Groundwater contamination as a potential result of closing down of the Trzebionka mine, Southern Poland

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Abstract: The Trzebionka mine runs underground exploitation of zinc and lead ore. Ore-bearing formation is a very productive aquifer, an important water bearing structure, called the Chrzanów main aquifer. It is composed of karst-fractured-porous dolomites, limestones and marls of the Triassic age. Long lasting drainage of the mine has led to the formation of the extensive depression cone which reaches the altitude +48 m a.s.l. in the central part of the aquifer. In 1997 the lower part of the mine was flooded to the altitude +55 m a.s.l. After ending of exploitation in 2006 year the whole mine will be flooded. The consequences of mining activity are significant changes of groundwater chemistry in the Trzebionka mine, especially permanent increase of sulphate ion concentrations up to 200 mg/l has been observed. Metal sulphide oxidation processes, especially of iron sulphides and precipitation of calcium and magnesium sulphates, endanger the quality of mine water in case of flooding of mine workings. The results of the flooding of the lower part of the mine are presented in the paper. An attempt has been made to estimate the dynamic changes to the water quality in the flooded part of the mine workings, using laboratory method of ion leaching.

1 INTRODUCTION

This paper presents the result of observations on the flooding of lower part of ore mine workings in the Trzebionka mine. It is a base to study on the influence of the ore mine closing down operation on hydrological conditions of the Triassic aquifer, as well as on the change of groundwater chemical composition.

The Trzebionka mine runs underground exploitation of zinc and lead ore. Ore mining is based on a zinc and lead ore deposit of the Mississippi Valley type located in the Upper Silesian Zn-Pb Ore District. Geological characteristic of ore mineralization is presented by Szuwarzyński (1998). These are strata-bound tabular ore bodies with very complex internal structure, hosted by the Middle Triassic dolomites (strictly, Lower Muschelkalk). They occur within the syncline called the Chrzanów trough connected to the marginal structures of Upper Silesian Basin. The main ore minerals are sphalerite and galena. They are accompanied by iron sulphides, cerussite, smithsonite, hemimorphite, etc.Typical wall rock is dolostone. Ore grade may be defined as low since it contains 3 -4% of zinc and approx. 1.5% of lead.

Ore-bearing formation is a very productive water-bearing structure called the Chrzanów major aquifer (Figure1, Różkowski, Chmura, Siemiński, eds., 1997). The groundwater of this aquifer is exploited by several wells for potable water-supply service, e.g. in the abandoned Matylda ore mine. Also water from the Trzebionka mine is used to supply the neighbouring towns and industrial facilities.

