Protection of drinking water supplies during partial closure of the mine

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ABSTRACT

The water intake in operating coal mine "Janina" supplies the town of Libiąż (Southern Poland, 18 000 inhabitants). The mean abstraction rate is about 6000 m^3/day, whereas maximum abstraction rate is 8200 m^3/day. There are two parts of "Janina" coal mine called "Ruch I" and "Ruch II". These parts are completely separated from each other and have no underground connections. The intake is located in the part of mine called "Ruch II", about 300 metres below the surface. Now, the exploitation in "Janina – Ruch II" is over and this part of mine will be closed. The future drainage of this part of mine will be done by pumps installed in shaft "Janina V". This will cause the change in drainage system – the underground intake has to be moved and the deep parts of the mine have to be flooded. Still, the town has to be supplied with water continuously. Furthermore, the quality of drinking water should be kept, although there is a danger of upward trend in SO_4^{2-} concentration as a result of flooding of deep parts of mine.

This paper presents the project of controlled flooding of deep parts of mine. The water table will be raised up by 64 meters and the aquifer of about 2 000 000 m^3 will be filled with water. This will allow the drainage by deep pumps installed in shaft "Janina V". To keep the concentration of SO_4^{2-} at acceptable level (less than 250 mg/dm^3), the change in drainage system should be done with great care and relatively slow. The estimated time of flooding that should allow keeping the quality of water at desired level is about 5 years.

INTRODUCTION

"Ruch II", the part of "Janina" coal mine (Upper Silesian Coal Basin, Southern Poland) is in fact an independent mine itself, accessed by two declines and the shaft "Janina V". There is a water intake for the town of Libiąż (18 000 inhabitants) in the workings of Janina – Ruch II. After finishing the exploitation in this area of the mine, the closing works have to be carried out in such way, as to ensure the permanent supply of drinking water keeping the legal standards.

It is envisioned, that the flooded voids of Janina – Ruch II would be drained by deep pumps installed in Janina V shaft. The analysis of the impact of change in draining system of Janina – Ruch II on the quality of mine water, as well as framework technology for finishing the exploitation in this area of the mine is presented in this paper.

Changing Janina V shaft into deep well requires the raise in groundwater level up to +1 m above sea level; this will result in increasing the volume of mine water aqufer W62 (1990) from about 70 000 m^3 to over 2 000 000 m^3. As a result of flooding the voids, the increase in sulphates concentration in mine water is expected. To keep the concentration below the level of acceptance (250 mg/l) the flooding process should be under permanent control.

GEOLOGY

The geological profile of the investigated area starts at the depth of about 1000 m with Orzesze beds – Carboniferous, mainly claystones. Then Łaziska beds come, consisting of intercalation of sandstones and claystones with the domination of the earlier ones. The sandstone beds reach 70 meters of thickness there, while the thickness of claystones that come along the coal seams usually reaches no more than 5 meters. Carboniferous ends with Libiąż beds, which are mainly sandstones, often conglomeratic and arkoses-like. The claystones are present only at the top and the bottom of all coal seams, although in some boreholes they were not detected. The upper part of Libiąż beds is not present at the investigated area due to erosion [1].

The overburden of Carboniferous rocks consists of Triassic, Tertiary and Quaternary. Triassic rocks are present mainly in western and northern part of the investigated area. These are mainly limestones and dolomites few meters thick; only locally their thickness reaches over 20 meters. Tertiary is represented by Miocene clays up to 160 meters thick, but locally Miocene is not present. Quaternary usually consists of sands sometimes with sandy clays at the bottom. Their thickness is usually few meters, very rarely exceeds 10 meters.

The mine works at Janina – Ruch II were conducted in Fields 10 – 11, at NW part of mining area "Libiąż IV". The exploited seams 116, 117 and 118 belonged to Libiąż beds (Upper Carboniferous) – see fig. 1. The seams dip at very low angles ($1 \div 2^{\circ}$) to NE [1].

There are no connections Between Janina – Ruch II and the main part of Janina coal mine – Ruch I. The division between the main parts of the mine goes along the fault zone.

