Natural processes caused by soil resaturation in the Patnow open-pit cone of depression

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Abstract. Patnow Open-Pit is one of the largest brown-coal post-mining workings in Poland. Natural flooding processes started in March 2001. Groundwater discharge to the open-pit is aided by water taken from a dewatering system based on a barrier of wells. This article presents the first stage of research and includes hydrogeological conditions in Pątnow area, piezometric water level data and chemical analysis of groundwater inflows and water supplied to the Patnow workings. It also describes some geotechnical problems connected with open-pit flooding.

Introduction

The process of exhausting brown coal resources in opencast mines forces the liquidation of mine industrial plant and the abandoning of open-pits. This abandoning process will take place in some large open-pits in Poland in the near future. The liquidation of mine industrial infrastructure and equipment is a short process and in addition it is more expensive.

In most cases the excavation of brown coal in Poland is located in areas where the natural groundwater level is close to terrain surface. The dewatering of orogen allowing excavation of beds is typical at polish mines and has often run for many tens of years. The water recharge is large in the majority of open-pit mines – up to a few cubic meters per one tone of lignite. The open-pit dewatering process results in a cone of depression extending a few kilometres.

Taking into account the hyrogeological conditions in polish brown coal mines, the open-pits are supposed to be reclaimed by their flooding by water. The liquidation of mine's dewatering system will result in mine flooding by water inflow from aquifers. The experiences from other countries show that the restoration process is extremely complicated.

Recovery water level rate in open-pits can have an influence on the chemistry of water in the artificial lake. The chemical composition of lake's water will determine the direction of reclamation processes especially in the restoration of water biology.

The recovery of piezometric water level within the cone of depression could bring the intensification of geotechnical phenomena in open-pit slopes (Dmitruk et al. 1998, Hajdo et al. 2000.). This process could result in tunneling, landslides and finally could change the boundary of artificial lake.

Patnow open-pit is one of the oldest in Konin region. The open-pit excavation started in 1957. The average output of Patnow reached 2.9 million ton per year and 17 million m^3 of overburden per year. Average depth of the open-pit reached 59 meter below the terrain surface. The last part of Patnow's bed was excavated until mid-2001, but the flooding process started in March/April 2001. The slopes of working were profiled with a gradient from 1:7 to 1:12. (University of Mining and Metallurgy supported research; project no. 11.11.100.270).

Geological and hydrogeological conditions

Patnow brown coal beds are located in Łódzka basin, Polish Lowland. Its geological profile consist of:

- Cretaceous sandy-clay marls, upper Jurassic calcareous sandstones,
- Tertiary sands under coal seat, brown coal bed and Pliocene clays,
- Quaternary sands, gravels and boulder clays

The geological conditions determine the following aquifers in the vicinity of Patnow open-pit:

- Cretaceous aquifer,
- Miocene aquifer,
- Quaternary aquifer.

Cretaceous and Miocene aquifers are continuous and regular. They both form the common Tertiary-Cretaceous aquifer with good hydraulic connections. Quaternary aquifer is generally non-continuous. In this aquifer water occurs locally in non-continuous aquifers formed in sandy lens located within boulder clays and shallow sands.

In the nearest neighbourhood of open-pit are located:

- in the South – Goslawskie Lake, Patnowskie Lake
- in the East – Wasowskie Lake, Mikorzynskie Lake, Slesinskie Lake.

In the natural conditions, lakes drained all aquifers trough the Quaternary erosion channel. As the dewatering process occurred, the direction of underground water flow was altered – with inflow to open-pit coming from the lakes (Figure 1).