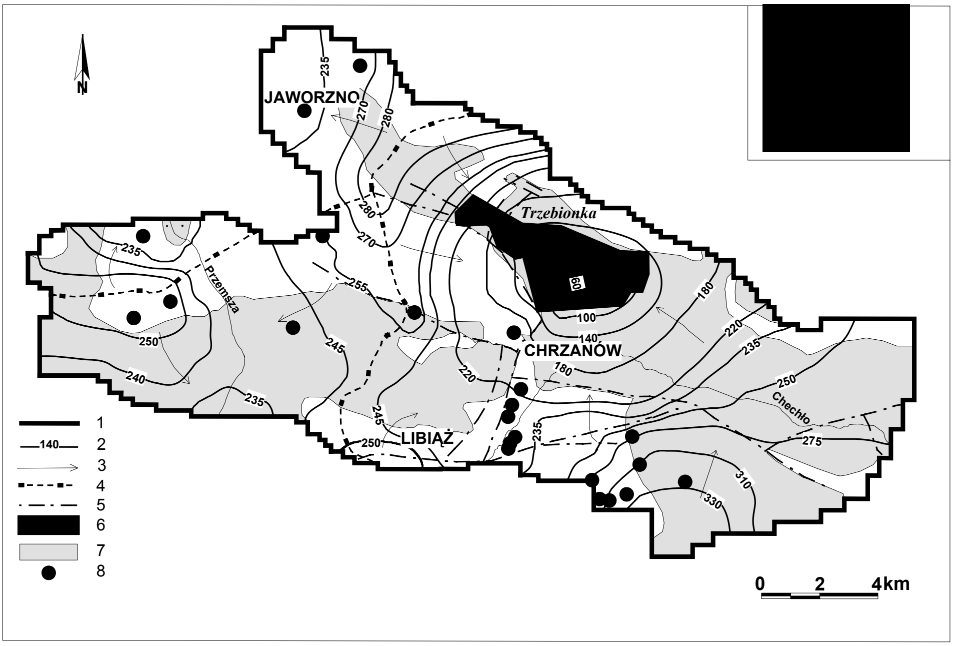
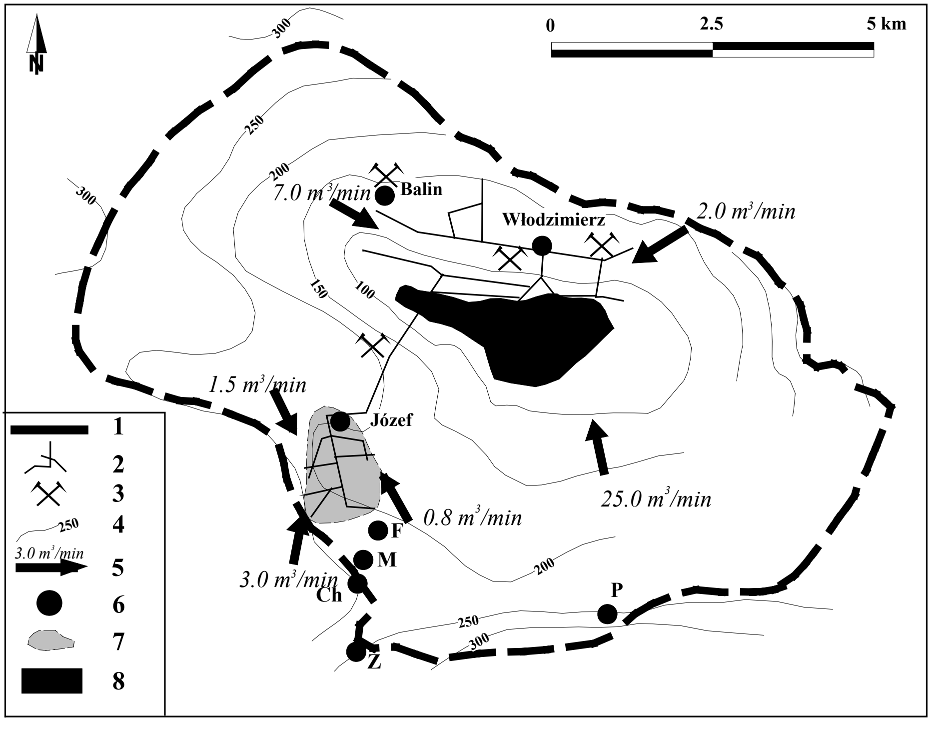


Figure 1 Hydrogeological map of the Chrzanów Triassic aquifer
1 - boundary of the aquifer model; 2 - contour lines in 1997; according to calibrated model; 3 – directions of groundwater flow; 4 – groundwater divide; 5 - faults; 6 – Trzebionka Zn-Pb ore mine; 7 -extension of the impermeable Keuper and Tertiary deposits; 8 - wells.

The decision to found the Trzebionka mine was taken in the years 1953-1954. First ore run of the mine in 1962. After its development in 1970-1975, the drainage base of mine has been stabilised on the level of sump of the local pomp station, defined as the altitude +48 m above sea level. The drainage of the mine has led to the formation of the extensive depression cone (Figure 2). This cone has reached its recent range in 1971. Its extension and shape is determined by structural conditions. These conditions are very important factor controlling groundwater flow directions within the aquifer (Szuwarzyński, 1998). During the following years only deepening of the cone has been observed. In 1997 the lower part of the mine was flooded. A new water table stabilised on the altitude + 55 m.

Depletion of the ore reserves together with the fact of the lack of possibilities of finding new deposits in the neighbourhood shall result in the end of mining activity. It is assumed that it may last for a few years (up to 2006 the latest). After ending of exploitation whole mine will be flooded.

The consequence of mining activity in the Chrzanów trough is significant change of the chemical composition of groundwater in the Trzebionka mine. Especially, permanent increase of sulphate ion concentrations was observed.