HYDROGEOLOGY

There are four groundwater aquifers in NE part of "Libiąż IV" mining area: Quaternary, Tertiary, Triassic and Carboniferous [1]. Quaternary groundwater aquifer consists of one, sometimes two water-bearing horizons in sands. Recharge is mainly through infiltration from the surface and the water is used by private household wells. Tertiary aquifer is formed by sand intercalations among 160 meters thick Miocene clays; nevertheless these water-bearing horizons Tertiary is considered to be a confining unit. Although Triassic aquifers are very important ones in the whole region, at the investigated area Triassic is not too thick and this aquifer is of minor importance there.

Carboniferous aquifer is connected with Orzesze, Łaziska, and (mainly) Libiąż beds sandstones. The last ones are arkoses with weak clay cement, porosity usually over 20% and variable grain size. Hydraulic conductivity varies from $1 \cdot 10^{-8}$ to $2 \cdot 10^{-6}$. Locally, along the fault zones the conductivity increases up to 10-100 times higher values. This aquifer has been drained by exploitation in 116, 117 and 118 seams. Before the mining activity started at Janina – Ruch II, the carboniferous aquifer was confined; groundwater was usually reached at the depth of 130 m (120 m above sea level) and it was rising up to depth of 20 m ppt (230 m above sea level).

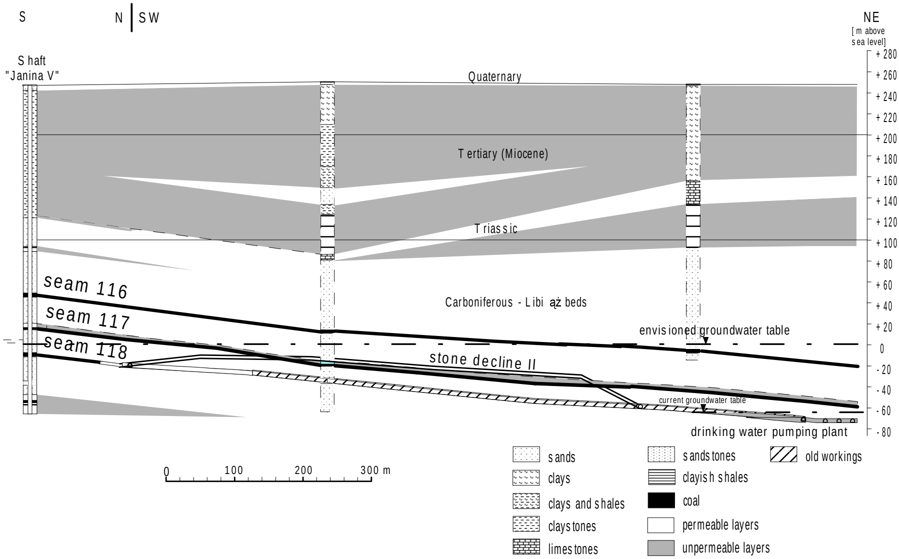

Fig. 1. Hydrogeological cross-section of Janina – Ruch II

ASSESSMENT OF THE IMPACT OF THE CHANGE IN DRAINIG SYSTEM ON MINE WATER QUALITY

MINE WATER IN JANINA – RUCH II

Coal seams at Janina – Ruch II have been accessed by two declines from the surface in 1974 and the shaft "Janina V" – made much later [1]. While drilling the declines, the maximum water inflow from Carboniferous aquifer was reaching 0.5 m^3/min from each of the two workings. In 1979, while the total surface of workings in Janina – Ruch II (mainly seam 116) was still below 1 km^2, the mine water inflow was about 5.5 m^3/min. Along with exploitation extension the inflow rate increased, and reached the maximum of 11.0 –11.3 m^3/min in the years of 1985 - 1989. From 1990 one can see the decreasing trend in the inflow rate. In 2002 the mine water inflow characteristics was as follows:

3.1 m^3/min - drinking water from the voids of seam 116 and the eastern part of Field 10 (seam118 voids),

1.3 m^3/min – industrial water from Field 11 and partially from currently worked longwalls in seam 118, field 10

0.4 m^3/min – industrial water from Janina V shaft,

3.2 m^3/min – industrial water from exploitation of seam 118, field 10 (western side).

