ENVIRONMENTAL ASPECTS OF USE OF THE CARBONIFEROUS WASTE-ROCKS FOR ROAD CONSTRUCTION

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ABSTRACT

Abundance of coal-mining wastes generated in the area of the Upper Silesia (Southern Poland) causes serious problem with their proper and ecologically safe utilisation. One of the proposed solutions of the utilisation of the waste-rocks is their use for cart-roads construction. Unfortunately waste-rocks are not neutral to the natural environment and they can cause more or less significant pollution of groundwater. The potential negative impact for the Triassic aquifer in the area of the Miedary groundwater intake has been assessed.

Based on an example from the Katowice region this paper presents assessment of the potential risk to groundwater caused by the coal-mining wastes. Assessment has been done for risk caused by leaching of soluble constituents already present in the raw waste-rocks and by the constituents originated during the time-dependent weathering.

Depends on local hydrogeological conditions these amounts of above mentioned constituents (316150 kg of SO_4^{2}, 7430 kg of Cl^- and 1150 kg of $N\text{-}NH_4^+$) can cause less or more significant risk to groundwater. Generally thin layers of utilised wastes make similar to thick landfill potential risk to groundwater. Recently observed increase of sulphates concentration in groundwater pumped from wells in Miedary intake can be partly caused by the constructed roads.

INTRODUCTION

Intensive coal exploitation (65 operating coal mines) in the Upper Silesia (Southern Poland) has resulted in the huge amount of waste-rocks. About 50 mln tons of the mined waste-rocks was generated in 1994 in the Katowice district. Only about 10 % of those waste-rocks was utilised in the underground workings. The remained of waste-rocks pose a serious ecological problem. One of the proposed solution to this problem is the utilisation of the waste-rocks for roads construction.

At the moment about 70 km of forest roads in the Katowice district are repaired. There are 230000 tones of coal-mining wastes predicted in 1994-1998 (max. 50000 per year). Roads, to be constructed are located in the capture zones of big groundwater-intakes. Therefore, it is necessary to estimate the potential danger of them for groundwater from the waste-rocks.

Solid mine-wastes have a considerable impact on the water environment, changing the quality of water in the areas of their storage. These changes are caused by leaching of the soluble materials wastes, with a different degree of toxicity.

Large area of storage (70 km x 4m = c. 280 000 m^2, i.e. 28 ha) enables the contact of the wastes with the precipitation-water and the air. This intensifies weathering and leaching of the soluble components of the stored wastes.

A coal mine wastes should not be treated as a static structure, which does not change under pressure of the external agents (Kempa et al, 1985; Sztelak & Szczepański, 1985; Twardowska et al, 1988). Consideration of the coal-mining wastes as a static structure results in the underestimation of the potential hazard to the water environment.

Basic factors deciding about the danger for the water environment from the stored mine-wastes, and describing a kind and the magnitude of infiltrating pollution coming from them are as follows:

- the contents of the soluble components and the dynamics of their production due to the physico-chemical processes
- a sort of components soluble in the leaching water
- the kinetics of the diffusion of the components to the water flowing through wastes
- hydrogeological and hydrological conditions of the area determining the scale and the range of migration of pollutants in the water environment

In this paper, for a chosen area of groundwater intakes in Miedary (Fig. 1) the potential impact of roads covered by the mine-wastes on the groundwater of the Triassic aquifer has been assessed.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The area shown in Fig.1 is located on the Cracow-Silesian monocline which is built up mostly of the Triassic rocks. According to S. Kotlicki's (1975) stratigraphic division of the Silesian Triassic, Triassic deposits of the investigated area are divided into the Lower, Middle and Upper Triassic sediments, facial sediments of the Bunter sandstone and the Muschelkalk.

Tertiary clays and claystones locally occur in the depressions of the top of Triassic rocks.

