A Zinc-Lead Ore Mine Water Contamination by a Paper Factory Fluid Waste

By Z. WILK,[1] A. F. ADAMCZYK,[1] J. MOTYKA[1] and S. WITCZAK[1]

Academy of Mining and Metallurgy, Institute of Hydrogeology and Engineering Geology, al.Mickiewicza 30, Krakow,Poland

ABSTRACT

A case study of migration of a paper factory fluid wastes, on the distance of 5 km from an underground disposal site to an ore mine is presented. The ore mine in question, situated in SW Poland is pumping 3.5 m^3/s (ca 300 000 m3/day) of groundwater, producing a cone of depression about 150 m deep and several kilometers wide. The migration of wastes (pollutant) occurs within the carbonate karstic aquifer of Triassic age. The aquifer is about 100m thick and is characterized by the coefficient of hydraulic conductivity equal to 8 m/day on the average.

The results of systematic measurements carried out for 13 years enabled to estimate the mean breakthrough curve of the pollutant. On this basis and taking into account the coefficient of hydraulic conductivity as well as the mean hydraulic gradient between the disposal site and the ore mine, the migration parameters of the polluting material, i.e. the real flow velocity, the effective porosity and the longitudinal dispersivity have been calculated.

As the measurements considered a long migration distance of the pollutant, the obtained hydrodynamic dispersion constant (dispersivity), in the authors opinion, is reliable enough to be applied for regional groundwater calculations, regardless of the "scale effect".

INTRODUCTION

The karst fissured Triassic aquifer in the Olkusz Mining District is one of the richest reservoirs of groundwater in Poland. In addition, there occur in the rocks of this region zinc and lead ores exploited for some hundred years. Intensive draining of the Triassic aquifer resulting from mining activities and concentrated on a small area has brought about the disturbance of natural water relations on a large scale. The depression cone formed around the mines and groundwater supply wells extends over a surface of some hundreds of square kilometers. The groundwater resources both in the Triassic aquifer and in others remaining in contact with it have become considerably impoverished.

The lowering of the water table in the Triassic rocks reversed the natural directions of groundwater flow and as a result caused the appearance of a number of disadvantageous phenomena. One of them was the disturbance of the layer of wastes on the surface of the territory or in higher situated sediments. The most dangerous proved to be the liquid wastes from a paper factory which after the lowering of the water table penetrated into the Triassic aquifer and contaminated the ground waters accumulated there. In that way a large quantity of pure waters flowing into the mine workings became unserviceable as a result of pollution by the paper factory wastes. In addition,the contaminated mine waters,discharged into surface waters, caused their degradation by impairing water quality.

An important step in getting information about the conditions of water circulation in karst-fissured formations is the determination of parameters governing the process of water exchange in this type of reservoirs. The complex structure of voids and passages in the aquifer affects the migrations rate and the hydrodynamic dispersion of the substances migrating with water (e.g.pollutants). In order to identify the migration parameters different kinds of tracer methods have been used. However, the parameters characterizing the dispersion, obtained from investigations of this type, vary depending on the length of the migration path (the so-called "scale effect" - [3]). For this reason results obtained in regional studies referring to long distances are particularly valuable. In professional literature such studies are rather rare on account of the fact that the migration time is measured in years. The authors of the present study discuss an example of the evaluation of migration parameters in a regional scale, obtained thanks to many years long observation of the migration of pollutants within a depression cone of a zinc and lead ore mine.

CHARACTERISTICS OF THE TRIASSIC AQUIFER

The karst-fissured Triassic aquifer forms a part of a widespread hydrogeological massif (Cracow-Silesian monocline) and it is characterized by the following mean values of the principal hydrogeological features: thickness 100 m, filtration coefficient $5.8*10^{-5}$ - $9.3*10^{-5}$ m/s (5 - 8 m/day), specific yield 0.035 and coefficient of storage in confined conditions $1*10^{-6}$ [4,7]. In the vertical profile of the Triassic aquifer there occur a few layers of different lithology.The prevailing rocks are dolomites and limestones with the dolomites dominating in the upper part of the profile, and limestones, marls, marly sandstones and marly dolomites in the lower part.