Figue 2 The hydrogeological map of the depression cone in the Chrzanów syncline
1 - range of the mine drainage and groundwater intake impact; 2 - main workings of the ore mine; 3 - shafts of the ore mine ; 4 – contour lines of the Triassic aquifer; 5 – direction and quantity of groundwater flowing to the mine working; 6 - active groundwater intakes in 1999 yr. (F - the "Fablok" Metallurgic Plant, Ch - Cold Store, M - the Meat Plant, Ż - the Żelatowa RPWiK intake; P - the Płaza Limestone Quarry) and those projected (Włodzimierz and Balin shafts of the Trzebionka ore mines); 7 – underground reservoirs in the mine workings (in 1999); 8 - the reservoir in the workings of the Trzebionka mine after the flooding of the part of workings (according to project).

2 HYDROGEOLOGIC SETTING

The Chrzanów aquifer is composed of karst-fractured-porous dolomites, limestones and marls of Triassic age (Rhoethian and Muschelkalk); the total thickness is about 20-150 m. Permeability of the carbonate complex determined by well pumpage varies from $1.1*10^{-6}$ m/s to $6.8*10^{-4}$ m/s (Kowalczyk et al., 1998). Most of the area is covered by Upper Triassic clays and Tertiary clays; the two formations of very low permeability. The nearly impervious substratum comprises marls, clays, mudstones, siltstones of varying age: Lower Triassic, Carboniferous and Permian. The local shallow Quaternary and Upper Jurassic aquifers are mainly present in the eastern part of the area.

The total amount of water withdrawn by wells and by mining workings is about 73 000 m^3 per day. 44 000 m^3 of this is daily being pumped by the Trzebionka mine. A result of a long-lasting dewatering of the carbonate complex is the lowering of the original piezometric surface which reaches maximum at about 260 m in the central part of the aquifer . At present the aquifer is partly confined and partly unconfined (Figure1).

The essential recharge of the carbonate aquifer occurs mainly by infiltration of precipitation from the outcrops and through the Quaternary deposits (Kowalczyk, et al., 1999). There are supposed additional sources of recharge: seepage from the rivers, downward leakage from the shallows aquifers, water losses in the water supply network and losses in the sewage, upward leakage from the Carboniferous aquifer, lateral inflow through the boundary. The original discharge from the aquifer went to the rivers. Currently the main discharge is due to water withdrawing from Zn-Pb ore excavations and groundwater intakes.

The water budget established by results of mathematical modelling (Kowalczyk et al., 1998) shows that the total renewable groundwater resources of the Triassic aquifer is equal to 101 000 m^3 per day (4.3 $l/s*km^2$).

It should be mentioned that the Trzebionka mine drainage involves almost exclusively the Triassic carbonate complex. Main directions and quantities of groundwater flowing to the mine are shown in Figure 2. In the area of mining drainage influence this complex is hydraulically well separated from the Upper Carboniferous aquifer. It is also well isolated from the shallow Jurassic aquifer. In this case, hydraulic contact between the aquifers is limited to direct surroundings of shafts and dip headings and some boreholes. Propagation of a such impact onto the larger areas is impeded due to relatively low permeability of the Jurassic formation. There is the hydraulic contact of the Triassic aquifer with the shallow Quaternary aquifer, particularly in the zones of the Triassic dolomite outcrops, where the intensive recharge of the Triassic aquifer takes place.

3 PLANNED METHOD OF THE MINE CLOSING DOWN OPERATION

Prospect of continuing exploitation of the Trzebionka mine is estimated for a few years, to 2006 yr. only. Due to organisational problems, the operation of mine closing down will be led in stages, and its end will be achieved by total flooding of mine workings. It can be expected that the closure will begin in 1.5-2 years after termination of ore exploitation. Earlier, on the turn of 2000-2001 years the deepest part of the mine, laying below the altitude +81 m a.s.l., will be flooded. It will be the ending of a first stage of the operation, having started in 1998 (Gandsdorfer et al., 1998).

Recently carried out the closure of the mine part includes the area where ore resources were exploited or the exploitation has been finished. The south-western part of this area is assigned to flooding. As a result, an underground reservoir of about 4 million m^3 of volume will be formed. Groundwater damming up will be led to achieve gravitational water overflow at the transportation level (altitude +81 m a.s.l.) where the main pump station is situated.

Selection of the closing down method of the mine part and, among the others, the decision to flood workings below the altitude +81 m a.s.l., has been preceded by analysis of the possible solutions. Earlier, in 1997 yr., groundwater pumping out has been prepared with the use of a well intake for feeding of the local water-supply service. For the needs of this intake the ZG Trzebionka S.A. (owner of the mine) has made existing recently a "small" underground water reservoir of about 190 000 m^3 in volume, where groundwater is dammed to the altitude +60 m a.s.l. (Figure 2). This reservoir has been formed by damming of groundwater runoff by concrete dams in drifts. Water outflow from the reservoir is regulated by valves. Groundwater is carried away to the pump station at the +48 m a.s.l., from which it is pumped out at the + 81 m a.s.l.