Quaternary deposits continuously cover almost whole area. Their thickness varies from a few meters (in uplands) up to about 60 m (in the buried valley of the Stoła river). They are represented by Pleistocene sands and fluvioglacial and glacial gravels and by glacial tills. Holocene sediments are represented by fluvial outwashes (i.e. sands, gravel, silts) occurring in the contemporary river valleys. The thickness of these sediments is about 3 m.

There are two useable aquifers in this area: Quaternary and Triassic.

The Quaternary aquifer occurs within discontinuous sand-gravel deposits of various thickness. The most resourceful parts of this aquifer have been observed in the area of present and buried valleys of the Stoła river. Generally, the Quaternary aquifer plays the minor and rather local role in the water supply, whereas the Triassic aquifer is the most important in this area.

There are three water-bearing horizons in the hydrogeological profile of the Triassic aquifer,:

1) Muschelkalk (Middle Triassic)
2) Roethian (Lower Triassic)
3) Middle and Lower Bunter sandstone (Lower Triassic)

The most important and resourceful ones are horizons of Muschelkalk and Roethian. Because of the frequent hydraulic connections they are treated as a single fissure-karstic groundwater complex called the Triassic carbonate series.

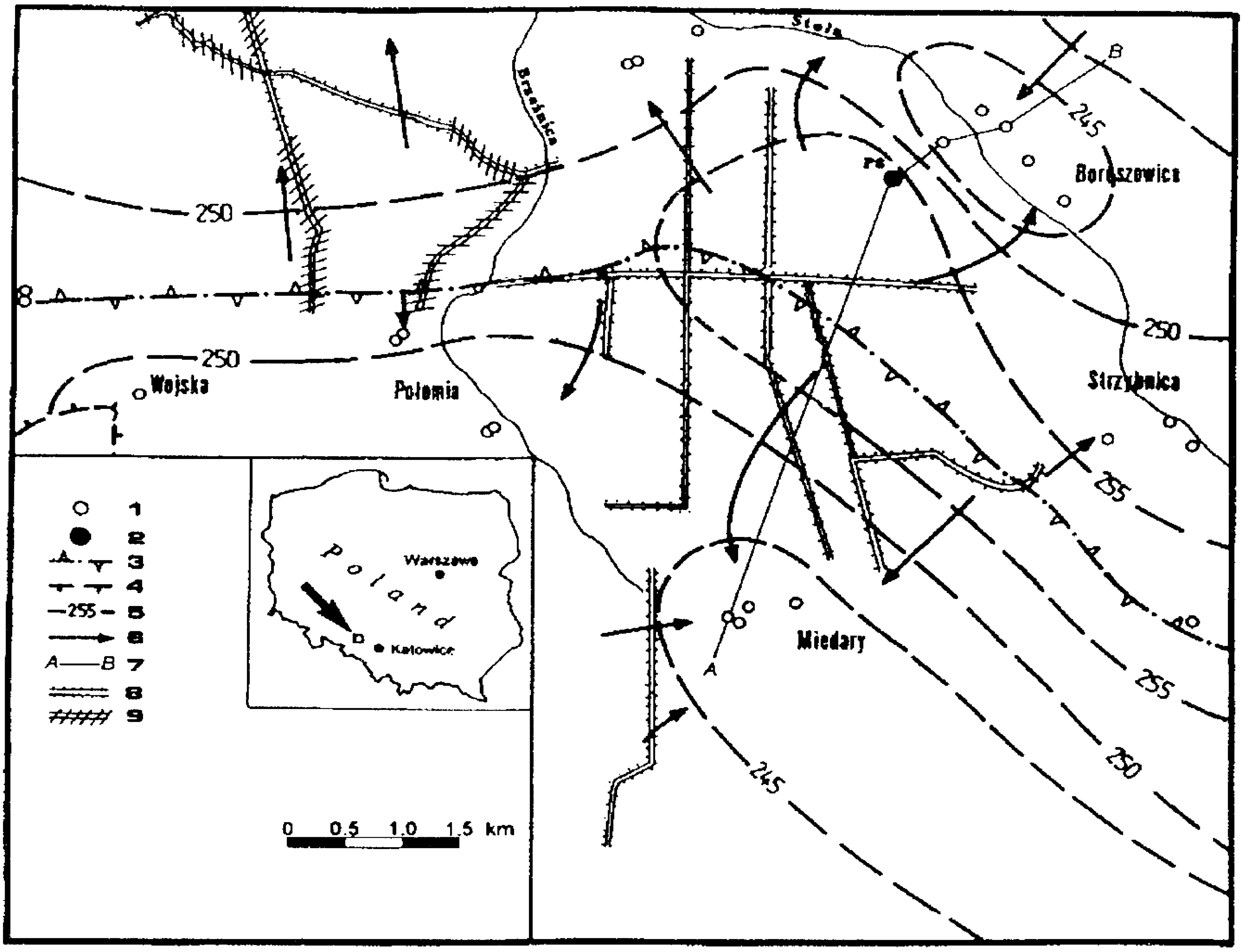

Fig.1 Hydrogeological sketch

Legend: 1- wells, 2- observation wells, 3- groundwater divide, 4- Triassic carbonate series extent, 5- water table contour of the Triassic carbonate series aquifer (according to Musiał,1994), 6- groundwater flow direction, 7- hydrogeological section line, 8- roads with permeable bedding, 9- roads with low-permeable bedding

Permeability, transmissivity and water-bearing capacity of these series vary. Hydraulic conductivity ranges from 1.1 x 10^{-5} ms^{-1} up to 1.59 x 10^{-4} ms^{-1} (Różkowski et al, 1991).

In the investigated area, the Triassic aquifer is very resourceful and intensively exploited by numerous intakes. Groundwater intake in Miedary, with the yield of about 2.5 million m^3/year, is one of them.

