RELATIONSHIP BETWEEN RENEWABLE ENERGY FROM LOW ENTHALPY MINE WATERS STORED IN POLISH HARD COAL MINES AND WATER HAZARDS IN ACTIVE COAL MINES

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ABSTRACT

Extensive water reservoirs with capacities of tens of millions of cubic meters were formed in mine workings when almost half of the hard coal mines in Poland were abandoned. Because of the quantity and temperature of the water, these reservoirs could potentially be used to provide sustainable energy. Simultaneously, they are a potential hazard for future coal exploitation in their vicinity. The effects that this will have on water management and concerns with respect to enhanced likelihood of water inrushes in active mines are discussed, including the likely effects of pumping the water back into the reservoir once the energy has been extracted. Detailed water hazard recognition will be necessary both for planned exploitation and for geothermal investments.

1. INTRODUCTION

Mines in two of three Poland's coal basins have been abandoned (fig.1), primarily due to economic reasons, such as resource exhaustion, but sometimes for political reasons. All of the mines in the Lower Silesian coal basin, in southwestern Poland, have been abandoned, and are now in the final stage of flooding.

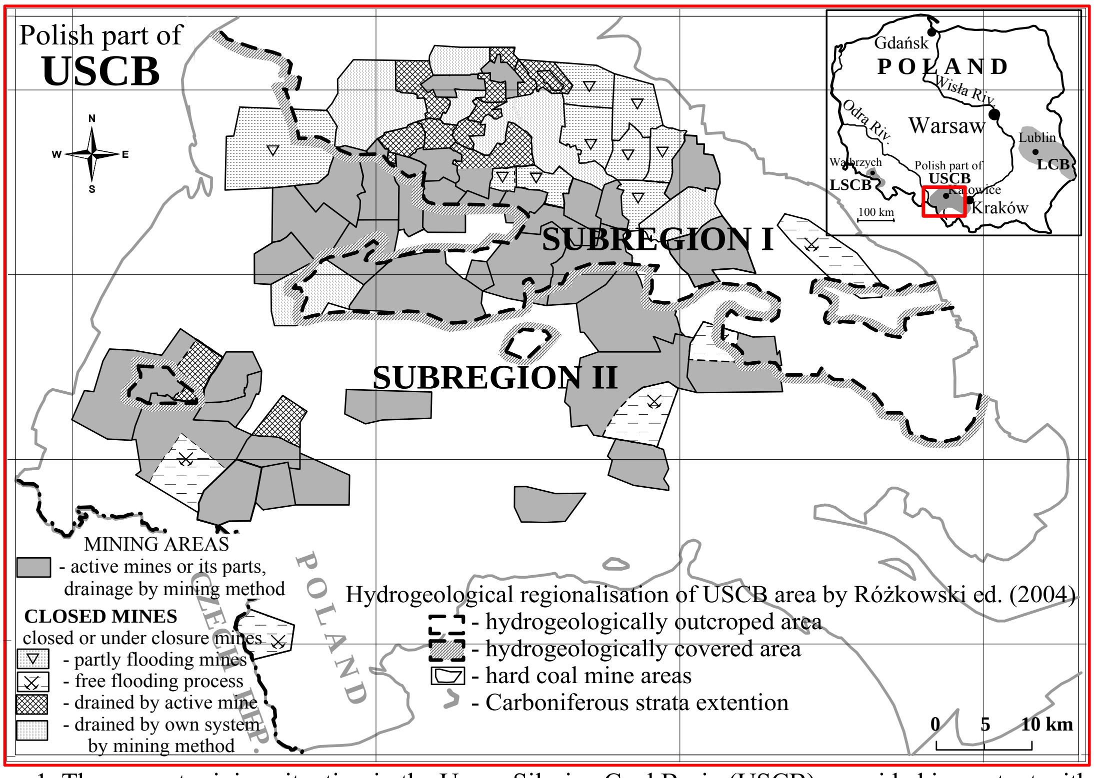

Figure1. The current mining situation in the Upper Silesian Coal Basin (USCB), provided in context with the hydrogeological sub-regions and the sketch of coal basins in Poland.

