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CHANGES IN THE GROUNDWATER DUE TO SURFACE MINING

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ABSTRACT

Open-cast mining operations conducted below groundwater table often affect the drawdown of the water table over large areas which as a consequence changes the natural regional hydrological balance. Remedial measures may include construction of new water intakes, and changes in the land usage may be necessary. Tipping of wastes (most often coal wastes and ashes) affects ground water pollution. Instead of removal of effects, preventive methods are recommended.

INTRODUCTION

In Poland as well as in many other countries surface mining continually gains the advantage over underground mining. This is because of safer working conditions, greater mechanisation possibilities and lower exploitation costs in surface mines. Surface mining, however, exerts an undesirable effect on the environment in general and ground-water in particular. The impact of surface mining on the groundwater should be considered in both quantitative and qualitative categories. Mining operations conducted below the groundwater table require a drawdown of the water table. This drawdown is effected both by the mine itself and by the draining systems. Such depression of the water table is not limited to the mine area; dependent on hydrogeological conditions it may extend for a number of kilometers outwards from the center of work. Therefore natural hydrogeological conditions are disturbed quantitatively without affecting the quality.

The mine dewatering in general affects the quality of the water discharged from the mines to the surface reservoirs. However this problem is not a subject of this paper.

A qualitative impact on groundwater occurs when open-pits are used for disposal of wastes, commonly the disposal of coal wastes and power-plants ashes in old open-pits.

QUANTITATIVE IMPACT

The horizontal and vertical development of the groundwater table drawdown, due to mining operation, is a function of many factors. The most important are :

- depth of the depression in the center of drainage
- geological structures of the entire region and their spatial disposition
- filtration coefficients and specific yield
- time

Therefore the geological and hydrological investigations for operations planning must not be limited only to the area assigned for the exploitation of deposits, but must consider also the adjacent areas. The basic elements of the investigation are the bore-holes, situated either in a rectangular pattern or in the form of radial lines starting at the centre of the exploited area (i.e. from the place where the greatest water table drawdown is anticipated). In the case of radial lines their number most often varies from 4 to 8. Concentration of bore holes should be greatest near the drainage center and least far from it (most frequently it varies from 0.5 to 3 km and depends on the distance from the centre). Length of these radial lines depends on the preliminary forecasted range of the depression cone developmenc which in the Polish mines is from 5 to 15 km, which is 50 to 100 times greater than the groundwater drawdown in the center of drainage. Such bore holes serve to determine geological structure of the region, thickness of the particular aquifers and links between them, and also to determine permeability of aquifers, situation of groundwater table and changes with time. Many of these bore holes are provided with filters and hermetically sealed to be used later as monitoring wells for periodic control of changes in the groundwater table during the mine exploitation. Results of the above mentioned investigation together with the results of other research should be specified in the Geological Report, and give the basis for mine design. Mine construction designs should include the forecast of mining impact on the groundwater in the adjacent areas and also the appropriate control methods. A forecast of the depression cone development with time has to be prepared in order to evaluate probable damages due to the groundwater table drawdown. Various methods can be used according to the geological structure of the considered aquifers and to the required degree of accuracy[1]. Recently in Poland the mathematical modelling method with computer simulation has been introduced. The model is based on the Boussinesque non-linear equation and includes three dimensional variation of anisotropy of permeability and precipitation infiltration[2]. Program consists of the "BELCHATOW" initial data base. The subprogram WODA, written in FORTRAN for the XFAM operating system, performs the conversion of the initial data entered in square pattern to a quasi-radial system. It is followed by the necessary averaging of filtration coefficients and of specific yield in particular sectors, performed by the WODA 1 sub-routine also written in FORTRAN. This sub-routine prints the results for each radial sector. The sub-routine WODA 2, then computes the range and shape of the depression cone and water inflow to the mine in each sector for the steady flow conditions. The sub-routine WODA 3 computes the filtration curves, for nonsteady flow, for the optional time step and automatically considers only those initial data in each sector which, for a given time step, are within the depression cone range.