The described area is in the reach of two major water basins: Lubliniec-Myszków and Gliwice divided by a hydrodynamic boundary (Fig. 1). This complex is recharged by a direct infiltration in the area of outcrops of carbonate series or indirectly through the Quaternary overburden of variable permeability (Fig. 2). The recharge occurs also by slow percolation through generally low-permeable upper Middle Triassic sediments.

There are two visible centres of the drainage in the hydrodynamic system. Both are related to the groundwater intakes in Boruszowice and Miedary (Fig. 1).

Hydraulic gradients vary from about 1-2 $^0/_{00}$ in the NW and W parts of the area, up to 7-13 $^0/_{00}$ in zones of the intensive drainage in the mentioned above intakes.

The real flow velocities in the Triassic basins, calculated for the effective porosity $n_0 = 0.06$ and average hydraulic conductivity $k = 1.3 \times 10^{-4}$ ms^{-1} (Witkowski et al, 1988), vary from 100 to over 1000 m/year. These are the average values for whole massif and they results from porous as well as fissured character of the groundwater flow. For the fissure-karst system, these velocities are much higher, from several hundred up to several thousand m/year. The fissure-karst hydraulic system will have the biggest influence on the maximum velocity of the migration of any possible pollutant.

Considering the location of roads, which to be repaired, groundwater intakes and the hydrodynamic system of the Triassic water-bearing horizon, it is clear that the Miedary intake is the most endangered because it is surrounded on three sides by 16 km of roads under construction (Fig. 1). Therefore that was selected for estimations of the potential risk from the mine-wastes to groundwater of the Triassic aquifer.

ASSESSMENT OF THE POTENTIAL RISK TO GROUNDWATER

In the area shown in Fig.1, Triassic carbonate series are covered by Quaternary deposits of different thickness and lithology,and locally by low-permeable argillo-arenaceous deposits of the Boruszowice and Miedary layers (upper Middle Triassic).

In the areas where the Triassic aquifer is covered only by thin sandy-gravel Quaternary deposits, groundwater is potentially endangered by pollutants percolating from the ground surface (Fig. 2). Roads under construction are located within this area.