In the Upper Silesian Coal Basin (USCB), many mines are in various stages of abandonment while others are still being exploited. The USCB mine waters range in temperature from relatively cold to more than 30°C in active mines (lower temperature then 26ºC is in abandoned mines - Karwasiecka et al. 2005), and in quality, from potable waters to brines (Augustyniak 2008, Różkowski ed., 2004,). Thus, mine water could provide local communities with geothermal energy, but it is appropriate to ask whether the associated water circulation might be dangerous for active mines or adversely affect the quality of surface water. The issue is timely. During the next 20 years, Poland is obligated to reduce energy consumption and greenhouse gas emissions by 20%, and to obtain 20% of its energy from renewable sources. At the same time, the demand for energy in Poland continues to increase while the technological structure of obtaining energy in Poland is and, at least for the next several tens of years, will be closely connected with mineral fuels, such as coal. Especially in the USCB, there are potential conflicts between opposing objectives, such as exploitation and rock mass drainage at active mines and the need to decrease their dewatering costs for example by water storage and its rebound.

2. MINE WATERS IN THE USCB AS A SOURCE OF ENERGY

Initially, interest in the USCB mine waters was concerned with aspects of water pumping, predicting changes in water quality and quantity, and the possibility of using the water; research on this topic in southern Poland from the 1970s and 1980's has been summarized by Różkowski (2008). Although researchers at the Central Mining Institute (Kotyrba and Michalak 1987) suggested the potential use of mine water for geothermal purposes, the thermal energy of mine waters was not generally considered an important aspect of its management. Only in the 1990s, after other countries demonstrated that the potential value of this thermal energy was significant, was research initiated on this topic in Poland (Kubski 1996; Karwasiecka 1996; Małolepszy 1998, 1999). Until the turn of the century, interest focused mine water pumped during mine dewatering. Thus, mine abandonment and flooding were already underway before potential use of water in the underground reservoirs became a research topic, despite the fact that researchers in other countries had suggested this possibility (Małolepszy 1999). Vast water reservoirs were being formed (Karwasiecka et al. 2003; Małolepszy 1999, 2003). Various hydrogeological prognoses were developed using diverse computational methodology, assuming straight reservoir capacity values and their recalculation to the energetic capacity of water (Solik-Heliasz 2007). The lack of homogeneous methodology and the assumption of homogenous levels of temperature decrease (ignoring the effect of the energy extraction) meant that these early calculations were more of an illusion than a realistic analysis of the potential energy of the mine water.

Properly calculating potential energy recovery from mine waters in the USCB is greatly complicated by ongoing exploitation in nearby active mines. The required dewatering greatly affects both the quantity of water available and its hydrogeochemistry. Potential investors must consider how the aquifer is being recharged, including such factors as the changeability of the hydrochemical conditions and the recharge origins of the deposit formations in the USCB (fig. 1).

Różkowski (2001) demarcated the undermined areas in the USCB, based on the extent that they had been hydrogeologically outcropped (Figure 1). Sub-region I is an area of intense water exchange, with high recharge values and lower mineralization than sub-region II, and lower temperature water flowing to the mine workings. The situation is improved by some thermal anomalies occurring in the northern part of the USCB (Karwasiecka 2001; Małolepszy 1999). A slightly different situation occurs in the hydrogeologically covered area (sub-region II), with reduced recharge, relatively low water inflow values, and high mineralization. These mine waters are characterized by generally higher temperatures, which are associated with the greater depths of exploitation, thermal insulation provided by thick rock series, and rock mass properties that indicate low water retention in rocks of deposit series (Rogoż 2004; Różkowski 2004; Wilk 2003). However, high water retention can occur in higher strength rocks (Bukowska ed. 2009), along with higher than expected stability of free voids created during exploitation (Bukowski 2002, 2009; Haładus et al. 2005).