The network of groundwater flow in the Triassic aquifer is made up of a porous, fissured space and karst voids [5,8]. The voids making up the pore space show a relatively greatest resistance for the groundwater flow and thereby the lowest water permeability. Nevertheless, their relative volumetric proportion in the bulk of the rocks under consideration is the highest in relation to the other elements of the network of the groundwater flow. The amount of water which may drain out by gravitation from the porous space reaches some ten to twenty percent in the dolomites and a few percent in the limestones [9].

The network of the conducting fissures whose hydraulic resistance of flow is considerably lower than of the small channels of the porous space takes up in the bulk of the examined rocks in most cases a volume equal to tenth parts of a percent. Nevertheless, due to their more or less uniform distribution in the massif of the examined rocks the fissures play an important role in water flow in the Triassic rocks. Karst forms are observed in the entire profile of the dolomites and limestones making up the Triassic aquifer. The karst voids are of different size. Typical karst channels, formed as a result of the dissolution of the rock are usually rather small, i.e. the surface of their section transverse to the flow direction is of the order of tenth parts of a square meter. Larger karst passages have developed on the bedding planes with the mechanical destruction of the rock contributing to this process. Many of them occur within the breccias being separated from above by an equilibrium arch .The dominating type of filled karst forms are the breccias at different development stages.

GENERAL CHARACTERISTICS OF THE MIGRATION PROCESS

The workings of the zinc and lead ore mine under consideration, pumping about 2.3 m^3/s (200 000 m^3/day) of groundwater, became polluted with lignosulphonate compounds. These compounds as cellulose factory fluid wastes have been deposited for nearly 50 years in the Quaternary aquifer at a distance of about 4 km from the mine workings. The development of the depression cone of the mine resulted in the penetration of pollutants into the aquifer of the carbonate formations of the Middle and Lower Triassic age. It has been found that the penetration of pollutants occurs through an erosion window in the isolating cover of the argillaceous formations separating the two aquifers (Fig.1).

The possible danger of polluting the waters of the Triassic aquifer was realized already before openning-up of the mine and the accompanying intensive drainage of the rockmass, however, there did not exist then any effective and economically justified methods to prevent the pollutions. On the other hand, investigations were initiated the aim of which, among other things, was to follow the progress of the pollution of the mine waters [1,6] from the moment at which the first signs of pollution appeared until its relative stabilization. Thanks to this it was possible to describe a unique case of the migration of pollutants in a regional scale in a karst-fissured layer. This again, after adopting certain simplifying assumptions, enabled to identify the migration parameters of pollutants under such conditions.

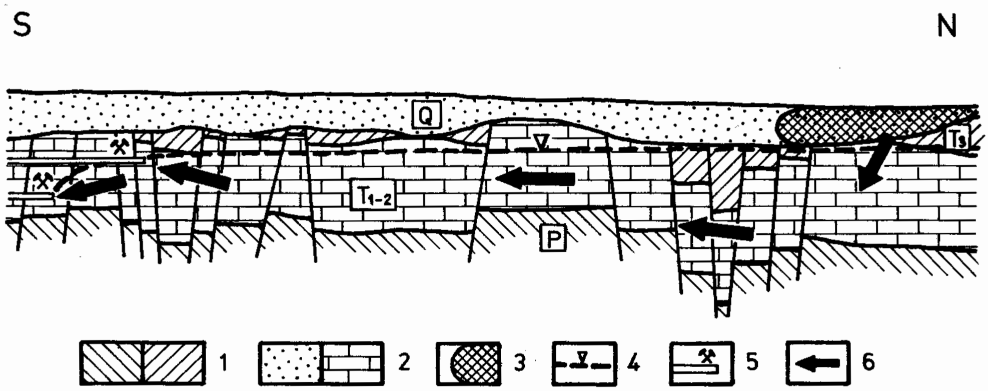

Fig.1.Scheme of a hydrogeological section illustrating the pollution process of the Triassic water.
1-non-permeable layers, 2-permeable layers, 3-pollution source, 4-water table in the Triassic, 5-galleries, 6-direction of pollutants flow, P - Permian, T_{1-2} - Lower and Middle Triassic, T_3 - Upper Triassic, Q - Quaternary.

CALCULATION ASSUMPTIONS

-The operation of a mine may be treated as that of a big well producing as a result of mining drainage a radial flow (Fig.2). This assumption has been confirmed both by the results of field observations and model investigations.