The potential risk to groundwater from the stored mine-wastes is related to:
- leaching of soluble constituents of the raw wastes
- leaching of soluble constituents originated during weathering of the wastes

Assessment of the potential risk caused by saluble constituents of raw wastes

The coal-mining wastes come from the Upper Carboniferous paralic series and consist of mudstones (about 60%), claystones (about 35%) and sandstones (about 5%). These wastes are grouped into three classes in the coal treatment:

- coarse material	> 80 mm	(5% of the total amount)
- medium-size material	20 - 80 mm	(20% of the total amount)
- fine material	0.75 - 20 mm	(75% of the total amount)

The concentration of pyrite in the wastes is variable but is generally high (from 0 up to 15 vol %). Because of the high amounts of calcium and magnesium carbonates (from about 5% up to about 19%) which neutralise most of the produced sulphur acid, the oxidation of pyrite does not lead to the acidification of the environment. This conclusion was confirmed by the laboratory experiments and the field observations (Twardowska et al., 1988, Drobek et al., 1994).

The contents of soluble constituents in raw wastes are about 0.1% (Drobek et al., 1994). Sulphates, chlorides and the sodium ions are the most important soluble constituents of the raw wastes. The total mass of the wastes suggested to cover roads, i.e. 230,000,000 kg contains about 230,000 kg of soluble constituents (Cl^- - 34200 kg, Na^+ - 84900 kg, SO_4^{-2} - 74300 kg, K^+ - 16500 kg, $N\text{-}NO_3^-$ - 900 kg, $N\text{-}NH_4^+$ - 5300 kg, Zn - 400 kg, Fe - 200 kg).

A study by J.Krawczyk (1994) suggests the fast leaching of chlorides from the Carboniferous rocks. A lisimetric examination showed that single exchange of water caused a 90% reduction of the Cl^- load. Results of that study also indicated a high velocity of Cl^- migration (about 1cm/d).

