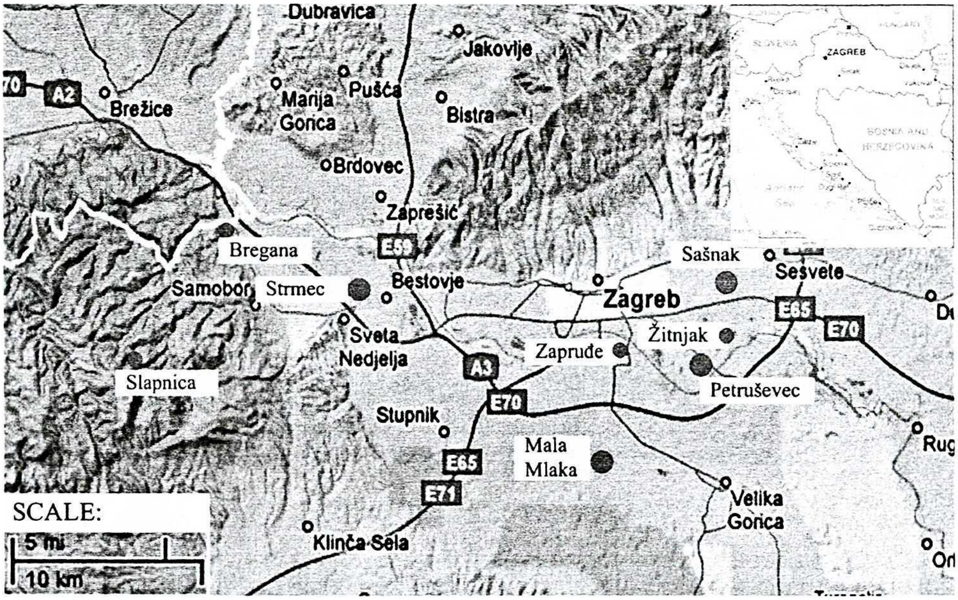

Fig. 1. Water-pumping sites location map [6]

ensure increased amount of water for the sake of appeasing growing needs for drinking water.

Methodical measurements of underground water level (UWL) and analysis of water samples quality are conducted for all water-pumping sites. The data are recorded, analyzed, commented on and presented to the authorized institutions and governmental departments in Zagreb. Thus determined were considerable reduction of UWL and changes of water quality in certain wells and observation water-pumping sites (piezometers).

RESEARCH AND FEATURES OF WATER-PUMPING SITES

The water supply system in Zagreb nowadays uses mainly the four dominant sites (systems) in the Sava valley, as shown in Figure 1. These are:

- Mala Mlaka water-pumping site, with a pre-pump water station of the Velika Gorica system (38%);
- Petruševec water-pumping site (21%);
- Sašnak water-pumping site (20%);
- Strmec water-pumping site (13%).

The other well systems provide the remaining 8%: Zapruđe with 280 dm^3/s, Slapnica 80 dm^3/s, Žitnjak 80 dm^3/s, and Bregana 30 dm^3/s. Mala Mlaka has 18 wells, Petruševec 5, Sašnak 6, Zapruđe 3, Strmec 6, and 1 well is at the Žitnjak water-pumping site.

The specialized departments in charge (Vodoopskrba i odvodnja d.o.o. Zagreb (ViO), Meteorological and Hydrological Service, Hrvatske vode, and their engaged services in Zagreb), regularly monitor the change of quality and quantity of water consumed by the city on daily, monthly and yearly basis. Water levels and outflows of surface waters are systematically monitored, as well as the running of active wells, water quality and changes of UWL at all active water-pumping sites, those previously used and water-pumping sites that are just being examined for future use (Kosnica) [2].

The quaternary aquifer in the valley of Sava has been interdisciplinary and it was thoroughly examined under many research programs financed by state and city institutions [7, 9]. In particular, a large number of structural piezometer boreholes were done for the purpose of determining the features of aquifers on various depths of quaternary sediments, and the change of UWL and water quality at particular locations has been monitored.

The results of monitoring the changes of water quality and UWL in previously carried out piezometer boreholes and wells provide the basis for assessment of features of quaternary aquifer in the valley of the Sava River. In order to note thoroughly the possible changes of UWL, lithological structure, water conductivity features of aquifer and water quality (in depth and lateral), two more structural piezometer boreholes were drilled at the Mala Mlaka water-pumping site (PB-24 and PB-29). Those two piezometers helped choose the location for two other wells.

Drilling samples provided through core drilling during the drilling of the two structural piezometer boreholes were interpreted, and 14 + 15 = 29 samples of the water-carrying sediments were taken into laboratory for granulometric analysis. By comparing sizes of grains in different samples from different locations and depths of sampling, changes of water conductivity features of sediments, laterally and vertically, were provided. A final plot of construction of piezometers and wells was made, and the fill-up intended for the stabilization of annular space [14] was defined. A great diversity of thickness of sediment grains was ascertained; from clay particles 0.0002 mm in size to pebbles of 56 mm in diameter, collected during drilling. Filtration characteristics of samples taken from shallower layers (up to 15 m of depth) are better than the ones from deeper intervals of sediments. The grain uniformity coefficient (d_{60}/d_{10}) is diverse and ranges between 32 and 457.