The total inflow rate to Janina – Ruch II mine is currently about 8.0 m^3/min of mine water, that consists of 3.1 m^3/min drinking water and 4.9 m^3/min industrial water.

The inflow of drinking water as well as the industrial water from the old workings is stable, as it comes from renewable resources. Only in the western part of field 10, seam 118, which is the area of current exploitation, the inflow rate increases, as the water comes from non-renewable resources there. The increased trend in mine water inflow of the last years was a result of intensification of longwall exploitation in this field. When exploitation stops, the inflow of industrial water will decrease. It is estimated, that at first the inflow would stabilise at the level of year 1998, that is about 3.5 m^3/min of industrial water and about 6.6 m^3/min of the total inflow to the mine. After few more years the inflow to Janina – Ruch II mine should reach the level of about 6 m^3/min.

Mine water inflow to Janina – Ruch II coal mine in the years of 1991 – 2002 is shown in table1.

Year	Industrial water	Drinking water	Total
1992	6.2	2.6	8.8
1993	4.6	4.5	9.1
1994	4.7	4.6	9.3
1995	4.4	4.6	9
1996	4.5	4	8.5
1997	3.8	4.6	8.4
1998	3.5	3.3	6.8
1999	3.8	3.1	6.9
2000	4.4	3.1	7.5
2001	4.4	3.3	7.8
2002	4.9	3.1	8

Table 1 Mine water inflow to Janina – Ruch II coal mine in the years of 1991 – 2002 [m^3/min]

DRAINING SYSTEM

There are two separate pumping systems for drinking and industrial water in Janina – Ruch II coal mine [2]. Drinking water comes mainly from draining of seam 116, exploited in years 1975-2000. The water runs down through 5 boreholes to seam 118 workings where it is mixed with the water from eastern part of field 10. Then, it flows down to the "water roadways" near the "investigation roadway" in the field 10. The industrial water from the western part of field 10 (about 3.2 m^3/min) comes also to this area; the total inflow of mine water is then about 6.3 m^3/min. There are separate water roadways systems for drinking and industrial water in this area. Drinking water is then directed by the pipeline to the water roadways of pumping plant in the area of Janina V shaft (fig. 2). Then, about 3.1 m^3/min of drinking water is pumped out to the water supply plant through the pipeline ϕ 406 mm installed in Janina V shaft.

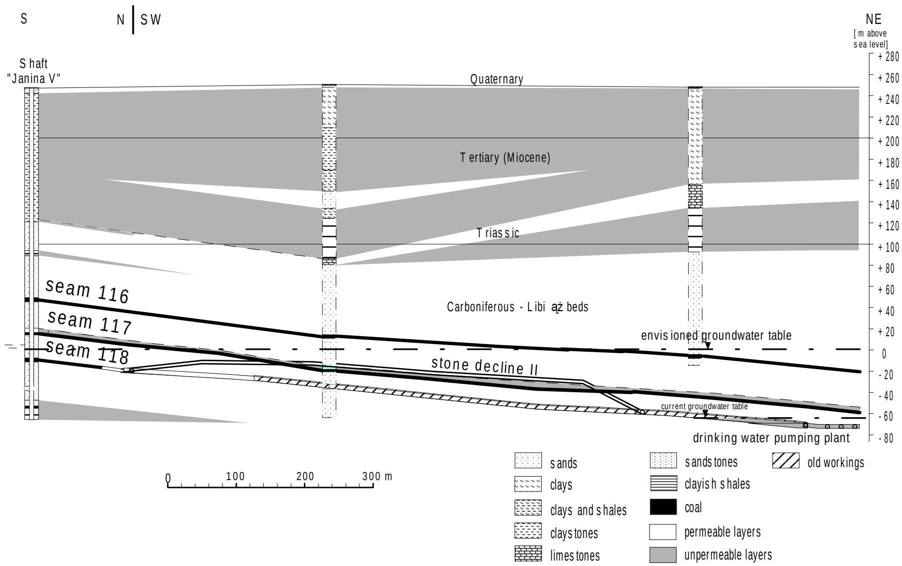

Fig. 2 Simplified map of seam 118

The industrial water from draining of seam 118 (about 3.2 m^3/min) and potential excessive amount of drinking water is directed to main water roadways of seam 118. There goes also the water flowing down from the old workings of seam 118, field 11 (about 1.3 m^3/min) and the water pumped out of the bottom of Janina V shaft (about 0.4 m^3/min). Then, the industrial water is pumped by main pumping plant through ϕ 308 mm pipeline installed in the venting decline to the Chechło stream.