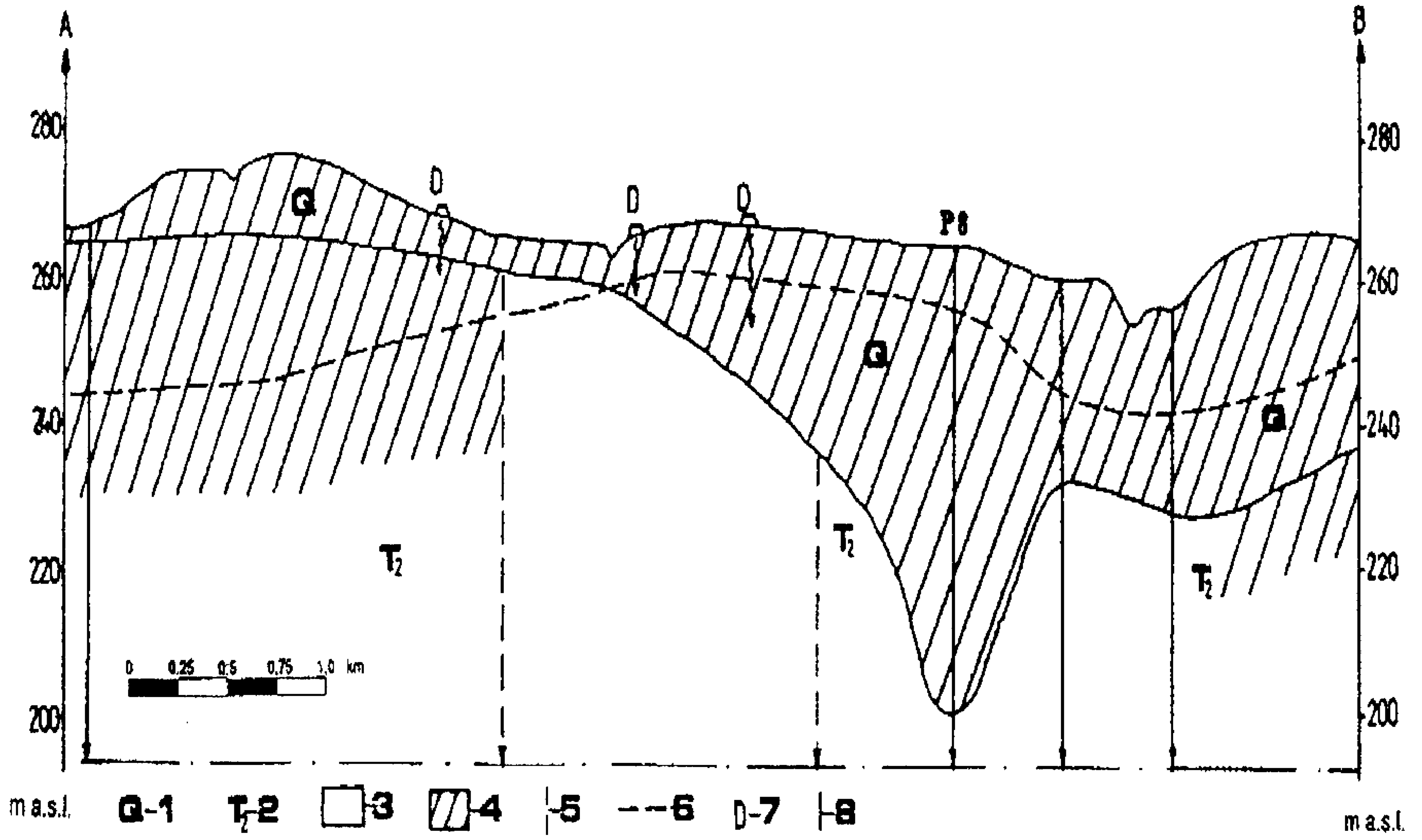

Fig.2 Generalised hydrogeological section

Legend: 1- Quaternary, 2- Middle Triassic, 3- permeable deposits, 4- deposits of different permeability (interbedded permeable and low-permeable deposits), 5- faults, 6- water table contour of the Triassic carbonate series aquifer, 7- roads under construction, 8- boreholes

Some 50000 tons of wastes are planned to be used for the construction of 16 km of roads in the area of the Miedary intake. Out of this amount, 7.43 tons of chlorides and 16.15 tons of sulphates may be washed out. This amount of chlorides is capable to polluting about 25000 m^3 of groundwater (above the acceptable level of 300 mg/dm^3). However, there may be over three times more, of sulphates, i.e. about 81 000 m^3 (for the acceptable limit of 200 mg/dm^3). Such a load of pollutants can cause an increase in the concentration of Cl^- by about 3 mg/dm^3 and of SO_4^{-2} by about 6.5 mg/dm^3 in 2.5 million m^3 of water pumped out from the Triassic aquifer in the Miedary intake per year. The natural concentrations of these ions in the water are 7-8 mg/dm^3 and 15-17 mg/dm^3, respectively.

A relatively high amount of nitrogen, especially of $N\text{-}NH_4$, is alarming. The total concentration of $N\text{-}NH_4$ in considered 50000 tons of wastes is estimated to be about 1150 kg. Assuming that this amount of $N\text{-}NH_4$ is washed out in one year, a pollution exceeding standards (>0.5 mg/dm^3) of 2.3 million m^3 of water can occur, which is 90% of water pumped out from the Miedary intake per year.

The other constituents, e.g. heavy metals, are washed out in small amounts and they cannot cause a significant risk to the water environment.

Assessment of the potential risk caused by soluble constituents originated during weathering processes

The amount of the soluble constituents in the raw wastes is only a part of the pollution load contributing to the risk to groundwater. The wastes on the ground surface, will be subjected to intensive physical and chemical changes, which will lead to physical, chemical and biochemical degradation of the rocks.

Because of their thickness between 0.3 and 0.5 m the wastes covering roads will weather rapidly.

Physical weathering leads to the disintegration of the wastes; whereas the chemical weathering causes oxidation of iron sulphides and hydrolysis of the oxidation products, buffering processes and the leaching of soluble constituents.