The structural piezometer boreholes are lined with polyethylene (HDPE) tubes of 110/100 mm in diameter. The wells are equipped with stainless steel water-permeable filters and massive tubes in dry and water-non-permeable sediments. The annular space of structural piezometer boreholes, as well as that of wells, is filled up with gravel of adequate sizes of grains, for stabilizing the surrounding sediments and other important functions. Installed in this way, the piezometers and wells are treated with prescribed procedures and used for trial pumping of the newly made wells.

No stratigraphic and geophysical research data on previous boreholes performed at Mala Mlaka water-pumping site have been found. Figure 2 shows the profile across four boreholes in the area around Prečko water-pumping site. In those drills, logging measurements of gamma, gamma-gamma and neutron values by depth were conducted, as well as stratigraphic interpretation of sediments [8]. Figure 2 shows the three erosion discordances which separate sediment groups I, II, III, and IV. The two deeper and a part of the third group of sediments belong to Pleistocene, while the upper part of the third and the fourth group of sediments are interpreted as Holocene sediments.

On the basis of the comparison of the features of lithological profiles of structural piezometer boreholes and wells at particular water-pumping sites with profiles and marked routes of erosion discordances in Figure 2, one can estimate the depth of Holocene at water-pumping sites as follows:

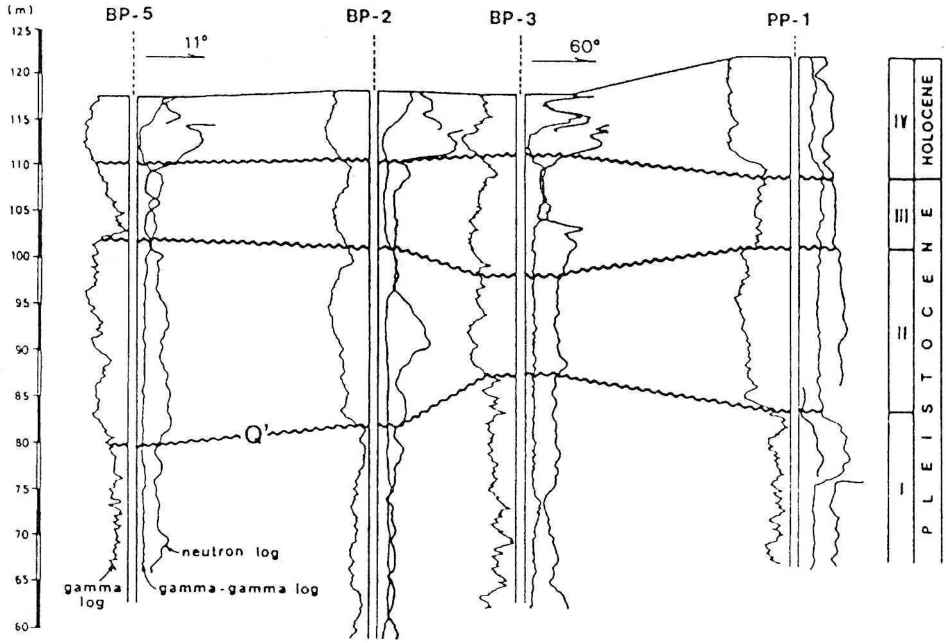

Fig. 2. Schematic correlative profiles across BP-5, BP-2, BP-3 and PP-1 boreholes conducted in the area around Prečko [3]

- Strmec 8–13 m,
- Ježdovac 9.4–10.5 m,
- Mala Mlaka 12.5–18 m,
- Zapruđe 11.7–12.7 m,
- Petruševec 20.5–30.4 m.

The depths of Holocene estimated in this way should be explored during possible future exploration work. Concerning better filtration features of Holocene sediments, it is valuable to emphasize the impact of the change of the static level of underground water (SLUW), in particular wells, on the value of their specific abundance [$dm^3/(s \cdot m)$]. Changes of UWL and the amount of pumping output in wells BZ-3 and BZ-4 at Zapruđe water-pumping site in February and March 2004 were measured at the exact point of the increase of water level of the Sava River and the increase of UWL in the aquifer and the above mentioned wells. The Zapruđe water-pumping site is near the Sava valley; therefore, the increase of the water level of the Sava resulted in the increase of UWL in the aquifer in a short while. Thus, the interval of the aquifer with the best water conductivity and retention features (Holocene) was suddenly filled with water, which caused multiple increases of specific abundance in the observed wells [$dm^3/(s \cdot m)$].