-The water movement towards the mine may be assumed as quasi-stationary. Such an assumption is possible since, as it follows from an analysis of development of a depression cone, in spite of continued fall of the water table since 1976 , similar gradients of water table at the particular sections have been observed along almost the whole path of the pollutants migration in the direction of the mine.

-The layer can be regarded as homogeneous with the mean filtration coefficient k = 8,0 m/day (on the basis of field investigations), average thickness m=100 m and the mean active porosity of the karst-fissured medium: n_o = 0,035.

-The injection of pollutants has a continuous character as the volume of the source of pollution will not decrease for more than a decade.

-The yield of the pollution source is stable. To adopt such an assumption under specific conditions is possible considering the free percolation of pollutants at constant difference of pressures as the water table of lower (Triassic) aquifer is well below the floor of the upper (Quaternary) layer.

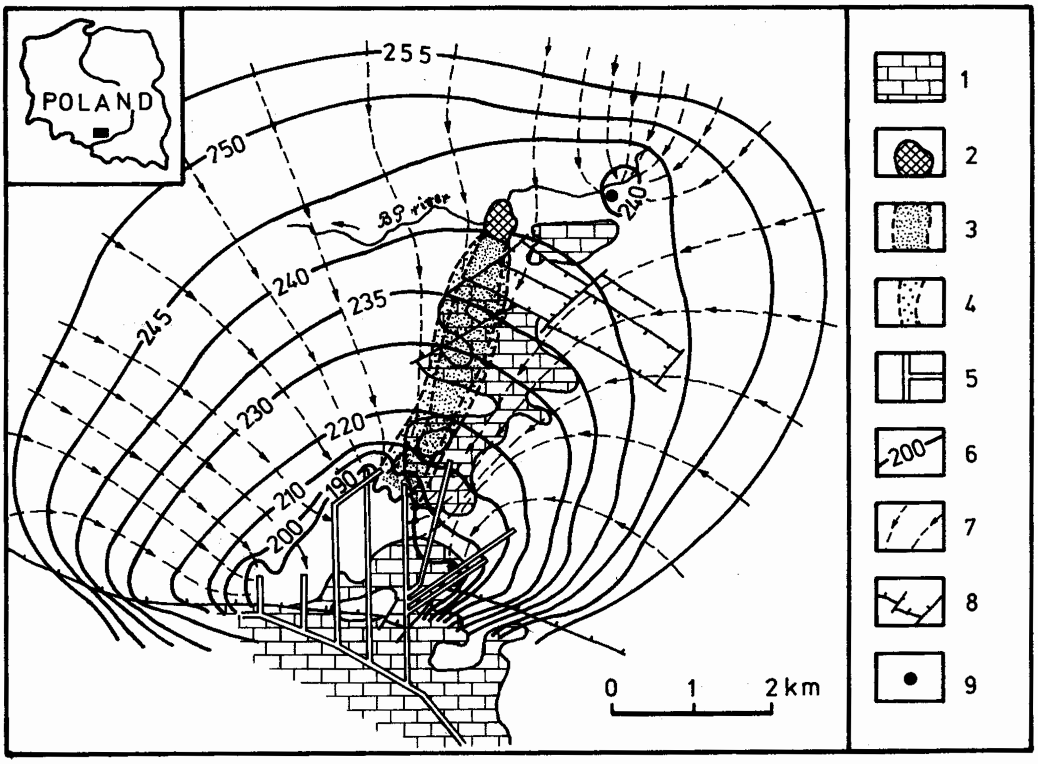

Fig.2. Migration of pollutants to the mine workings.
1 – outcrops of the karst-fissured Triassic formation below the Quaternary, 2 – pollution source, 3 – stream of strongly polluted waters, 4 – stream of moderately polluted waters, 5 – outline of mine workings, 6 – contours of water table, 7 – selected stream lines, 8 – major faults, 9 – wells.

–The pollutants do not become decomposed or absorbed in the aquifer.The lignosulphonate compounds are the stable fraction of the waste sulfite liquors appearing in the pollution source, and their decomposition is so slow that in the approximate calculations they may be regarded as retaining the qualities of a conservative tracer. The actual behavior of these compounds in the process of their migration to the mine is at present a subject of intensive research.