A risk caused by the oxidation of iron sulphides (pyrite and marcasite) is especially important. This is because of the formation of large amount of soluble sulphates, and possibility of acidification of the environment. The potential acidification of the environment can be neutralised by carbonates which occur in the wastes. The neutralisation processes cause also a reduction of sulphate leachates. Results of the laboratory experiments (Twardowska et al., 1988) and the modelling of the natural hydrological cycle (Witczak & Postawa, 1993; Szczepańska et al., 1996) indicate that stored sulphides decay due to the long-term processes, causing a risk to the water environment for decades. Especially high degree of risk to the environment is observed from the weakly buffered wastes.

The process of sulphides decomposition in the wastes is quite regular and it is possible to describe it by the first degree kinetic equations. The half-time of the decomposition ($t_{1/2}$), is taken from the laboratory experiments and it varies from 29 to 10500 days, with the average value of 588 days (Twardowska et al., 1988), depending on a litostratigraphic position. The half-time of the decomposition of the coal-mining wastes from paralic series will be between 300 and 500 days (Twardowska et al., 1988). According to the results obtained by „Combipol" Company (1988) the half-time of the decomposition of sulphides in coal-mining wastes from the coal mine „Gliwice" varies between 181 and 650 days, with the average value of about 400 days. This average value fits very well to the above mentioned values.

Assessment of the total amount of sulphates originated during sulphides decomposition can be done by production rate index (R_{SO4}) with reference to the total mass of stored wastes.

$$R_{SO4} = 20800\ G_s/t_{1/2} \qquad \text{where:} \qquad [1]$$

R_{SO4} - production rate index of sulphates in wastes [g/Mg d]
G_s - contents of sulphur (in sulphides) in wastes [%]
$t_{1/2}$ - half-time of the decomposition [d]

According to the results obtained by „Combipol" Company (1988) the sulphates production rate index varies between 1.68 and 8.84 mg/kg d, with average value 4.45 mg/kg d.

The average contents of sulphides sulphur in the wastes is about 0.2 % (GIG, 1994, Combipol,1988). Taking into account this value the 50000 tons of wastes planned for the utilisation will contain about 100 tons of sulphur which may turn into 300 tons of soluble sulphates.

About 222.5 kg per day, i.e.over 81.2 tons per year, of dissolvable sulphates can originate in these 50000 tons of wastes, assuming that the sulphates production rate index is 4.45 g/Mg d.

Assuming that the half-time of the decomposition is 400 days and concentrations of sulphides sulphur in the wastes is 0.2 % the production rate index estimated from the formula [1] is 10.4 g/Mg d. From this production rate index follows that, about 598 kg per day, i.e.over 218 tons per year, of soluble sulphates could originate in the 50000 tons of wastes. This value is over 2 times bigger than previous one.

Taking into consideration only the half-time of the decomposition of 400 days maximum about 137 tons of soluble sulphates per year will originate from 50000 tons of the wastes.

Regardless of the value accepted, i.e. 81.2 or 137 or 218 tons of sulphates precipitation will play the decisive role in their leaching from the wastes. Because the utilised wastes will be situated above the groundwater table, precipitation will be only one source of water flowing through its. From over 13400 to over 17900 m^3 of water may percolate through these wastes, assuming that:

- the average annual precipitation in the investigated area is 700 mm (at Łubie meteorological station, for the period 1982-1994)
- the area covered by the utilised wastes is about 64000 m^2
- the effective infiltration is 30-40%.

Described wastes have some buffering properties, therefore the leachate will contain between 3 and 5 g of sulphates in 1 dm^3 (Twardowska et al.,1988). A stream of infiltrated water is able to leach from 40 up to 67 tons of sulphates per year, from 50000 ton of wastes assuming that the effective infiltration is 30%, or between 54 and 89 tons per year, assuming that the effective infiltration is 40%.

It is important to note that the total amount of sulphates in leachates from the coal-mining wastes should not exceed 80 tons per year. Eighty tons of sulphates are able to contaminate about 400000 m^3 of water above the acceptable for potable water standards (200 mg/dm^3).