The contractor of the next investment, and afterwards its user, would be the intercomunnal association. Since the change of the conception of water supply service for the nearby towns and settlements, the project has been abandoned. In this situation, with the lack of technical reason for maintenance of existing dewatering system as a whole, the decision has been made to close the pump station at the +48 m a.s.l., consequently leading to the flooding of the deepest part of the mine and enlargement of the existing reservoir (Figure 2).

Similarly as in the case of the "small" reservoir, the flooding of mine workings was preceded by the exploitation of the deposit left and the first development including the protection of sand backfill against washing during groundwater damming up. Next, there were built the barriers enforcing groundwater flow in the range of the reservoir through defined workings omitting the post-exploitation cavities, if it is possible. Groundwater damming up will begin by the end of 2001 yr. and will last for 2.5 to 3 months.

After the flooding there will be gravitational groundwater overflow to the water drift at the + 81 m a.s.l. The expected inflow at this overflow will be lower or, at most, equal to groundwater amount recently pumped out at the +81m level. , i.e. maximally about 28 m^3/min (Podsiadło et al, 1999). As it is now, groundwater flowing out this overflow will be mixed with another groundwater flowing into the mine workings, both the natural one and effluent from the hydraulic backfill. Collective mine groundwater will be applied the same way as it is now, i.e., to provide for the plant needs (hydraulic backfilling and the supply of benefication plant), and water excess will be feeding the local water supply facility.

4 CONSEQUENCE OF THE PARTIAL FLOODING OF THE MINE WORKINGS ON THE GROUNDWATER

Relatively small range of alterations, involving the rise of the groundwater level in the range of the mining structure of about 20 m, should not cause larger changes in groundwater conditions in the described area. Within the Triassic multiaquifer formation there would be infilling of the deepest part of the depression cone and return to the pressure values on the turn of the sixties. It will not influence the amount of inflow to the mine and does not cause the changes in the depression cone range which is mostly controlled by structural factors. A new drainage base will stabilise at the level defined by the +80 m a.s.l., much lower than the natural drainage base in the structural unit dewatered by the Trzebionka mine, which has been situated in the Chechło river valley on the altitude about +250 m a.s.l. (Szuwarzyński, 1998). Good confinement of the Triassic multiaquifer formation excludes also any impact of groundwater horizon rising on the multiaquifer formations in the cover and substratum of the Triassic formation.

5 PROBLEM OF GROUNDWATER QUALITY AFTER FLOODING OF THE MINE WORKINGS

Mining activity causes changes in chemical composition of groundwater, either that flowing through the mine workings and migrating in the rock massif within their direct surroundings and, at larger distances, within the zone of the mine drainage impact. These changes are caused by the following factors:

1) influence of different media used in the mining process (fuel, lubricants, explosives);

2) presence of organic pollution connected with the use of wood, technical fabrics or presence of people in workings;

3) generation of mechanical pollution caused by mixing of pure natural groundwater with backfilling effluent and mixing of these groundwaters with pulverised crude ore in mine workings, where movement of LHD machines occurs;

4) weathering of rocks in the range of the mine drainage, as well solid ore body as crude ore left in the bottom of stopes.

Since their limitations, three first factors show a transient character. Their impact will end with termination of exploitation, and possible impacts of some of them (for example, the increase of bacterial populations, oil traces, etc.) may last a little longer at much smaller scale or may appear after the ceasing of causes, for instance, as a result of working washing during the flooding. It is worth to mention that the closure impact will be advantageous in some range, as there always were large problems with groundwater pollution in this single-level mine without possibility to separate the stream of industrial wastes.

The problem of groundwater chemistry changes, related to its contact with weathering products, seems to be quite different. In relation to this type of alteration it can be expected that after termination of mining activity there will be return to the natural groundwater chemistry within the Triassic multiaquifer formation, but it will be preceded by a period of increase of pollution content (Motyka et al., 1998). It is difficult to estimate precisely how long such an intermediate period will last and how large the scale of changes will be.

