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INFLUENCE OF GROUNDWATER EXPLOITATION ON WATER QUALITY. RETKÓW–STARA RZEKA INTAKE CASE STUDY

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ABSTRACT

Extensive exploitation of groundwater from quaternary deposits of fluvioglacial origin, reaching annually over 1.5 mln m^3 in Retków–Stara Rzeka water intake, affected both chemical composition and physical properties of water. Detrimental changes in water quality were manifested mainly by an increased alkalinity, hardness, electrolytic conductivity as well as by raised concentration of iron and manganese ions or sulphates. The value of water alkalinity has increased from below 1 meq/dm^3 to over 4.5 meq/dm^3 in 1986 and 1994, respectively. Conductivity, strongly related to overall mineralisation of water (Total Dissolved Solids – TDS content), over the same period increased on average from about 150 µS/cm to over 550 µS/cm, and in some wells reached nearly 900 µS/cm. Total water hardness increased in the respected period from 60 mg $CaCO_3$/dm^3 to 300 mg $CaCO_3$/dm^3, sporadically reaching even 460 mg $CaCO_3$/dm^3. Iron concentration rose from values at the level of 0.1 mg Fe/dm^3 prior to intake exploitation, to nearly 4 mg Fe/dm^3 in 1994. Similarly, a significant increase of manganese content from values lower than 0.03 mg Mn/dm^3 to about 0.5 mg Mn/dm^3 in 1986 and in 1994, respectively was observed. Due to increased concentration of iron and manganese groundwater no longer complies with Polish or European quality standards for drinking water, with regards to these chemical elements. Performed analyses have proved high infiltration of contaminated water from a shallow ground level to the main level at which the wells are tapped to occur in the area of the intake. Analyses have shown that almost impermeable layer of loam that separates the first and second (exploited) aquifers is not continuous.

Key words: groundwater intake, groundwater quality.

INTRODUCTION

Extensive exploitation of groundwater tends to bring adverse effects such as land subsidence and settlement of structures erected upon, which result from increased effective stress due to lowering the groundwater table within the area of the depression cone. Lowered groundwater table can also lead to deteriorating soil moisture conditions and detrimentally affect cost-effectiveness of agricultural production. Another, frequent occurrence related to extensive exploitation of groundwater, is water escape from shallow, dug farm wells.

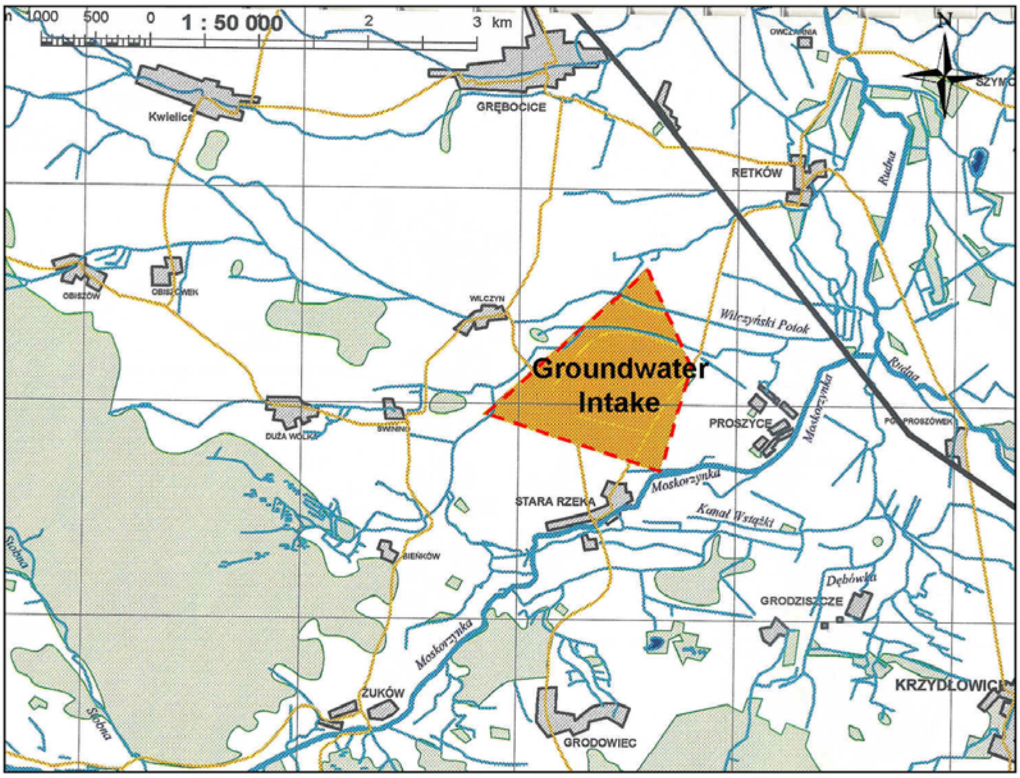
Nevertheless, among all the detrimental effects resulting from exploitation of groundwater, changes in physical properties and chemical composition of water are of particular significance. Due to the lowered groundwater table in the vicinity of an intake, the thickness of the unsaturated zone tends to increase, hence under oxidising conditions within the drained zone specific chemical processes are activated which in turn invoke changes in physical properties and chemical composition of water. Oxygen and carbon dioxide from the air reacting with minerals from the soil environment lead very often to an increased hardness and mineralisation of water, as well as higher iron and manganese concentrations that may be serious in terms of economic results brought about.