CHEMISTRY OF THE MINE WATER

Table 2 contains the results of chemical analysis for both drinking and industrial water. Drinking water, coming mainly from seam 116 draining, has usually low concentrations of chlorides (7 – 114.8 mg/l) and sulphates (39 – 259.6 mg/l); the total mineralization is below 1 g/l. The type of the water has been changing through the years, as a result of mixing the different types of water. Nevertheless, the main anion was always HCO_3^-, often along with SO_4^{2-}; Cl^- was usually below 10%. Na^+ has been the cation of the highest concentration; the next ones were Mg^{2+} and Ca^{2+}. The pH of the water in the last 10 years varied in the range of 7.5 – 8.6. After the exploitation at Jania – Ruch II stops, the amount (estimated at 3.1 m^3/min) and quality of mine water should not be changed as long as the draining system works the same way.

Table 2. Physicochemical composition of mine water of Janina - Ruch II mine

Year	Inflow rate m^3/min	Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	Fe(tot.)	Mn	Cl^{-}	SO_4^{2-}	HCO_3^{2-}	Mineralisation
		mg/l								
Drinking water										
1992	2.6	64.5	48.7	145.2	1.7		114.8	179	341.6	915
1993	4.5	69.7	52	105.7	0.3		87.4	127	403	850
1994	4.6	60.2	42.1	147.5	-		81.2	111	464	910
1995	4.6	64.1	53.5	142.4	< 0,05	0.15	102.8	167.9	417.9	822
1996	4	61.1	52.3	163.2	< 0,05	< 0,05	109.9	220	439.2	938
1997	4.6	64.1	50.4	132.4	0.04	< 0,02	85.1	165	408.7	800
1998	3.3	59.1	44.4	116.2	0.07	0.23	72.7	130	402.6	701
1999	3.1	47.6	35.7	134.3	0.05		79	130	384	790
2000	3.1	55.1	41.3	105.6	0.37	< 0,02	72.7	102	384.3	642
2001	3.3	57.3	42.4	107	0.02	0.06	63.8	92	393.5	634
Industrial water										
1992	6.2	39.2	32.4	187.7	3		130.7	159.6	250.1	838
1993	4.6	57.2	39	196.5	1.1		188	153	360	1000
1994	4.7	51	38.4	208	0.4		170	188	317	990
1995	4.4	42.1	35.2	269	<0,05	<0,05	237.5	179.8	372.1	1007
1996	4.5	61.7	46.1	108.5	<0,05	<0,05	82.6	132.8	413.6	735
1997	3.8	65.1	51	117.7	0.02	<0,02	85.1	177	405.7	807
1998	3.5	53.7	43.3	178.9	0.08	0.13	141.8	144	396.5	838
1999	3.8	60.2	34.8	363	0.63		362	211	390	1350
2000	4.4	71.2	53.2	246.3	0.32	0.11	198.5	270	399.6	1129

Though the industrial water came from draining of the workings in seams 116, 117 and 118, now the majority of the inflow comes from seam 118, western part of field 10, that is the main area of current exploitation. Before 1998, when the fresh water from seam 116 draining was still mixed with industrial water, the mineralization was usually below 1 g/l and the chlorides and sulphates concentrations was respectively 40 – 237.5 and 56,56 – 188.0 mg/l. In 1998 the inflow rate of the industrial water was the lowest: 3.5 m^3/min. In the next years it has been increasing, along with more intense exploitation of seam 118, western part of field 10 (now it reached 4,9 m^3/min). The mineralization of industrial water has also grown up; it reached the maximum of 1.35 g/l in 1999. The initial water type (HCO_3-Na-Mg) was also changing; with the increasing significance of sulphates and chlorides.