The higher temperatures of water within the hydrogeologically covered area have generated greater interest from the geothermal energy perspective, but, because of the depth of these mines, the salinity of the water, the rate of recharge, and the location of these waters with regard to potential recipients, conditions within this part of the USCB are less advantageous than in mines situated in the hydrogeologically outcropped part of the USCB.

Almost every abandoned mine has the capacity to contain several dozen millions of cubic meters of water. At the current level of flooding, these capacities range from several to tens of millions of cubic meters of water on the average. Slightly less than 50% of this water could easily be extracted in sub-region I during dewatering; the values in sub-region II may exceed this percentage.

Currently, nine abandoned and partially flooded mines are being dewatered with deep pumping stations (at sites indicated by the triangles in fig. 1), to protect active mining operations against the water hazards from the very large water reservoirs. The water from these pumping stations is simply discharged into surface watercourses, without any energy recovery. Some of the mine reservoirs that are being dewatered are adjoining mines with large resources. These fields are usually accessible and would be relatively easy and cheap to exploit. As the energetic structure of European countries, including Poland, changes, independently of trends and fluctuations, these reservoirs and mine waters will become more important as a medium of 'clean' energy. Thus, it is likely that in the future, priorities may be reversed. Then, when mine waters and the energy accumulated in them becomes the subject of management, it can be assumed that extraction of coal from the active mines may be viewed as a potential source of water hazard to the proper functioning of the 'geothermal reservoirs,' and even their existence. The scale of water hazard will only be different considering its predicted results.

3. INTERRELATION OF WATER HAZARDS FOR MINE WORKINGS OF AN ACTIVE MINE AND WATER ENERGY RESOURCES IN AN ABANDONED MINE RESERVOIR

Accessibility of water being stored in mine workings of abandoned mines varies, depending on the presence and maintenance of mine shafts in post-mining areas currently being converted into pumping stations. According to previous practice and geological and mining law in Poland, most entry points to mine workings had to be sealed. Monitoring of the flooding process through shafts and a few boreholes has been sporadic. Pumping security in abandoned mines is point, passive - security. Thus, if an active mine accidentally started draining water (or water inrush) from one of these abandoned mines, these pumping stations may not provide much protection. A so called active security for active mines is in this case their own dewatering system and retention of mine workings as well as reduction of water inflow to their own mine workings situated on higher mining levels. However, the effects of such an event are hard to predict (fig. 2). The occurrence of water hazard may take place due either to instability of the rock mass in the area separating a part of deposit being exploited from the abandoned mine or excessive water rebound in the abandoned mine reservoir.