In the paper an analysis of groundwater quality affected by a long-lasting and extensive exploitation of groundwater in Retków–Stara Rzeka water intake, located in the area of Barycko–Głogowska valley, in the region of Major Groundwater Basin (GZWP) No 314, is presented.

NATURAL ENVIRONMENT IN THE GROUNDWATER INTAKE REGION

The Retków–Stara Rzeka groundwater intake is located in the Dolnośląskie Voivodship, within Grębocice commune between Retków, Stara Rzeka, Wilczyn, and Proszyce (Fig. 1) and consists of 9 production wells that supply water from fluvioglacial formations of the valley it is located in Barycko–Głogowska valley.

Fig. 1. Location of Retków–Stara Rzeka groundwater intake



The intake area is flat, with its elevations ranging from 87.85 m to 84.51 m above the mean sea level. The region lies in the warmest climatic zone in Poland, with annual average temperature and average temperature for the vegetation period (April to September) corresponding to slightly above 8 °C and 14 °C, respectively. Average total annual precipitation reported by Czaban et all. [1] and calculated for data collected from 1957–1997 amounts to 614 mm and 383 mm for Rudna meteorological station and the vegetation period, respectively.

In the intake area, covering about 1200 ha, two aquifers occur, namely the upper one that supplies water to dug wells, and the bottom one, so called main exploited aquifer into which screens of production wells are installed.

The upper aquifer is formed from sand and gravel with a small addition of silt and clay and its thickness reaches up to 10 m. It bears water whose phreatic water table was located, prior to exploitation, at the depth of 1-3 m. The upper aquifer is closely related to surface water courses of the Rudna river and its tributaries: Moskorzynka and Wilczanski Potok (brook), Czaban et all. [1]. Since it is not isolated from the surface, the layer is supplied by atmospheric precipitation and therefore is susceptible to chemical and biological degradation due to sources of local contamination.

In the upper aquifer bottom a formation of impermeable or semi–impermeable structures of typical thickness ranging from 2 to 10 m was found. It consists of clay, loam and silt, and from place to place also peat. Its local discontinuity at the vicinity of 7-S well, near Proszyce and Proszówek alike, has contributed to creating a hydraulic contact between the upper and bottom aquifer, Czaban et all. [1].

The exploited aquifer is composed from formations of fluvioglacial origin such as sands and gravel with builders and cobbles that are widely and equally distributed all over it. The average thickness of the exploited aquifer reaches 30 m, while the hydraulic conductivity varies within the range 1.4 to 2.2×10^{-5} m/s.

The main exploited water-bearing stratum is supplied from the area of a folded moraine to the south and west of the intake, as well as directly from atmospheric precipitation at places where its discontinuities (hydrogeological windows) occur in the impermeable or semi–impermeable stratum that separates the upper and the exploited aquifer.