CALCULATIONS AND INTERPRETATION

In a radial flow such as in the case under consideration (Fig.2) the pollutants flowing from the injection area towards the mine are subjected to longitudinal and transverse dispersions enclosing a water stream of definite width. However, since we are interested only in the estimation of pollution of the mine waters, the transverse dispersion can be neglected in approximate calculations. Moreover, all the streams meet in the mine workings and the total of the pollutants carried by them down into the minewaters. Such an arrangement allows, according to Zuber [11], to reduce the radial flow to the process of unidimensional dispersion and to apply in calculations a simple model of dispersion described by a formula or to make use of its normalized form, that of a breakthrough curve.

The possibility of the application of a simple formula for a karst-fissured medium follows from the scale in which the migration of the pollutants is taking place: the migration path exceeds many times the dimensions of the inhomogeneity of the aquifer. The method described by Zuber (op.cit.) assumes a close observation of the changes in the concentration of the tracer (pollutant) in time and after an appropriate fitting of the nomogram has been obtained it enables to determine the migration parameters. In the nomograms normalized by Zuber (op.cit.) the relative concentration of the tracer: $\bar{C} = C/C_m$ and the relative breakthrough time: t_o/t have been taken into consideration, in which:

- $\bar{C}$ – relative concentration of the tracer,
- C – concentration of the tracer at the receiving point,
- C_m – maximum concentration of the tracer at the receiving point resulting from the mass balance of the injected and the received tracer,
- t_o – time of the tracer breakthrough in days,
- t – time in days measured from the beginning of injection.

In the case under consideration a modified version of this method has been applied. The progress of the mine mine waters pollution (the breakthrough curve) has been illustrated by demonstrating the changes in total load of pollutants. The graph of the normalized curve of load changes in real time scale (Fig.3) has been fitted in with the graph illustrating the changes in the pollutants load. This is methodically correct and it permits to demonstrate better the changes in the load of pollutants with time.

The application of Zuber's nomogram requires the mean travel time of water from the point of injection (source of pollution) to the measurement point (mine) to be assessed. This time has been determined on the basis of calculations made along the stream line of the current marking the probable path of pollutants flowing into the mine. Use has been also made of the mean parameters of the aquifer and the distribution of the hydrodynamic field in the region between the mine and the pollution source, obtained on the basis of earlier model investigations. This time is equal to 1805 days.

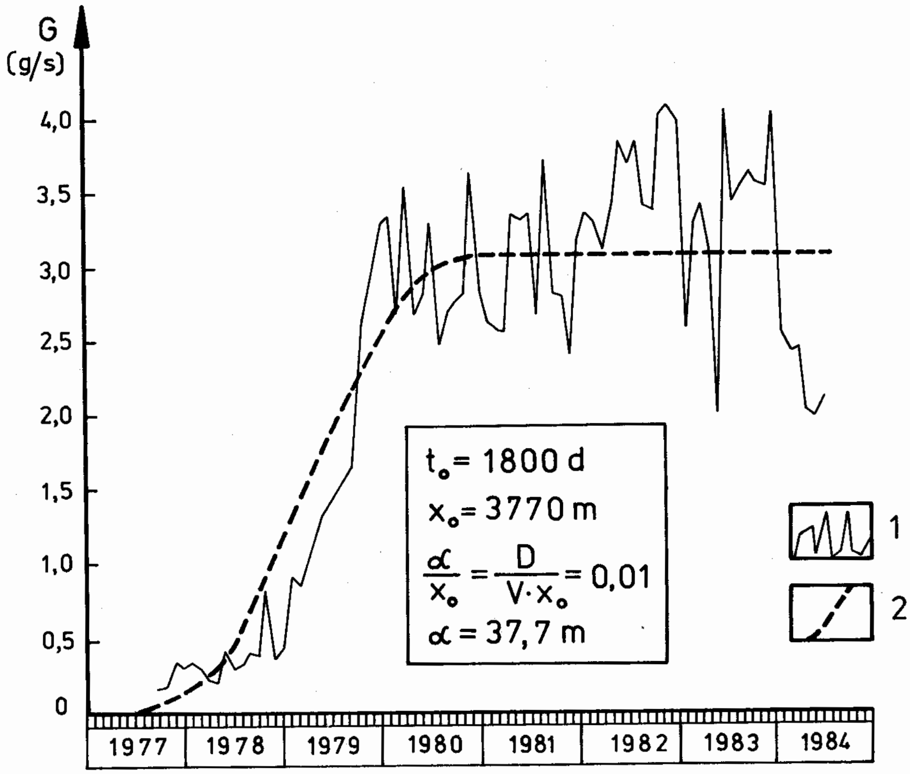

Fig.3.Changes in the pollutants load in the mine waters with the breakthrough curve indicated in real time scale.
1 - real curve, 2 - theoretical (normalized) curve.