At present this program is being tested in practice in the Belchatow mine, where the drainage systems pumps 350 m^3/min and the groundwater drawdown is about 100 m and is planned to reach 300 m in the next 8 years. The cone of depression has at present a radius of 8 km and is expected to reach 20 km.

The deep drawdown of the groundwater table changes the entire hydrological balance in the region. Investigations of hydrological balance (in the aeration zone) and the hydrogeological balance have indicated[3] that within the range of the depression cone (effected by mine draining operations) changes occur, i.e. the surface run-off decreases by about 30 per cent, groundwater evaporation by 100 per cent, evaporation from the land surface by about 15 per cent, while infiltration of precipitation increases by 70 per cent, and the underground run-off increases by about 100 per cent.

These phenomena affect two areas of human activity. First, and quite important but easy to solve, are the changes in commercial groundwater intakes. Second, and more difficult is the necessity for a change in crop structure, which should be very carefully investigated and different recommendations made for each type of soil.

The great economic and environment significance of these phenomena requires not only proper forecasting but also current control. For monitoring purposes a network of piezometers (consisting of exploratory holes provided with filters and the currently executed special wells, together with the network of existing commercial wells) should be built around the mines. Regular measurements of the groundwater table should be carried out in all those piezometers. The resulting data should be used to check the forecasts and to plan the subsequent removal damages. The problem of damage has been solved so far only by changes in crop structure and construction of new water supply systems [1]. These are only defensive methods and not therefore the best. More active methods based on the construction of sealing screens around mines, which on one hand would stop the inflow of water into the mine, and on the other hand would limit the external development of the depression cone around the mine, should be developed in future[4]. Methods of sealing with injection into the porous aquifer of hardening materials, or clay diaphragms placed in deep and narrow ditches, are used in construction operations. Such methods although technically possible are not used in surface mining due to high costs of their construction. The future however may change as the cost of water and prime farm lands rises.

QUALITATIVE IMPACT

As has been said already, the influence of surface mining on the water quality is indirect and is due mainly to the disposal of coal conversion and coal treatment wastes in old openpits. This problem has been neglected for a long time, but in the seventies intensive investigations commenced. The first large project on this subject was the project[4,5] realised in Poland by Poltegor and sponsored by US EPA. The aim of the project was :

- to determine qualitatively and quantitatively the impact of coal refuse and coal ashes disposal on the groundwater quality,
- to determine spatial and time interrelations of pollutants' propagation,
- to suggest some improved methods of storage,
- to elaborate the recommendations for tests, forecasts and control systems.

The project included field investigations on two test disposals, the laboratory analyses of water and wastes and model tests. For the realisation of this program two test waste disposals were built.

Disposal No. 1 - of volume 1500 m^3 was located at the bottom of a sand-pit, on a sand bed which had filtration coefficient about 50 m/day. The groundwater table was a few centimeters below the sand surface, i.e. just under the floor of the disposal. The stored material consisted of 70 per cent coal refuse and 30 per cent ashes coming from coal fired power plants. Within this disposal and its immediate vicinity 12 monitoring wells were constructed. During a period of 15 months, groundwater was sampled from these wells for chemical and physical analyses every 3 weeks. Measurements of the water table level were simultaneously carried out. These tests were then continued at 6 weeks and 3 months intervals. Each time a comparative sample of "pure" groundwater was taken before it entered the zone of disposal influence, at a point upstream of the groundwater. Simultaneously, in the nearby hydro-meteorological station, observations of local precipitation and temperature were carried out. This was very important as the disposal was being washed by the rain water, so leaching and carrying pollutants down to the aquifer.

Apart from these analyses the wastes were leached in laboratory filtration columns under optimum washing conditions, with the object of obtaining maximum possible concentrations of particular washable components.