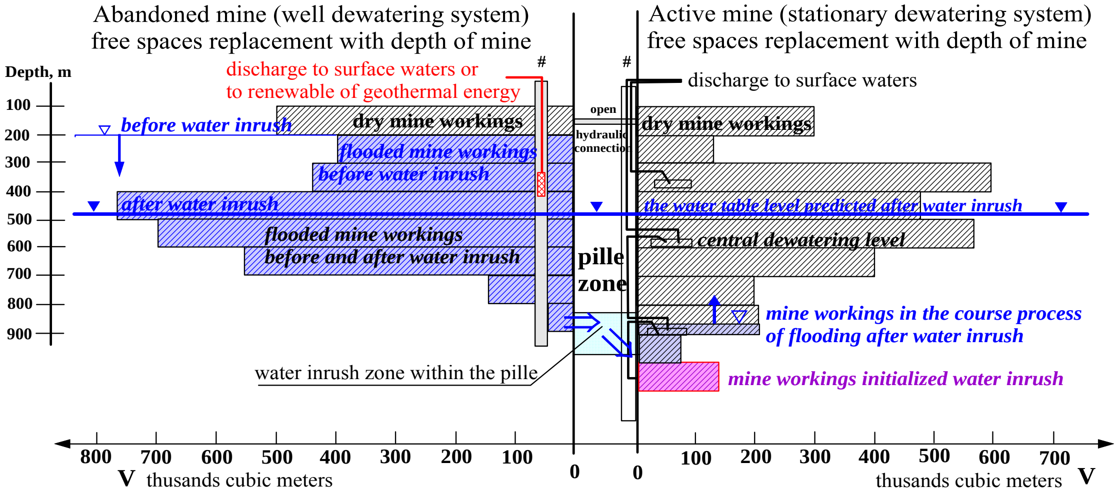

Figure 2. Possible results of inrush for deep mine works from the very large abandoned mine water reservoirs (⇒ - location of hypothetic inrush).

The occurrence of such an inrush will cause activities that will tend to reduce water inflow in the active mine. The final result will depend on the intensity of the inrush relative to the defensive capacities of the dewatering system. In extreme cases, water will flow to the lowest situated mine workings and then flood until water pressure equalization occurs in both mines or until water begins to flow into another mine. If the active mine is unable to reverse the effect of the inrush, it may be able to limit the extent of flooding through dewatering, and thereby continue to mine down to the level of the nearest connection with the next mine being dewatered or to where the water table equalizes.

In the abandoned mine the change of factors determining water balance of the reservoir will occur. In the best case, when the water recharge of the reservoir is greater than the uncontrolled outflow to the active mine its pumping station will be able to continue without changes to the water table, though its efficiency would be decreased by the outflow. However, when the reservoir recharge value is exceeded by the outflow, a progressive impoverishment of reservoir resources and lowering the water table until outflow and inflow values are equalized will take place. This will continue until the water table in the reservoir reaches the level of the lowest hydraulic connection with the endangered active mine.

Presumably, such events will be short-lived, assuming that the dewatering systems of the active mine are adequately designed to protect the mine workings from such an event, but the long term effect of the increased pumping costs on the mine's finances must be considered. In case of total loss of active mine ability to protection a diametrical change of water flows directions and lack of possibility of mine dewatering a flooding of its mine workings to the level of the nearest connection with the next mine being dewatered or to water table equalization should be taken into consideration.

Examples of water table maintenance in deep abandoned mine reservoirs are now occurring in the USCB. The reduced exploitation in adjacent areas of active mines was the result of mine works concentration. In one example from the central part of the USCB, part of a coal deposit belonging to mine "S" is located near an abandoned and flooded mine (mine "K") up to the ordinate of -200 m (fig. 3). The border part of the mine "S" deposit is located on the ordinate of about -500 m. About 10 million Mg of good quality coal is imprisoned in two seams with a total thickness of about 17 m in the border area with mine "K" (Bukowski 2009). Mine "S" plans to exploit at least part of this deposit, to the extent that it is recognized and accessible. Concerns are caused by the more than 7 millions m^3 of water that resides in mine "K" (fig. 3).