The structural piezometrical boreholes are equipped (HDPE) with polyethylene tubes 110/100 mm in diameter and filled up in annular space with gravel of adequate features. Striped filters with 3.0 x 50.0 mm cuts and nets of 2 x 2 mm openings are built into intervals of 11.50–27.50 m in the PB-24 borehole, and intervals of 11.00–13.00 and 15.00–28.50 m in the PB-29 borehole. The bottom of the sediment tube lies at the depth of 29.5 m in PB-24 and 30.5 m in PB-29 (Figs 3 and 4). The piezometers were treated successfully, followed by taking samples of water from different depths. The results received by conducting structural piezometrical boreholes comprise the main basis for choosing the construction of exploitation wells. The choice of the filters and protection tubes is based on the three most important factors:

- required mechanical resistance of filters and tubes in given circumstances of installation and using of wells;
- features of aquifer and quality of underground water concerning corrosion and incrustation;
- potential possibility of appearance of ferruginous bacteria.

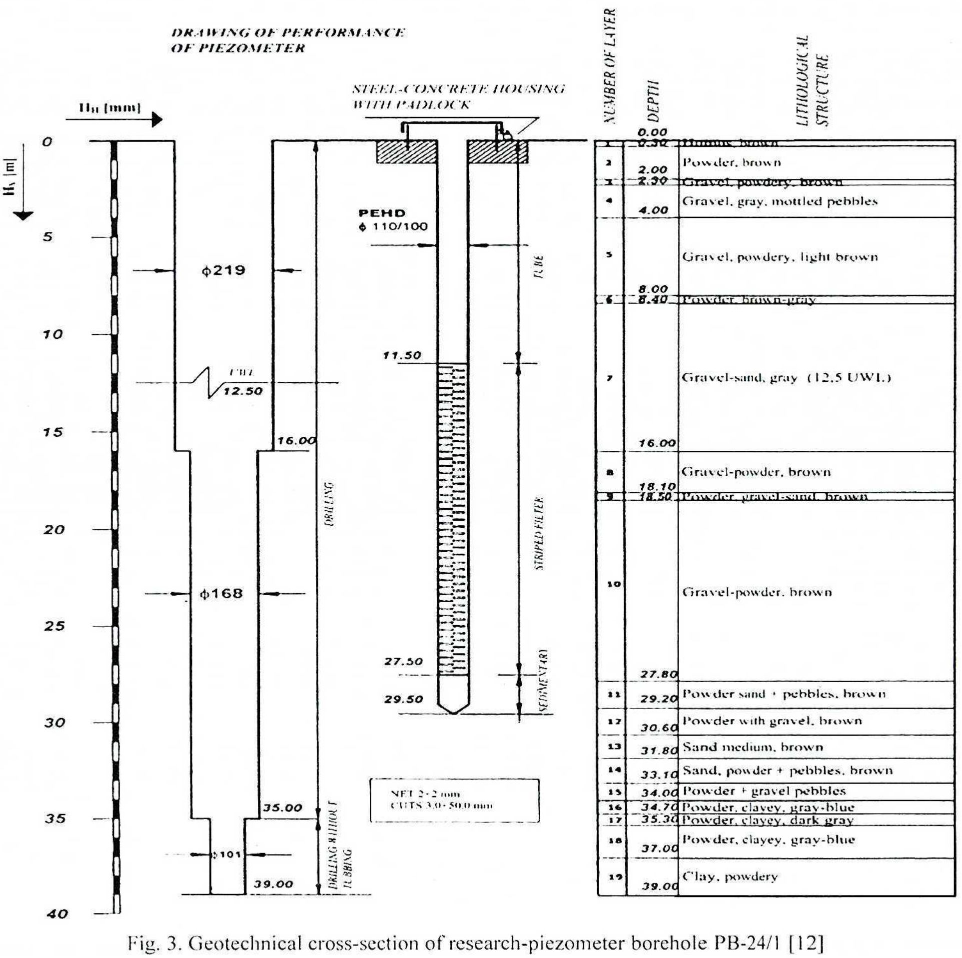

Fig. 3. Geotechnical cross-section of research-piezometer borehole PB-24/1 [12]