MINE WATER QUALITY FORECAST AFTER STOPPING OF EXPLOITATION

From the point of view of mine water use it is important to predict the quantity and quality of industrial water after the closure of Janina – Ruch II coal mine. This water once mixed with drinking water, should still serve as a drinking water resource for the town of Libiąż. The key issue for this forecast is the analysis of inflow rate and the chemical composition of the industrial water in Janina – Ruch II coal mine.

After the closure, the various types of water flowing into the workings will be mixed. Furthermore, the inflow from the western part of field 10, seam 118 would be decreased in rate because of diminished share of non-renewable resources from overlying sandstones in total inflow rate. For this share is considered to be significant, it is estimated that the industrial water inflow rate should decrease from 4.9 to 3.5 m^3/min. After taking the drinking water (3.1 m^3/min) into consideration, the total inflow rate after closing Janina – Ruch II should be about 6.6 m^3/min; in the following years it can decrease a little bit more and reach the level of about 6 m^3/min.

Currently, the simple mixing of drinking water and industrial water can decrease the quality of water. Industrial water contains 311.3 mg/l of chlorides (data from 2001) and 340.8 mg/l Na+K, while drinking water – only 63.82 mg/l of chlorides and 107.01 mg/l Na+K; also mineralization of industrial water (1,225 g/l) is almost twice as high as of drinking water (0,63 g/l). Mixing these waters in current proportions would give the water of less than 1 g/l mineralization, 215.4 mg/l of chlorides and 143.5 mg/l (values below the limits for drinking water), only 250.2 mg/l Na+K can be interpreted as Na over 200 mg/l (the limiting value). However, after closing the mine the significant decrease in inflow of NaCl-rich water from non-renewable resources. This should result in decrease in mineralization of industrial water and consequently improve the quality of mixed water, that should keep the quality of drinking water.

The existing examples for of mine closure [3, 4] show that the min danger for the mine water quality after closure is increasing concentration of sulphates. Closure usually results in flooding of some parts of the mine, that were for years exposed to oxidation of sulphides present in coal itself, as well as in the surrounding rocks. After the flooding of mine voids, the oxidised sulphides are easly dissolved in water and that is the reason for increasing concentration of SO_4^{2-}. Fig. 3 shows the SO_4^{2-} concentration as well as pH vs. time for the water flowing out of the aquifer in seam 301 in the nearby coal mine "Siersza" [5]. Before the flooding, the rate of water flowing out from old workings in seam 301 was 2.5 m^3/min and the SO_4^{2-} concentration was about 86.4 mg/dm^3. Just after the flooding, the outwash from the aquifer (of estimated volume of 400 000 m^3) increased in SO_4^{2-} concentration up to 1431 mg/dm^3. Then, due to washing the aquifer with the fresh water from infiltration, the SO_4^{2-} concentration decreased to 381 mg/dm^3 after about two years. The initial pH of about 7.0

decreased at first to about 6.0, and then increased again to 7.0. The similar and pH behaviour has been recorded at flooded parts of Janina –Ruch I coal mine

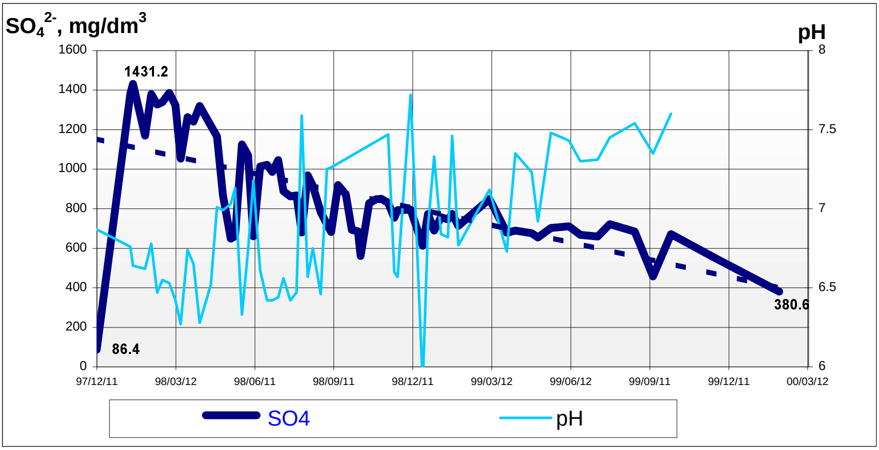

Fig. 3 SO_4^{2-} concentration and pH vs. time for the water flowing out of the aquifer in seam 301 in the coal mine "Siersza"