The moment when the depression cone of the mine reached the pollution source, i.e.1.IV.1974, has been recognized as the beginning of injection. The mean load of pollutants received in the mine was determined by examining the concentration of pollutants in waters from the particular regions of the mine and by measuring the flow intensity of these waters.

After plotting the changes in the load time it has been found that the best fit of the experimental points with Zuber's breakthrough curve, represented in the scale of real time, has been obtained for a curve with the parameter:

$$\frac{D}{v^*x} = \frac{D_L}{v^*x} = 0.01$$

Since in the dispersion process the main part is played by the hydrodynamic dispersion then, neglecting the dispersion resulting from molecular diffusion , we may write:

$$\frac{D_L}{v*x} = \frac{\alpha_L}{x} = 0.01$$

The constant of the longitudinal dispersion (dispersivity) when the length of the filtration path along determined stream line, x= 3770 m, will thus be: α_L = 0.01*x = 3770*0,01 = 37,7m. It characterizes approximately the extent of the inhomogeneity of the medium (size of the block). The obtained result α_L=37.7m represents a value corresponding to the expectations for a karst-fissured medium. A constant of a similar order, α_L = 60 m, has been obtained by Bredehoeft and Pinder [2] for cavernous limestones.

References

1. Adamczyk, A.F. and S. Chawinski. Pollution of mine waters with lignosulphonate compounds in the Pomorzany mine (in Polish, English summary). Przegl. Geol. 7, pp. 348-353 (1980).
2. Bredehoeft J.D., Pinder G.F. Mass transport in flowing groundwater. Wat.Resour.Res.9/1 (1973).
3. Fried J. Groundwater pollution mathematical modeling improvement or stagnation? Studies in Environ.Sci. v.17,pp.807-822 (1981).
4. Motyka, J. and Z. Wilk. Variation of water permeability with depth of the pumping tests (Silesia-Cracow monocline) (in Polish, English summary). Kwart. Geol. v.20, no 2, pp. 381-399 (1976).
5. Motyka, J. and Z. Wilk. Hydraulic structure of karst-fissured Triassic rocks in the vicinity of Olkusz (Poland). Kras i Speleol. v.5(XIV), pp. 11-24.(1984).
6. Wilk Z., Adamczyk A.F., Chawinski S. The problem of pollution of the Pomorzany mine waters by the wastes of the paper industry in the light of new investigation. (in Polish). Mat.Sesji Nauk.: Rozwoj regionalnych badan hydrogeologicznych w Polsce. Wyd.AGH Krakow,pp.301-317.(1986).
7. Wilk, Z. and J. Motyka. Groundwater storativity of karst-fissured Triassic rocks in the eastern section of the Cracow-Silesian monocline (in Polish, English summary). Rocz. Pol.Tow.Geol. v.50, no 3/4, pp. 447-484.(1980).
8. Wilk, Z., J. Motyka and I. Jozefko. Investigations of some hydraulic properties of karst solution openings and fractures. Ann.Societ.Geol.Poloniae, v.54,no 1/2, pp.15-43.(1984).
9. Wilk, Z., J. Motyka, S. Borczak and Z. Makowski. Microhydraulic properties of the Muschelkalk and Rhoethian rocks of the southern section of the Cracow-Silesian Monocline (Poland). (in Polish, English summary). Ann.Societ.Geolog. Poloniae. v.55, no 3/4, pp. 485-508.(1985).
10. Wilk Z., Zimny W. Hydrogeological problems connected with the development of mining in the Olkusz region (in Polish). Zesz.Nauk.AGH,no 361,Geologia,z.17, Krakow.(1973).
11. Zuber A. Tracer dispersion at flow through porous media with respect to hydrogeological applications (in Polish). Zesz.Nauk. AGH,Seria:Mat.,Fiz.,Chem.,7.(1971).