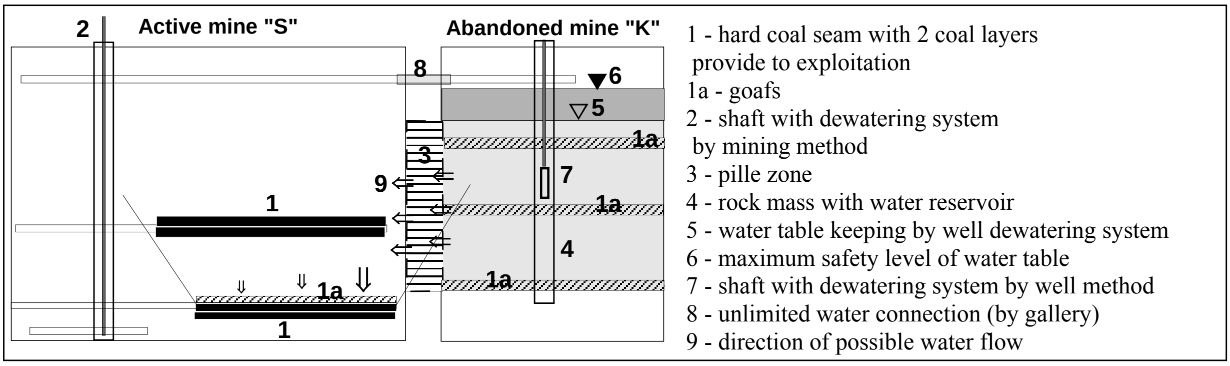

Figure 3. Situational scheme of the area of “S” and “K” mines

Within the area of the mine “K” reservoir, there is a pumping station that protects mine “S” and maintains the water level at a depth that prevents water from flowing to the active mine workings through hydraulic connections. Pumping preserves the water table at the -200 m ordinate. About 6.0 m^3/min of water with a temperature of 20ºC and about 6 g/m^3 of mineralization are received from the mine “K” workings, which is a good forecast for the energetic potential of these waters. On the basis of this data, experimental heat recovery from such pumped waters has been considered for investments by one of the Silesian mines. The “K” mine reservoir was treated as a bunker of an energy medium and an energy generator.

This example of energy potentially being generated from a Polish mine reservoir causing a potential water hazard in a neighbouring mine has already been described (Bukowski et al. 2007; Karwasiecka et al. 2004). Mining in the vicinity of mine “K” was not considered although the water reservoir was considered for geothermal investment. Also the results of investment decisions in case of an uncontrolled water outflow from the reservoir were not considered.

In order to define safety conditions for an active mine and reservoir resources, safety zones (Bukowski 2009) were established using a graphical method based on the reach dispersion of main influences (deformations) from the exploitation in following layers in the seam planned for exploitation (according to Kowalski 1985) and the width of the safety pillar (fig. 4). Using this method, it was determined that the planned exploitation in mine “S” should not cause violent water inrushes.

4. PREDICTING AND PLANNING OF RESEARCH FOR ENERGY-RELATED INVESTMENTS IN COAL MINES IN THE USCB

Because the aspirations of active mines are to lower the water table in a reservoir while energy investors seek the most cost-effective means of energy recovery, which includes increased pumping, investors need a reliable information about possible difficulties. Only in-depth mining and hydrogeological analysis as well as detailed research of the reservoir capacity may enable a correct assessment for target projects for both coal exploitation and water-energy projects. In addition, geothermal investment typically will require the neutralization of polluted mine water before the mine water is discharged; Water pumping back into the mine workings of another abandoned mine is also considered. It is particularly important to make the potential investors aware that reverse water pumping to an abandoned mine is possible when the reservoir in such mine is not hazardous what requires balancing both the level of the water and the thermal balance within the reservoir.