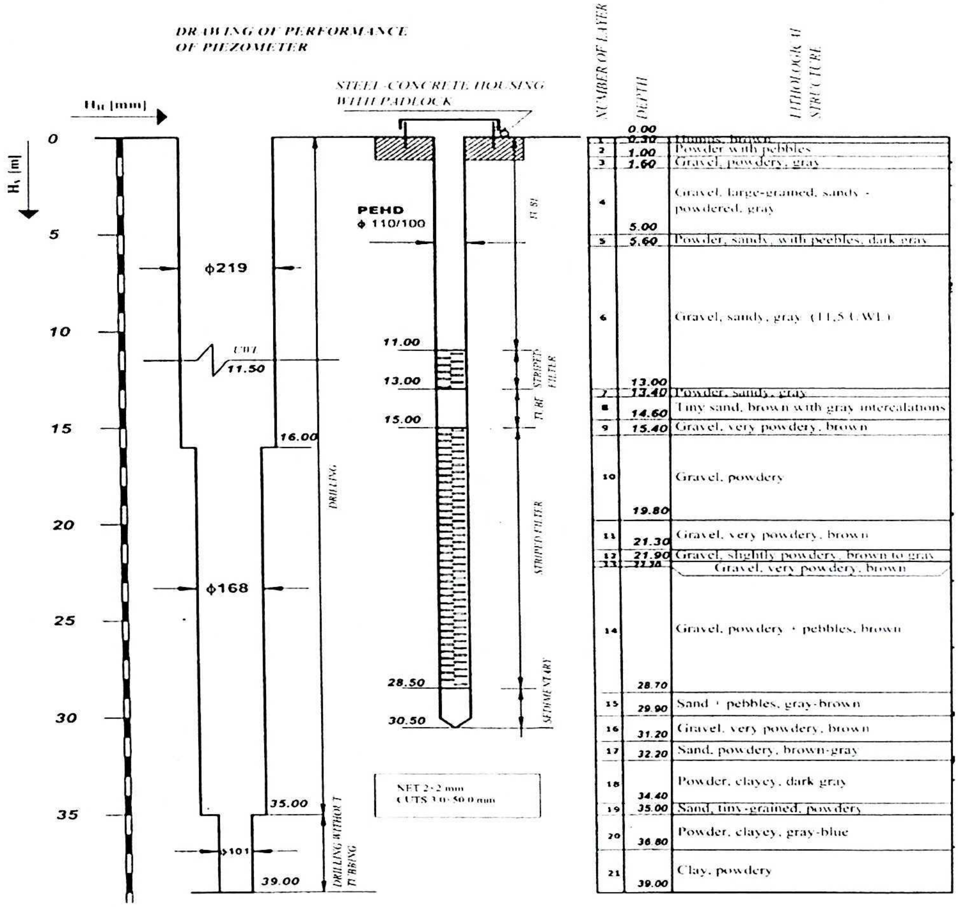

Fig. 4. Geotechnical cross-section of research-piezometer borehole PB-29/1 [12]

CHANGES IN WATER QUALITY BY DEPTH

The samples of underground water, i.e. groundwater at Mala Mlaka were taken several times by pumping with Grundfos pump at three levels (Tab. 1). On May 19, 2004 sampling was conducted by taking samples from greater to lesser depths, while on July 29, 2004 sampling was conducted by taking samples from lesser to greater depths, immediately after dipping the tube (acceptable treating of piezometer and clear flow of underground water through the piezometer filters was presupposed) [2].

Table 1. Sampling depths and pumping times

Location	Sampling date	Pumping depth	Pumping time	Pumping power
PB-24/1, PB-24/2, PB-24/3	19.05.2004	14 m, 18 m, 22 m	5 min	350 Hz
	29.07.2004	14 m, 18 m, 22 m	immediately	250 Hz
PB-29/1, PB-29/2, PB-29/3	19.05.2004	14 m, 20 m, 24 m	5 min	350 Hz
	29.07.2004	14 m, 20 m, 24 m	immediately	250 Hz

The water samples were analyzed using standard methods and techniques prescribed for analysis of drinking water. The results are shown in Tables 2 and 3.

Table 2. Results of PB-24 borehole analysis

Location	PB-24 14 m		PB-24 18 m		PB-24 22 m	
Date	19.05.2004	29.07.2004	19.50.2004	29.07.2004	19.05.2004	29.07.2004
Indicator						
Water level [cm]	1125	1176	1125	1176	1125	1176
Temperature [°C]	13.2	12.9	13.0	12.9	13.5	12.9
pH-value	7.15	7.01	7.16	7.01	7.16	7.03
Electrical implementation [mS/cm]	895	885	895	900	895	900
Fluorides [mg/dm^3]	0.04	0.04	0.04	0.04	0.04	0.04
Chlorides [mg/dm^3]	27.1	29.5	27.0	27.2	26.9	27.5
Nitrates [mg/dm^3]	7.3	7.6	7.1	7.1	7.1	7.2
Sulphates [mg/dm^3]	2.9	34.2	42.9	41.4	42.8	41.4
Na [mg/dm^3]	13.1	17.0	13.1	12.5	13.1	12.4
K [mg/dm^3]	1.3	2.9	1.3	1.3	1.3	1.2
Ca [mg/dm^3]	142.4	140.8	142.4	140.8	142.4	140.8
Mg [mg/dm^3]	34.0	34.0	34.0	34.0	34.0	34.0
Fe [μg/dm^3]	4.5	24.0	0.0	0.6	6.7	0.0
Mn [μg/dm^3]	0.4	0.4	0.7	0.2	0.5	0.4
Pb [μg/dm^3]	7.0	14.0	1.0	1.0	4.0	12.0
Total org. C [mg/dm^3]	0.44	0.46	0.38	0.39	0.44	0.43
Evaporated residue 105°C [mg/dm^3]	600	630	560	620	570	640
Annealing residue [mg/dm^3]	400	360	400	370	370	360
Dissolved CO_2 [mg/dm^3]	49.3	66.0	49.3	66.0	49.3	66.0