Besides, it is difficult to define chemical parameters of groundwater in the described area, specific for the natural conditions. There is not a great deal of data coming from the period before the beginning of the mining activity, and those surviving do not seem to be reliable in many cases. Generally, it can be assumed that the recharge way, similar conditions of groundwater circulation, and first of all, high homogeneity of the circulation environment support almost stable groundwater chemistry within the Triassic complex. These groundwaters represent the following types: bicarbonate-calcium, bicarbonate-calcium-magnesium, sulphate-bicarbonate-calcium, and sulphate- bicarbonate-calcium-magnesium ones. They are slightly alkaline groundwaters, with pH value in the range from 6,9 to 8,3. Groundwater hardness, mainly of carbonate type varies from 4.27 to 11.04 mval/l. Since their total mineralisation, defined as dry residue, is within the interval of 300-600 mg/l, they belong to fresh waters with good quality parameters, what is connected, among the others, with optimal content of ions thought to be advantageous (among them Mg, Zn, Li and others).

Under conditions of the active mine, the constant increase of sulphate ion content has been detected in the mine groundwater. Its concentration has reached a level near 200mg/l in the nineties (Figure3). The constant increase of groundwater hardness accompanied it. Moreover, accurate research of chemistry of groundwater flowing into workings situated on the borders of the mine infrastructure has revealed that inflowing waters are generally characterised by parameters similar to those typical for natural conditions, i.e. with sulphate ion [SO_4^{-2}] content lower than 100 mg/l (Motyka et al., 1999). It could mean that weathering has caused essential changes in chemistry of water-bearing rocks in the larger surroundings of the mine, within the drainage zone.

The first observations concerning changes in chemistry during flooding of workings have been accomplished by infilling of the "small" reservoir “pz-5” at the +48 level. At the first stage, after the reservoir infilling, the increase of mechanical contamination has been detected on outflow, mainly related to argillaceous suspension. It lasted about 2 days and was connected with "flushing" of the flooded workings. Such phenomenon should not occur during recently planned enlargement of the reservoir, because the suitable protection will be made during the mentioned above first development.

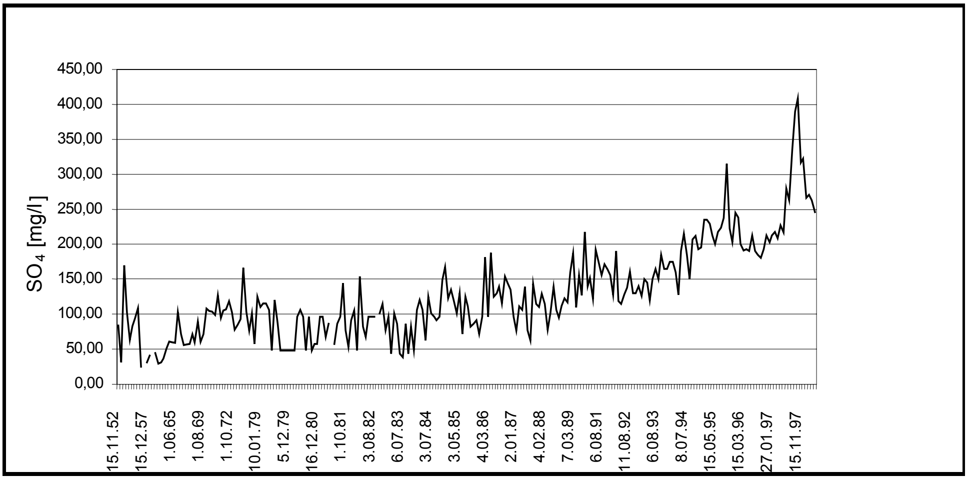


Figure 3 Changing of sulphates concentration in the Trzebionka mine water

The second element of changes in chemistry of groundwater flowing out the reservoir was the increase of sulphate concentration. During the first hours it reached a level of about 1 g/l (according to information given by workers of the water conditioning station). The following days brought its decrease to the value of about 400 mg/l, and subsequent lowering to the values from before the reservoir infilling, i.e. to about 200 mg/l (Figure4). It lasted several months (Motyka at al., 1998). The trend of groundwater chemistry alteration can be predicted as similar for the part of the mine assigned to the recent flooding. As in the case of the "small" reservoir infilling, there will not take place conditions enabling occurrence of higher concentrations of heavy metals, particularly lead and cadmium (Motyka et al., 1998).