All water samples were physico-chemically analysed for 17 designations, and every third series for 45 designations, together with heavy metals.

First small symptoms of pollution were found in the immediate subsoil of the disposal site after one month of storage. The largest amount of pollutants found downstream of the ground was about 7 months after storage, after a period of heavy rains.

The content of particular components rose in groundwater as follows (max. values) : sodium from 3.0 to 500 mg/l, chlorides from 10 to 400 mg/l, potassium from 2.0 to 40 mg/l, magnesium from 10 to 30 mg/l, sulphates from 100 to 900 mg/l, phosphates from 0.05 to 0.3 mg/l, boron from 0.2 to 2.0 mg/l, molybdinum from 0.005 to 1.0 mg/l, copper from 0.003 to 0.2 mg/l, strontium from 0.07 to 0.4 mg/l, cadmium from 0.002 to 0.005 mg/l, cyanides from 0.002 to 0.008 mg/l. No increase, however, was observed in the content of iron, manganese, aluminium and chromium. Increase in content of zinc, mercury and lead was doubtful.

In general during the 2½ years 11,500 kg of pollutants, i.e. 0.7 per cent of the disposal volume, and about 70 per cent of all its soluble substances were washed out from the 1500 m^3 disposal.

Most of the pollutants (90 per cent) were washed-out in the direction of the greatest downgrade of the groundwater table, and only 10 per cent in the directions of smaller gradients of water table.

Disposal No. 2 - an old open-pit of stowing sand (with disposal volume 1 million m^3) was used as a second test disposal. Coal wastes in the rates 20 - 40.000 m^3/month were stored there. Fourteen monitoring wells were constructed around the disposal at the distances of 100-1000 m to monitor hydrogeological conditions and water quality.

The monitoring of groundwater lasted 5 years; in the same period the wastes were leached in glass columns in the laboratory. The first signs of groundwater pollution were found about one year after the beginning of disposal but significant pollution occurred after two years. The maximum pollution was registered during the fourth and at the beginning of fifth year after disposal. The most significant pollutants were TDS, Cl, SO_4, N_{NH_4}, Fe, Al, Cr, Cu, Sr, Cd and B, and the pollution with Pb, Zn, Mo was possible but doubtful.

Model tests - investigations carried out on soil models and on analogous models showed that :

- within the limits of 2 per cent difference between the polluted water and pure water density no vertical migration of the polluted water was found below the disposal,
- the main migration took place in the zone close to the ground water table and in the zone of capillary rise; this tendency was greater the smaller the amount of pollutants,
- if the disposal has lower permeability than the surrounding aquifer, the stream of pollutants leaving the disposal has a tendency to get thinner,
- local depression of the aquifer floor increases thickness of the pollution stream, while local elevations cause the local thickness to reduce.

The tests on the EHDA model enabled reproduction of hydrodynamic networks and pollutant migration velocities quite accurately, but gave poorer results in predicting particular component concentrations.

In summary the research suggests the following recommendations[4,5]

(i) Classification of wastes from the point of view of their potential hazard created to the groundwater;

(ii) Laboratory tests of waste for preliminary evaluation of impact on groundwater;

(iii) Classification and evaluation of disposal sites in different hydrogeological conditions regarding their different hazard;

(iv) Planning and designing of disposal systems;

(v) Accurate design of monitoring systems and control measures.

CONCLUSIONS

1. Surface mining may often cause lowering of the groundwater table, and in consequence could form a widely developed depression cone. It can also change hydrological balance of the region and result in a need to change the crop structure and to build substitute water intakes.

2. Storage of coal refuse and ashes in open pits substantially affects the groundwater quality.

3. Prior to planning of mines and disposals investigations and prognoses should predict the scope of possible changes in groundwater.

4. More effective methods of protecting groundwater from the effects of mining and waste disposal should be introduced instead of trying to solve existing problems in this field.

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