The time theoretically necessary for leaching of 99% of sulphates originated in the wastes from considered wastes is over 7 years, at the assumed half-time of the decomposition of 400 days. If the sulphates production rate index was higher the amount of precipitation could be not high enough for removing them. In this case, the negative impact of the wastes on the natural environment will be observed for longer time than it could be expected from the kinetics of sulphides decomposition. In spite of that, the sulphates production rate index will decrease proportionally to the sulphides loss, but during a certain period of time the rate of sulphates leaching will be limited by the amount of precipitation.

The important fact is that even tens centimeter-thick layer of the wastes is able to contaminate the infiltrating and percolating water with sulphates to the same degree as a thick landfill (Twardowska et al., 1988).

The data presented above assume that all pollutants leached from the utilised wastes will reach groundwater. Taking into consideration geological and hydrogeological conditions of investigated area and different times of water percolation from the surface to the Triassic aquifer (from less than 2 years to over 25 years) this load of pollution will be additionally distributed in time. Moreover, assessment of the real risk to groundwater should take into consideration the capability of the water-bearing system to absorption of contaminants. This is related mainly to NH_4^+ ions, which absorption and decay are variable and depend on Eh conditions. In the case of conservative Cl^- and SO_4^{2-} ions this factor does not play an important role.

GROUNDWATER QUALITY

Groundwater pumped out from the Miedary intake is generally of good quality. Exceeding standards concentrations of measured pollution indicators are not observed and their concentrations are within the range of the hydrogeochemical background concentrations determined for the Triassic aquifer. Changes of concentrations of selected groundwater pollution indicators in the well No.4 in the Miedary intake are presented in Tab.1

These data suggest :

- general increase of Cl^- concentrations
- consequent increase of SO_4^{2-} concentrations
- lack of trends in NH_4^+ concentrations
- current significant increase of NO_3^- concentrations

Tab.1 Changes of concentrations of selected groundwater pollution indicators (well No.4 - Miedary intake)

Indicator [mg/dm^3]	Year		
	1995	**1996**	**1997**
Cl	8,0	10,0	10,0
SO_4	16,9	17,3	27,6
$N\text{-}NH_4$	0,047	0,007	0,015
$N\text{-}NO_3$	0,007	0,08	0,2

Increase of sulphates concentrations over 60% is alarming. This significantly increasing trend can result from the negative impact of aerial sources of pollution, which cause general regional increase in the concentrations of sulphates recorded in most of the observation sites of the regional groundwater quality monitoring network (Witkowski at al., 1996). Local sources of pollution also contribute to this trend. Constructed roads can be one of the additional local sources of pollution in this area. Unfortunately without field investigations assessment of their real impact on the groundwater quality is impossible.

CONCLUSIONS

- Location of these constructed roads in the described area poses apotential risk to groundwater. The roads are situated in areas of direct recharge of the major Triassic aquifers which have been recognised as zones requiring high and maxim protection (Witkowski et al., 1988).
- The Miedary groundwater intake is surrounded from three sides by 16 km of roads under construction and, therefore, is potentially the most endangered.
- Assessment of the degree of harm caused by coal-mining wastes should consider the potential risk due to soluble constituents from raw wastes as well as by soluble constituents originated during weathering of the wastes. Significant risk to groundwater is caused by soluble sulphates originated in the utilised wastes as a result of sulphides decomposition. About 316.15 tons of sulphates (16.15 tons from raw wastes and 300 tons originated during sulphides oxidation) can be washed out from 50000 tons of wastes provided for utilisation. Estimated average half-time of the decomposition of sulphides in the coal-mining wastes is about 400 days.
- Generally thin layers of the utilised wastes are similar to thick landfill in causing potential risk to groundwater. Recently observed increase of sulphates concentrations in groundwater pumped out from wells of the Miedary intake indirectly support that conclusion.

Assessment of the real impact of considered wastes needs more detailed investigations of the roads bedding and periodical monitoring of the groundwater quality in the vicinity of repaired roads.

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