Table 3. Results of PB-29 borehole analysis

Location	PB-29 14 m		PB-29 20 m		PB-29 24 m	
Date	19.05.2004.	29.07.2004.	19.05.2004.	29.07.2004.	19.05.2004.	29.07.2004.
Indicator						
Water level [cm]	928	1045	928	1043	928	1043
Temperature [°C]	12.7	12.4	12.7	12.3	12.8	12.3
pH-value	7.28	7.14	7.25	7.15	7.28	7.14
Electrical implementation [mS/cm]	735	755	735	755	735	755
Fluorides [mg/dm^3]	0.06	0.06	0.06	0.06	0.06	0.05
Chlorides [mg/dm^3]	20.2	22.9	20.2	22.9	20.3	22.9
Nitrates [mg/dm^3]	9.4	8.1	9.4	8.1	9.4	8.1
Sulphates [mg/dm^3]	20.8	21.6	20.9	21.8	21.2	21.8
Na [mg/dm^3]	8.9	10.0	8.9	12.1	8.9	10.1
K [mg/dm^3]	1.4	1.4	1.4	1.4	1.4	1.4
Ca [mg/dm^3]	108	108	108	108	108	108
Mg [mg/dm^3]	31.1	31.1	31.1	31.1	31.1	31.1
Fe [mg/dm^3]	5.1	7.7	12.9	33.6	22.5	90.1
Mn [mg/dm^3]	0.5	0.3	0.4	0.5	1.1	1.7
Pb [mg/dm^3]	2.0	2.0	5.0	8.0	5.0	0
Total org. C [mg/dm^3]	0.37	0.98	0.38	0.55	0.38	0.83
Evaporated residue 105°C [mg/dm^3]	450	480	460	490	460	530
Annealing residue [mg/dm^3]	330	280	320	300	310	330
Dissolved CO_2 [mg/dm^3]	32.6	45.8	33.4	45.8	32.6	45.8

The water samples were taken from PB-24 and PB-29 piezometers twice (in May and July 2004), at three different depths. During the May sampling, a five minute pumping session was conducted, and the results of analysis clearly showed that the figures of the examined indicators are of equal values, i.e., that there is practically no difference in the quality of water depending on the level of pumping; this was true for both locations.

The second sampling was organized in July 2004, but this time attention was placed on immediate sampling from every particular level, and the results clearly showed that the figures for most examined indicators significantly differ depending on the sampling depth. At PB-24 piezometer site there are noticeable differences in concentration depending on the sampling depth for most indicators, although the differences point to the conclusion that the water is of the same quality throughout the entire layer.

At the location of PB-29 piezometer there are also noticeable differences in concentration depending on the sampling depth, but for iron and manganese indicators the difference becomes considerable with depth: in the 14 m layer, the concentration of iron was 7.7 μg/dm^3, while at the depth of 24 m, the concentration was 90.1 μg/dm^3. A similar ratio was ascertained for the concentration of manganese: at the depth of 14 m, the concentration was 0.3 μg/dm^3, while at the depth of 24 m, the concentration was 1.7 μg/dm^3.

The increased amounts of manganese and iron are evident in the water sample taken from the deepest interval (24 m), in PB-29 piezometer. This is similar at the Petruševec water-pumping site, which was examined and analyzed by the scientific team at the Faculty of Mining and Geology [3]. Because of the appearance of manganese in water in certain wells at the Petruševec water-pumping site larger than MDK, five samples of sediment received from different depths of the borehole were analyzed. The samples were marked with numbers and the intervals of the borehole from which they were taken: 2 (5–6 m), 4 (15–16 m), 5 (19–20 m), 6 (23–24 m) and 8 (34–35 m). In Sample 6 taken from the 23–24 m depth interval of the borehole, the largest content of reductive fraction related to the manganese oxides was determined, containing concentration of Mn(MN) = 787.89 ppm. The sample contains the largest reductive fraction related to the amorphous iron oxides Mn(AF) = 181.5 ppm and carbonate fraction Mn(CC) = 115.42 ppm. The sample has also indicated the highest contents of Fe, Zn, Co, Cu, Cr, Ba, Ni, V, Al, Ti and Pb, as well as the highest content of quartz and the lowest content of calcite in relation to other samples [3].

CHANGES IN GROUNDWATER QUALITY, LATERALLY AND TEMPORALLY

The quality of surface and underground waters depends on several different factors, such as the intensity and quality of precipitation, the intensity of evaporation, the soil and rocks the water flows through, the supplements to the soil for the purpose of fertilization and protection from weeds, substances contained in waste water from industrial drives and other various activities, and from the settlements [5].