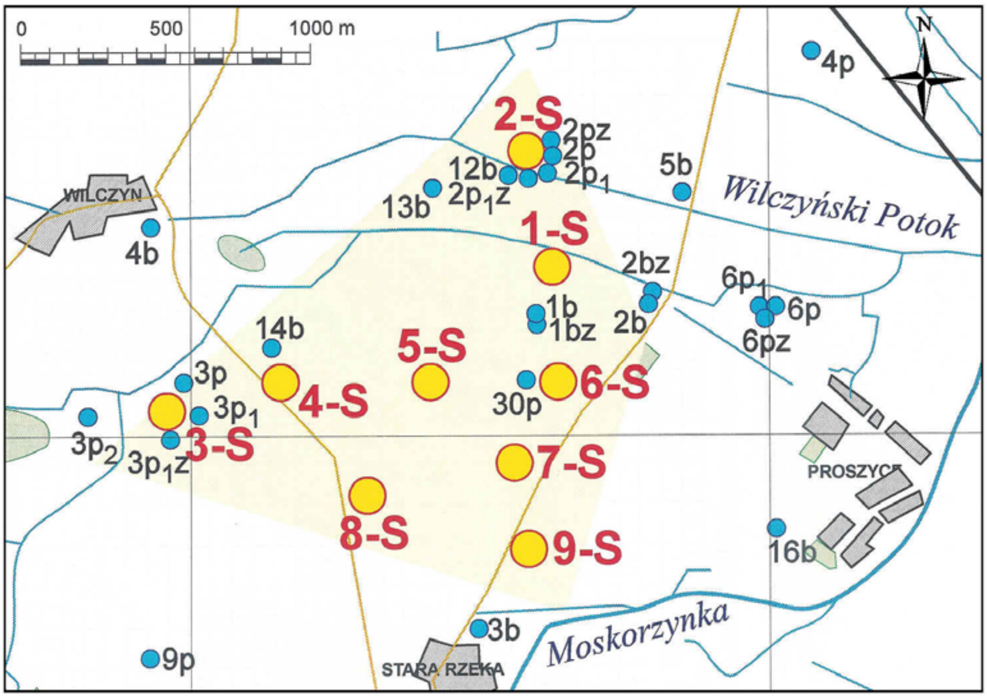
The major part of the resource area of the groundwater intake is covered mainly by sandy and silty/loamy soils that correspond to circa 60% and 34% of the total area, while a mere 6% of it is covered by soils of other grain size distribution. The respective soils fall into IIIa, IIIb and IVa taxonomy classes. In the land use structure of the area agricultural usage prevails - about 90% of the total area, while nearly 4% of it are covered by woods and forest stands. On arable lands mainly cereal crops and rape *Brassica olleifera* are cultivated.

WATER INTAKE FEATURES, DEPRESSIONS AND PUMPING RATES

The intake was constructed in 1976-1977 by Kombinat Geologiczny 'Zachód' in Wrocław and consists of 9 production wells, each 250 mm in diameter with depth ranging from 50.0 to 59.5 m. The wells are distributed within a polygon of the area of nearly 5 km^2 (Fig. 2).

The distances between the wells range between 400 and 500 metres, total resource area of the intake covers around 1200 hectares.

Fig. 2. Location of wells and piezometers in Retków – Stara Rzeka groundwater intake