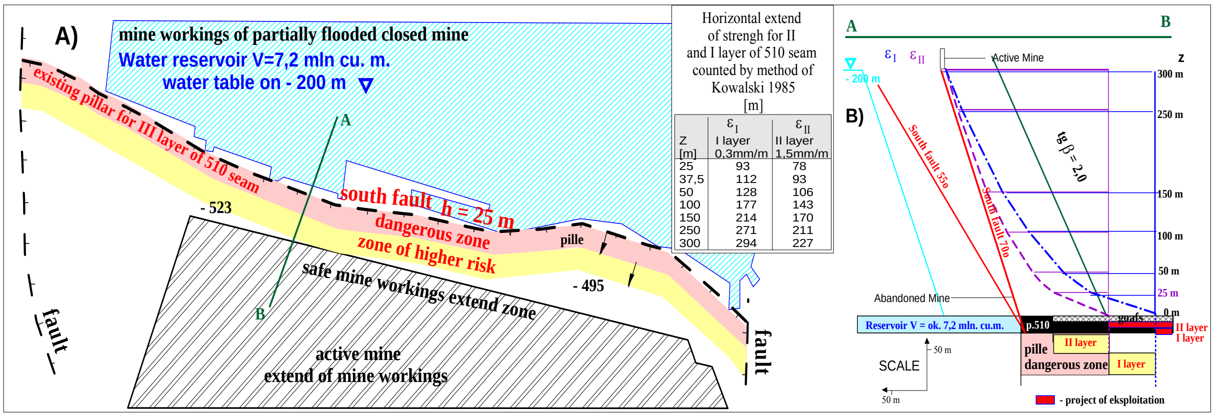

Figure 4. The indication of safety zones from a potential water hazard on mining maps based on the calculated critical dimension of safety pillar A) and after the designed front of exploitation moving away from the reservoir (fold) B)

Pumping water into an abandoned mine is not safe and effective when doing so would endanger an active mine. However, it is technically possible to pump water cooled during the energy recovery process into mine workings of the same reservoir, to be reheated, though this would not reduce the quantity of polluted mine water being discharged. Water pumped back during exploitation of an intake will be considered additional inflow of water to the reservoir. As water table maintenance on constant level is the aim of deep waters pumping, water additionally entered to the reservoir must be received by deep pumping station together with natural inflow. In determining the water balance, this water will be a quantity that has to be summed with the natural inflow of the reservoir. Unless pumping is increased, this will accelerate water table rebound in the abandoned mine and increase water hazards for any nearby active mines. Thus, water pumping into mine workings that border an active mine in the USCB will only take place where natural inflows have begun to decrease, where the effect of such a decrease may adversely affect geothermal investments.

5. SUMMARY AND CONCLUSIONS

Given the current mining situation in Poland and the need to enhance renewable energy production, Polish mines vary with respect to their potential for energy recovery. This diversity results from the geological structure and hydrogeological conditions within the Polish part of the USCB, the rock mass temperature and the temperature of the water that flows to the mines, the conditions and means by which the mines are dewatered, their location with respect to surface infrastructure, etc. One of the criteria for geothermal investments is the possibility of water hazard occurrence and its neutralization that until recently has not been adequately considered is the hydrologic interaction between abandoned and active mines, including the possibility of potentially hazardous water inrushes in active operations. The minimum basic requirements for such a use of mine water in deep abandoned mine reservoirs in the USCB should be: a detailed and homogenous (comparable) capacitive analysis and understanding of the reservoir, full consideration of whether water hazards might occur, and a full assessment of how to prevent such a hazard.

The location of the wells and whether water is returned underground after energy recovery will determine the extent of thermal changes within a geothermal reservoir. Other factors that must be considered include the connectivity between mines, the permeability of the void space (whether underground openings have collapsed), and the permeability of the surrounding rock mass, based on modeling conducted in closed reservoir (Małolepszy 2003; Renz et al. 2009). It should be emphasized that constraints imposed by ongoing exploitation in any mine connected to or adjoining the abandoned mine reservoirs will limit the full usage of numerical implements in the assessment of mine waters usage for energy purposes.

In the author's opinion, future conditions of exploitation as well as the scale of water hazards will force attitudes on the water hazard issue, indication of conditions of safety in mines, the manners of dewatering as well as on management of water flows and discharges to become more conservative, to ensure safety in the mines. This will affect how mines are dewatered and how and where the pumped water is directed.

The water hazard of potentially intense, long-term water flow from a reservoir that could contain millions of m^3 of water could be disastrous to an active operation. However, such an event could also diminish the water resources in the reservoir resources of the abandoned mine. As the energy resource, for which the water is a carrier, declines, the installation used for energy recovery will lose its basis for existence.

Models of water and heat flows within the reservoir are not enough to ensure rational management of coal resources, water, and energy as well as the environmental effects that mine water discharges have on the surface environment. Investment safety for the construction of energy recovery from mine water installations in the USCB will require thorough hydrogeological and geomechanical analysis to assess potential changes in hydrodynamic conditions, especially where active and partly flooded mines co-exist.

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