Table 4 contains the mean values of several component contents in water samples taken in the period between 1998 and 2002 at the water-pumping sites Petruševec, Sašnak, Mala Mlaka, Strmec and Zaprude. The average contents of individual components in water vary from site to site. Distances between them, as well as their distance from the Sava water-pumping site, are illustrated in Figure 1. Table 4 shows significant differences in the content of individual components in the water in piezometers, measured at approximate distances of 2 km at the same water-pumping site, at approximately the same depths of water sampling.

Table 4 shows the largest content of manganese at water-pumping sites Petruševec and Strmec. Therefore, a drive for demanganising water from the wells B-4 and B-5a was built in the year 2002 on the water-pumping site Strmec. Water from the well B-5 had the largest content of manganese, which placed the well out of use. The largest content of dissolutions was found in the water at the Sašnak water-pumping site prompting in 1987 the first, and in 1993 the second phase of installing equipment for removing trichlorethane and tetrachlorethane compounds from the water by absorption with active coal.

Figure 5 shows diagram values of changes of the concentration of nitrates found in the groundwater samples from four observation wells on the Mala Mlaka water-pumping site during the 10-year period of observation, from 1991 to 2000. Two trends are obvious: the trend of increased concentration of nitrates, from 7 mg N/dm^3 in September 1991 to 15 mg N/dm^3 in March 1994, and the trend of decreased content of nitrates, from higher values in March 1994 to 6–7 mg N/dm^3 in December 2000.

Table 4. Results of analysis of water samples from specific wells at five water-pumping sites

Water-pumping site	Petruševec B5a	Sašnak-teglica B1	Mala Mlaka B29	Strmec B6	Zapruđe B1
Temperature [°C]	13.7	13.9	12.6	12.4	13.3
UBB37 in 1 cm^3	0	1	0	0	0
NBK in 100 cm^3	0	< 1	< 1	< 1	< 1
Nitrates [mg N/dm^3]	1.12	3.55	5.50	2.15	0.91
pH value	7.48	7.18	7.21	7.19	7.45
El. implementation [mS/cm]	468	773	742	709	453
Cl [mg/dm^3]	9.4	25.0	19.1	9.7	7.6
Dissolved O_2 [mg/dm^3]	2.0	6.4	7.6	4.2	2.8
Sulphates [mg/dm^3]	20.2	48.8	30.9	39.6	19.1
Na [mg/dm^3]	6.67	16.84	10.66	8.01	6.51
K [mg/dm^3]	2.01	3.25	2.57	3.47	2.17
Ca [mg/dm^3]	72.19	113.96	112.43	110.08	71.12
Mg [mg/dm^3]	18.94	29.47	30.71	33.03	17.43
Fe [μg/dm^3]	1.90	2.68	1.99	3.36	1.19
Mn [μg/dm^3]	1.5	0.66	0.51	1.06	0.77
Pb [μg/dm^3]	2.31	3.20	3.53	3.23	2.30
Spent Salt brine p [Mmol/dm^3]	0.34	1.01	0.91	0.97	0.36
Carbonate hardness [mg/dm^3]	218.5	330.8	332.70	345.3	212.7
CO_2 [mg/dm^3]	15.02	44.34	40.54	42.59	15.79
Annealing residue	279.38	473.33	459.33	444.67	264.67
Redox pot. [mV]	172.1	305.5	395.6	459.4	194.8

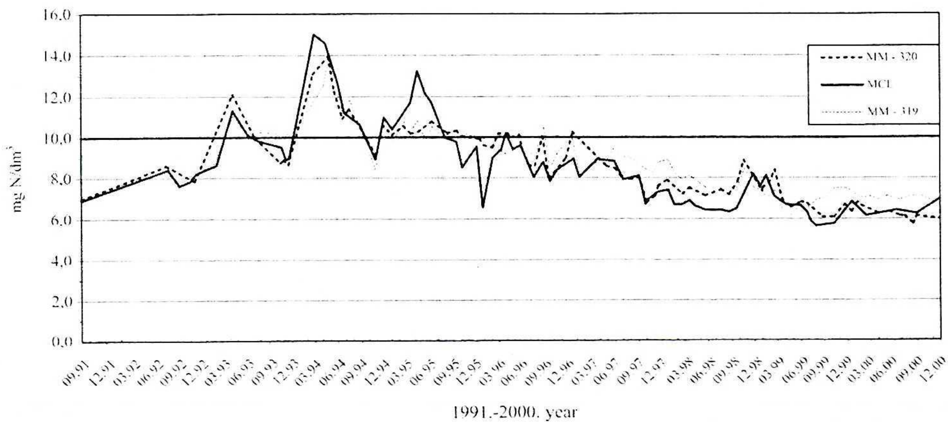

Fig. 5. Changes of concentration of nitrates in groundwater samples at Mala Mlaka during 10-year observations [11]