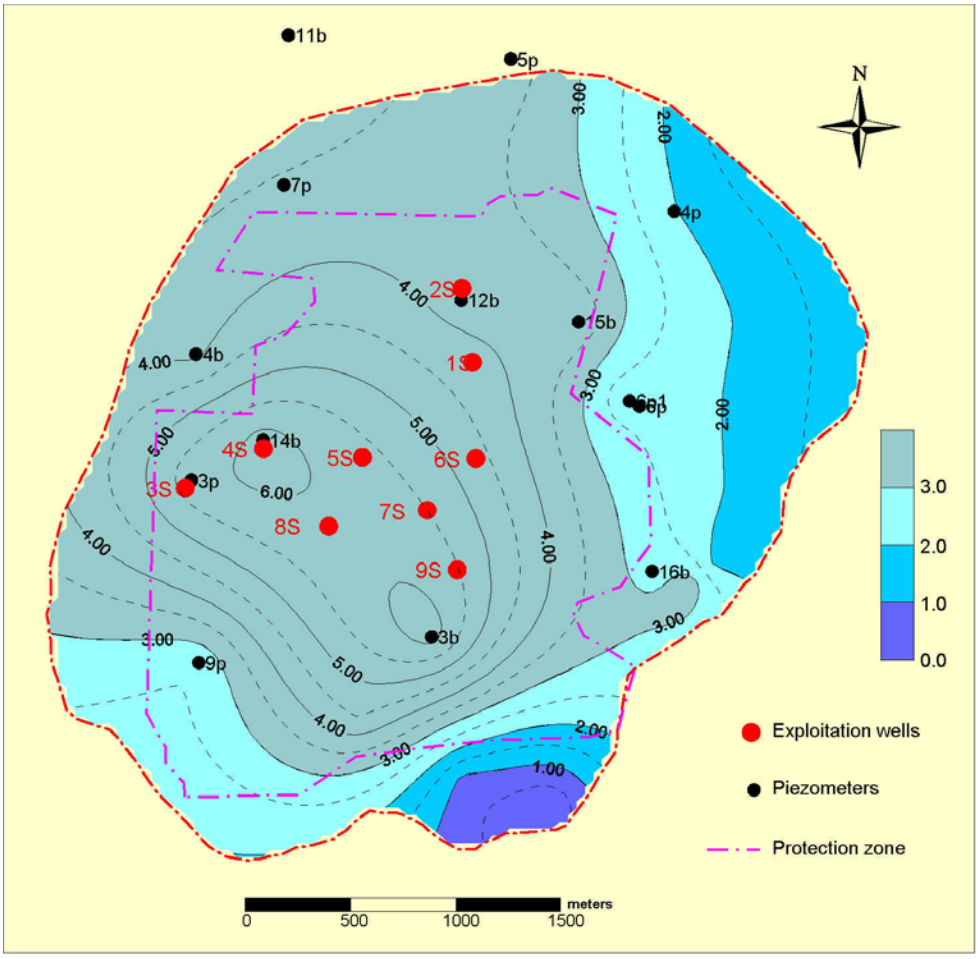


Approved pumping rate for the category B of the intake is equal to Q=320 m^3/h, at well depressions within the range from 5.0 to 7.6 m. The intake has been certified and given a legal permit, issued by Legnica Voivodship Office in 1995 for the maximum water withdrawal rate of 320 m^3/h water.

The groundwater withdrawal was initiated towards the end of 1988. The intake wells work interchangeably, with a number of 4 to 5 wells pumping concurrently. Average annual water consumption volume over the period from 1989 to 1997 reached circa 1.5 mln m^3.

To monitor the dynamics of the water table changes during the exploitation, a network of several piezometers (observation wells) in the vicinity of the groundwater intake was implemented (Fig. 2 and 3).

Fig. 3. Groundwater depth contours during exploitation, September 1992.



Before the exploitation started the water table had been located at the depth of 40 cm to about 4 m below the site surface. Direct measurements of the water table in the wells and piezometers gave in May 1977 an average depth of 1.63 m, which corresponded to a value of 17 mln m^3 for the unsaturated zone volume within the resource area. Groundwater depth contours chart for the entire resource area of the intake over its exploitation period dated for September 1992 is presented in Fig. 3. The average depth for that period was equal to 3.50 m below the soil surface. Thus, the unsaturated zone volume in comparison to its conditions in 1977 was determined to be increased to 36 mln m^3.

EXPLOITATION IMPACTED GROUNDWATER QUALITY

Nearly doubled volume of the unsaturated zone in the resource area of Retków–Stara Rzeka groundwater intake has brought rapid changes both in physical properties and chemical composition of groundwater in the considered area. The results of the performed research on water quality in selected wells prior to exploitation, i.e. in 1986, and in the course of exploitation between 1994 and 1996 are presented in tables 1 to 6. Data focus on particular water parameters that were most heavily impacted by the exploitation.

Water conductivity, which depicts total water mineralisation, raised from the value of 150 µS/cm recorded in 1986, to an average exceeding 550 µS/cm; in some wells, namely 3–S and 4–S wells, the recorded value neared 900 µS/cm (see Table 1).

Table 1. Electrical conductivity for groundwater in wells

Well number	Electrical conductivity (µS/cm)		
	1986	1994	1996
1-S	181.1	540.0	528.8
2-S	207.0	576.0	542.3
3-S	132.8	733.5	892.6
4-S	168.7	787.5	807.8
5-S	157.5	585.0	546.0

Water alkalinity, which reflects bicarbonate and carbonate ions content, (Appelo and Postma [2]) raised from the value below 1 meq/dm^3 to over 4.5 meq/dm^3 in 1986 and 1994, respectively (Table 2). Similarly, total water hardness over the respected period was increased from the value nearing 60 mg $CaCO_3$/dm^3 to 300 mg $CaCO_3$/dm^3, sporadically even as high values as 460 mg $CaCO_3$/dm^3 were recorded (Table 3). Iron concentration changed from the level of 0.1 mg Fe/dm^3 prior to exploitation, to nearly 4 mg Fe/dm^3 in 1994 (Table 4). Significant increase in manganese content from 0.03 mg Mn/dm^3 to about 0.40 mg Mn/dm^3, and to still a higher value of 0.50 mg Mn/dm^3 was also observed for the years 1986, 1994, and 1996, respectively (Table 5).