It is expected, that also in Janina – Ruch II every change in draining system would at first lead to increase the sulphates concentration in mine water. Only after the hydrodynamic conditions become steady, the mineralization and sulphates concentration would decrease, as a result of mixing with fresh water infiltrating from the surface. The next stage of flooding should be allowed only after the chemical composition of the water becomes steady and the concentration of sulphates decreases to the proper level. The sulphates concentration as well as the mineralization in the water pumped out from the mine should be kept at the levels of drinking water standards, therefore the closing works and the flooding of Janina – Ruch II should be performed along very strict rules.

PROPOSED DRAINING SYSTEM AFTER THE MINE CLOSURE

After stopping the exploitation at Janina – Ruch II coal mine the water from partially flooded workings will be pumped out through the Janina V shaft [2]. At first, after the field pumping plant in field 10 would be off, the draining will be done by mobile pumping set installed in "stone decline II" to the seam 117, until the water table reaches about 24 meters below sea level. By this time, the pumping system of deep wells in Janina V shaft has to be installed and ready to work; the water will be pumped then from the bottom of the shaft. During the filling of the old workings between 24 and 19 meters below sea level, two pumping system would work at the same time. This is not the best solution from the technical point of view, so the target solution would be to install the deep pumps set in Janina V shaft over the highest level of water inflow (12.9 m below sea level). This, together with the dimensions of pumping set, determines the minimal dynamic level of pumping at 1 m above sea level. Taking into consideration the possible outwash of sulphates, the emergency level of pumping should be no higher than 11 m above sea level.

The time to reach this draining system is hard to estimate, because it depends on various parameters. The most important of them are:

- mine water inflow rate,
- the dynamics of sulphates concentration,
- the time needed to stabilise the SO_4^{2-} ion concentration at the level allowing the next stage of flooding,
- technical possibilities.

The roughly estimated time to change the draining system would be few years.

As a result of closing down the pumping plant in northern part of field 10 and moving the mobile pumping set upwards in stone decline II in the seam 117, the volume of flooded workings will constantly increase. The current flooded aquifers W62 (1990) and W64 (1990) of total volume 68 000 m of will be connected. The volume of one future aquifer will depend on the level of groundwater table. This relations are shown in tab. 3.

Table 3 The relations between the groundwater level, the time, and the volume of flooded voids in seam 118

groundwater level	volume increase	total volume	time of the filling
H [m asl]	ΔV [m^3]	V [m^3]	t [month]
-63	0	68 000	0
-24	777 000	845 000	4
-19	206 000	1 051 000	5
-12	289 000	1 340 000	6
1	733 000	2 073 000	10

The time of filling the voids given in the table 3 has been estimated assuming the natural inflow rate at the level of 8.0 m^3/min, the constant pumping of drinking water at the rate of about 3.1 m^3/min and the constant movement of mobile pumping equipment whithout the longer stops at any level. The real time seems to be longer, about 5 years.

CONCLUSIONS

1. The closing works in Janina – Ruch II coal mine should be done with great care in order to secure the continuous supply of drinking water for the town of Libiąż through the intake in the old workings of seam 118.
2. It is necessary to raise the level of groundwater table up to 1 m above sea level in order to install the deep pumping set in shaft Janina V. It is expected, that the flooding would result in increased concentration of sulphates, therefore it should be done under continuous control in order to keep the mine water still below the limit of 250 mg/l SO_4^{2-}.
3. As a result of groundwater table raise to 1 m above sea level, the total volume of flooded workings will be about 2073000 m^3.
4. The time of flooding would depend on the changes in mine water quality; rough estimation is 5 years.
5. After the field pumping plant in field 10 would be off, the draining will be done by mobile pumping set installed in “stone decline II” to the seam 117, until the water table reaches about 24 meters below sea level. By this time, the pumping system of deep wells in Janina V shaft has to be installed and ready to work.

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