INCRUSTATION AND CORROSION IN WELLS

As the grain size distribution in samples of aquifer has crucial importance in choosing the openings of filters and granulometric content of stabilizer of sediments, so the quality of underground water is of crucial importance for choosing the materials for the construction of wells, and especially for the types of filters and pumps. To avoid harmful corrosive and incrustation effects, selection of both size and adequate type of the filter, as well as regular control and well maintenance, are of great importance. The best known authors of literature specialized in technology of construction and servicing of wells conducted in alluvial sediments consider incrustation and corrosion the most harmful manifestations which jeopardize the lasting efficiency of retaining underground water through wells. Based on the results of analyses shown in Table 1, filters, protective tubes and centralizers made of stainless steel SS-304L 800/8 mm were the ones chosen. Filter openings are 2 and 4 mm, and the stabilizers of sediments are of grain sizes 1–3.15 mm and 3.15–8 mm respectively, in terms of the known principles [13].

Incrustation is the appearance of accumulations of silt, clay, biomass, carbonate, iron, manganese and other substances non-dissolvable in water. Accumulations of the above mentioned substances (incrustation) lead to plugging of the entrance part of the well that consists of a filter, a built-in gravel cover, and sediments (aquifer) near to the filter. The appearance of a more intense incrustation increases resistance of the water entering the well, thus reducing the specific abundance to a half of the initial abundance within 2–5 years [4].

Reducing specific abundances of wells can cause corrosion of wells and filters. Corrosion of particular metal parts or of the whole construction of wells is expected and actualized during the capitation of the corrosive underground water. Because of the corrosion of filters and/or protective columns, increased openings appear in wells through which particles of aquifer sediments (sand) can intrude. Intrusions of sand can cause very harmful abrasion of parts of pumps and other equipment in the water supply system. Intrusion of sand can fill in the filters and a large part of the well, thereby bringing into question the abundance and stability of the well.

Clarke and Barnes researched the appearance of corrosion and incrustation in the wells in the valley of the river Ind in Pakistan during the 1960s and published their estimations, which proved to be accurate [1]. The basic indicators of incrustation are the following features of water:

- pH value > 7.5;
- carbonate hardness > 300 mg/dm^3;
- iron content in water $Fe > 0.5$ mg/dm^3;
- manganese content $Mn > 0.2$ mg/dm^3.

Basic indicators of water corrosion are:

- pH value < 7.0;
- content of total dissolved substances TDS > 1000 mg/dm^3;
- appearance of dissolved oxygen in water > 2 mg/dm^3;
- appearance of H_2S even lower than 1 mg/dm^3;
- CO_2 content > 50 mg/dm^3;
- chloride content > 500 mg/dm^3. [4]

Corrosiveness of water is stronger when two or more of the above mentioned conditions are met. Higher values of pH and the presence of oxygen in water hasten the incrustation in the case of a significant presence of iron and manganese. Table 5 shows values of electric implementation in units μS/cm – approximately 35% smaller than the value of the total TDS (Total Dissolved Solids, i.e. total mineralization of water, measured in mg/dm^3) mineralization. The requested and received data on the quality of the water in wells can be provided by supervising service. The results of physical and chemical analyses of water distributed in the water supply system are shown in Table 5. The table shows only the main features that characterize the water concerning the prediction of appearance of incrustation at the portion of the well through which groundwater enters it at the increased speed of flow, and corrosion of the metal parts of the construction of the well.

Table 5. Laboratory results of analysis of the content of components which are indicators of incrustation and corrosion of water in wells at several water-pumping sites

Well		pH value	Carbonate hardness [mg/dm^3]	Fe [μg/dm^3]	Mn [μg/dm^3]	O_2 [mg/dm^3]	Electric implementation [μS/cm]	CO_2 [mg/dm^3]	Chlorides [mg/dm^3]
Strmec	SB-5	7.08	385	0.0	0.2	5.4	800	57.2	10.8
	SB-7	7.08	380	0.0	0.3	4.7	795	52.8	11.8
	SB-8	7.17	365	0.0	0.8	4.7	760	44.0	10.5
	SB-9	7.21	315	0.0	0.8	2.5	660	35.2	10.5
	SB-4	7.08	390	0.0	0.2	3.5	810	52.8	15.4
Zaprude	BZ-3	7.47	215	0.9	0.0	2.9	445	17.6	9.1
	BZ-4	7.45	220	5.3	0.3	2.1	445	18.5	8.8
	BZ-1	7.47	176	3.9	0.2	2.5	445	17.6	8.8
Mala Mlaka	MB-1	7.10	315	0.9	0.6	7.1	710	41.4	19.9
	MB-2	7.12	330	0.7	0.5	8.2	735	44.0	22.1
	MB-3	7.03	365	0.0	0.8	8.9	825	53.7	23.5
	MB-4	7.13	385	0.8	0.2	6.5	870	49.3	28.7
	MB-5	7.3	360	3.3	0.6	9.3	840	44.0	31.1
	MB-6	7.17	385	0.0	0.3	7.5	785	39.6	23.1
	MB-7	7.24	335	0.0	0.2	8.2	730	32.6	17.8
	MB-8	7.19	350	0.0	0.4	7.7	770	37.0	19.2
	MB-9	7.30	305	0.0	0.3	9.0	675	26.4	14.7
	MB-10	7.34	290	0.8	0.7	8.7	640	22.9	11.2
	PB-24	7.15		4.5	0.5	4.7	895	49.3	27.1
	PB-29	7.28		5.1	0.5	6.5	735	32.6	20.2
Petruševec	BP-5	7.46	222.50	1.75	28.08	1.50	471.59	16.25	8.17
	BP-5a	7.46	230.00	0.45	41.07	2.10	475.00	28.20	6.68