Table 2. Alkalinity for groundwater in wells

Well number	Alkalinity (meq/dm^3)		
	1986	1994	1996
1-S	0.6	4.5	3.9
2-S	0.9	4.6	4.4
3-S	0.8	4.3	4.6
4-S	0.6	4.8	4.7
5-S	0.8	4.3	4.2

Table 3. Total hardness for groundwater in wells

Well number	Total hardness (mg $CaCO_3$/dm^3)		
	1986	1994	1996
1-S	63.2	285.3	264.3
2-S	52.9	309.7	290.0
3-S	51.4	370.6	461.4
4-S	64.1	379.7	430.2
5-S	73.9	290.1	292.8

Table 4. Iron content for groundwater in wells

Well number	Iron content (mg Fe/dm^3)		
	1986	1994	1996
1-S	0.02	2.80	3.22
2-S	0.04	3.80	3.60
3-S	0.10	2.95	0.66
4-S	0.11	3.19	4.07
5-S	0.10	2.37	2.63

Table 5. Manganese content for groundwater in wells

Well number	Manganese content (mg Mn/dm^3)		
	1986	1994	1996
1-S	0.03	0.38	0.44
2-S		0.28	0.30
3-S	No data	0.48	0.57
4-S		0.36	0.48
5-S		0.40	0.43

Table 6. Sulphate content for groundwater in wells

Well number	Sulphate content (mg SO_4^{2-}/dm^3)		
	1986	1994	1996
1-S	18.8	46.1	47.0
2-S	9.3	46.9	41.7
3-S	0.8	119.8	51.5
4-S	12.6	98.8	100.4
5-S	32.1	55.6	65.8

With respect to quality standards for groundwater issued for the purpose of environmental monitoring (PIOS [5]), all the components and parameters of water prior to the exploitation met the highest mandatory requirements enabling to classify Retków–Stara Rzeka groundwater resources as the highest class Ia. While exploiting the intake, a significant deterioration of the water quality has taken place. Dropped parameters for electrolytic conductivity has resulted in lowering water quality in general to class II, and in wells 3-S and 4-S even to class III in 1996. With regards to total hardness and iron content, water quality class was degraded to class Ib, whereas for manganese content it fell to class II in 1994, and further down to class III in 1996.

Since iron and manganese content no longer meet the requirements for drinking water standards [Dz.U. 2002 nr 203 poz. 1718], special water treatment has to applied which increases the production costs.

Deterioration of groundwater quality has taken place due to calcium carbonate and dolomite leaching processes in excessively aerated zone of swollen volume, as explained by the equations provided by Kowalski [4]:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^- \quad (1)$$

$$CaMg(CO_3) + 2CO_2 + 2H_2O \rightarrow Mg^{2+} + Ca^{2+} + HCO_3^- \quad (2)$$

The increase in iron content undoubtedly resulted from oxidation of insoluble pyrite FeS_2 in the aeration zone, which occurs frequently in fluvioglacial sediments, Kowalski [4]:

$$FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4 \quad (3)$$

$$5FeS_2 + 14NO_3^- + 4H^+ \rightarrow 7\,N_2 + 10SO_4^{2-} + 5Fe^{2+} + 2H_2O \quad (4)$$

Similarly to pyrite oxidation, another oxidation process takes place upon insoluble manganese sulphide MnS.

Significant increase in water total alkalinity (HCO_3^-) (Table 2) can be regarded as an evidence for the assumed chemical reactions of leaching carbonates (1), (2) to have taken place, since it is closely related to the concentration of bicarbonate ions (HCO_3^-). An increase in sulphates concentration (Table 6) can be viewed as confirmation of their oxidation, equations (3) and (4), which took place as a result of soil profile aeration due to the lowering of groundwater table.

SUMMARY

Extensive exploitation of Retków–Stara Rzeka groundwater intake located in quaternary sediments of fluvioglacial origin led to deterioration of water quality in the considered region. The lowered level of groundwater table in the vicinity of the intake was followed by an increase in unsaturated zone thickness and under conditions of aerated soil profile in the dewatered zone specific chemical processes have been activated, namely carbonate leaching, as well as iron and manganese sulphides oxidation. Increased in water hardness, total mineralisation, as well as iron and manganese ions concentrattions contributed to degradation of groundwater quality supplied to the region. Both manganese and iron concentrations reached the levels which require water treatment before supplying it to the potable water system. The performed analysis of the observed changes in water quality proved weak isolation of the exploited aquifer from the upper water-bearing aquifer which consist from impermeable layers separating both aquifers. Most likely it results from discontinuity of the separating semi–permeable layer.

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