The described phenomenon is caused by generation of new substances in workings and rocks surrounding them. They are the products of weathering in the rock massif exposed to aeration as a result of dewatering. Weathering products of sulphide minerals composing the deposit of Zn-Pb ores, especially iron sulphides - pyrite and marcasite, are of particularly high importance (Motyka et al., 1999). As a result of the process very well water-soluble sulphates are generated which presence is revealed just after their contact with water. Such groundwater chemistry alterations are transient features and their occurrence has lasted since the total sulphate washing.

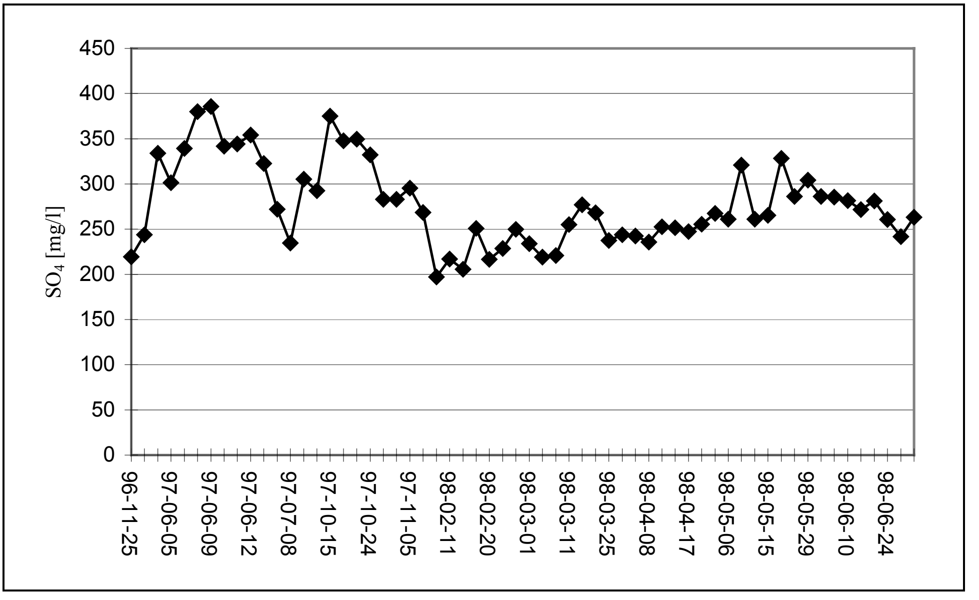


Figure 4 Changing of sulphates concentration in the water from “pz-5” reservoir.

6 CONCLUSIONS

The better recognition of mechanism of generation of soluble sulphates in the mine workings will be able after the end of flooding of workings in the recently closed down part of the mine. It could be expected that they give results providing the means to work out prediction of groundwater chemistry changes during the final mine flooding and after its termination. Then the primary groundwater conditions will be restored from before the beginning of mine activity.

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Zanieczyszczenie wód podziemnych jako potencjalny skutek zamknięcia kopalni „Trzebionka" (południowa Polska)

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Streszczenie: Kopalnia Trzebionka prowadzi eksploatację złóż rud cynku i ołowiu. Seria złożowa występuje w profilu hydrogeologicznym zasobnych zbiorników użytkowych wód podziemnych (GZWP). Kompleks wodonośny stanowią dolomity, wapienie i margle triasu środkowego i dolnego, posiadające szczelinowo-krasowo-porową sieć hydrauliczną. W wyniku długotrwałego odwadniania kopalni wytworzył się rozległy i głęboki lej depresji; zwierciadło wody w centralnej części zbiornika zostało obniżone do poziomu 48 m npm. W 1997 roku został zatopiony najniższy poziom eksploatacyjny kopalni do rzędnej 55 m npm. Po zakończeniu eksploatacji rud przewiduje się całkowite zatopienie kopalni. W wyniku działalności górniczej nastąpiły znaczne zmiany składu chemicznego wód dopływających do kopalni. Obserwowany jest stały wzrost zawartości siarczanów w wodach kopalnianych. Zagrożeniem jakości wód podziemnych w związku z zatapianiem wyrobisk górniczych są procesy utleniania głównie siarczków żelaza prowadzące do powstawania siarczanów wapnia i magnezu. W artykule przedstawiono wpływ zatopienia dolnego poziomu kopalni na jakość wód podziemnych. W drodze badań laboratoryjnych dokonano próby oceny dynamiki zmian jakości wód w zatopionej części kopalni.