The above mentioned factors and the data in Table 5 are used for estimating the potential for corrosion and/or incrustation of groundwater at water-pumping sites. Table 5 shows the pH values of groundwater samples larger than 7; therefore, incrustation does not favor these pH values. The pH values of water in the wells at water-pumping sites Mala Mlaka, Zaprude and Petruševec are near 7.5, thus indicating the possibility of incrustation. The carbonate hardness of water is over 300 mg/dm^3 in almost all wells at water-pumping sites Strmec and Mala Mlaka, which also favors the appearance of incrustation. The content of iron and manganese in the water is lower than 0.5 and 0.2 mg/dm^3 respectively, and the content of dissolved oxygen in the water is high, which may favor the appearance of incrustation, as well as corrosion [4].

H_2S has not been found in any of the analyzed water samples. All water samples have a confirmed lower content of chlorides and values of dissolved substances (TDS) than that indicating corrosiveness of water. The content of dissolved oxygen (O) is larger than 2 mg/dm^3 in most of the wells, and the content of dissolved CO_2 is larger than 50 mg/dm^3, but only in the water samples from the wells MB-3, SB-4, SB-5, and SB-7. A larger content of dissolved oxygen and CO_2 causes corrosion of the wells' metal construction. Since the filters, i.e. the wire winds are the most exposed to the impact of corrosion, most wells contain wires made from stainless steel. Most wells have installed in them a cathode protection of the metal parts from corrosion, which can cause increased incrustation in the wells; thus, this area needs to be studied with special care. Moreover, wells need to be protected from incrustation using various prevention measures.

Table 5 shows a data comparison characteristic of incrustation and corrosion features of water in the old wells and the two new piezometers. One can notice the increased carbonate hardness, content of iron, and the decreased content of dissolved oxygen, as well as the increased electric implementation of the water samples in the new piezometers in relation to the water in the old wells at the Mala Mlaka water-pumping site.

CONCLUSION

Two structural piezometer boreholes and two pumping wells at the Mala Mlaka water-pumping site were done in 2004, at the locations near old wells of lesser water quantities. After treating the new PB-24 and PB-29 piezometers, samples of water from different depths were taken and analyzed in May 2004. The samples were extracted after intensive pumping of water at every interval; therefore, the results of sample analyses did not differ in samples from different depths. For this reason, it was decided in August to collect the samples once again, from depths of 14 to 28 m, but without mixing the water in piezometers through pumping, because the piezometers were treated long enough, and clear water was received. Increased manganese content in the water samples taken from the deepest intervals of piezometer PB-29 is similar to the one at the Petruševec water-pumping site, which was investigated and analyzed by the scientific team at the Faculty of Mining and Geology [3].

Although the fear from incrustation in wells is larger than that from corrosion, the right decisions concerning the preventive protection of future wells from incrustation and the impact of corrosion on the filters, pumps, wires, etc. will be reached on time.

In addition to the cathode (anticorrosion) protection of metal components in wells, ViO is taking significant preventive measures against the impact of incrustation on filters [4], these being:

- reducing incoming speed of groundwater into the well;
- well treated wells;
- reducing the amount of pumping [m^3/h] and increasing hours per day;

- carrying out more wells smaller in diameter and capacity;
- more frequent actions of methodical control and cleaning of wells.

Also recommended is isolation of the intervals with increased presence of iron, manganese and other possibly harmful components in groundwater in cases when they are ascertained beyond doubt by structural borehole(s). This way the quality of water in the well/water-pumping site can be efficiently protected.

Keeping in mind the locations of the abandoned water-pumping sites in relation to the known polluters in their inflow area in the valley of the Sava, an adequate approach to the programming and realization of the research of the relevant parts of alluvial aquifer is recommended for the purpose of a more accurate determination of the cause of groundwater pollution, as well as profitable procedures for enhancement of the water quality. Also explored should be the possibilities of profitable use of water from certain abandoned water-pumping sites for various technical purposes which do not demand the standard of quality that drinking water does.

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