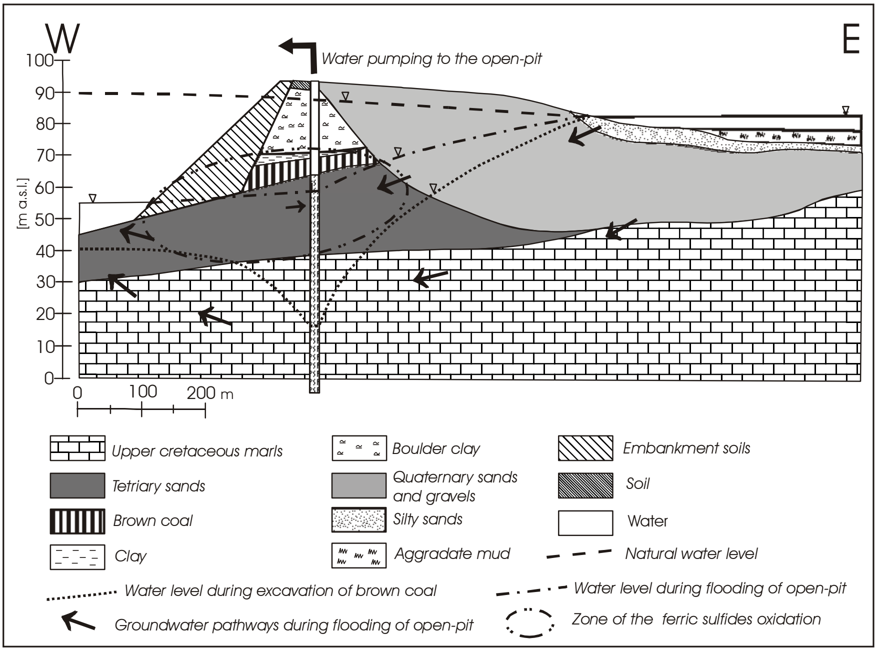

Fig. 1. Hydrogeological scheme in the East part of Patnow open-pit

Open-pit dewatering system

Patnow open-pit dewatering system consisted of:

- Dewatering galleries with shaft and dug wells; they have been closed by working face,
- Pumping plant located on the bottom of working,
- Barrier of 35 wells that was constructed to lower groundwater level during excavation in neighbourhood of safety pillar at the Mikorzynskie Lake.

The discharge from the dewatering system for the period 1986 - 1999 is presented in Figure 2.

Landslides

As the excavation of the beds located near to the safety pillar had been stopped and the slope had been profiled with overburden, the well barrier activity was finished and the recovery of water level was initiated. Only the pump station continued it's dewatering operation for the open-pit. The total recovery of water level reached 15 m at the well barrier line. The first local landslide processes occurred about one year after the dewatering in wells had been stopped.

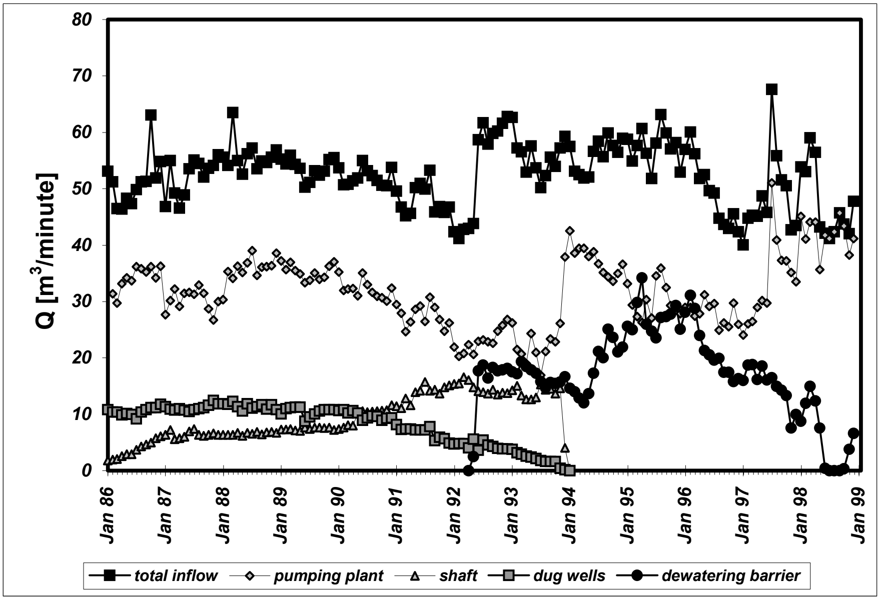

Fig. 2. Total and partial inflow to the dewatering system of Patnow open-pit.

The local landslides and tunneling have followed the increase of water pressure in Quaternary aquifer and the occurrence of water thrust for dumping ground of low permeability (boulder clays) in the northern part of open-pit. The yield of water leakage from exhibited aquifer reached ca. 1 m^3/minute at the beginning. After some time it stabilized at the level from a few to over ten L/minute. The area of slope damage reached ca. 6 ha.

The damage to slope not profiled by overburden has followed the increase of water level. This slope was steep and located in Tertiary sands. The tunneling from scarp of open-pit has occurred there. The total outflow of water from the aquifer reached ca. 2.5 m^3/minute and the area of surface damage reached ca. 7 ha. The ground floating with outflow was stopped after the construction of an embankment with overflow spillway.

Open-pit flooding

At the beginning of April 2001 natural flooding process commenced. The increase of ground water level is monitored. Selected wells of the barrier restarted pumping in June 2001. Water is now pumped directly to a reservoir which helps to decrease the hydraulic gradient in the area of slope. Furthermore it helps to decrease the amount of water flowing through the resaturated zone. This is important due to the fact that water flowing through the resaturated zone leaches weathering minerals and this process could worsen water quality in reservoir. So, the reservoir is supplied with unpolluted water.

Figure 3 presents the increase of water volume in Patnow reservoir. It has been changing linearly so far. It confirms the fixed groundwater inflow to the open-pit of 27,5 m^3/min. If inflow from well barrier is 12 m^3/min, then the groundwater inflow through the bottom reaches ca.15.5 m^3/min.

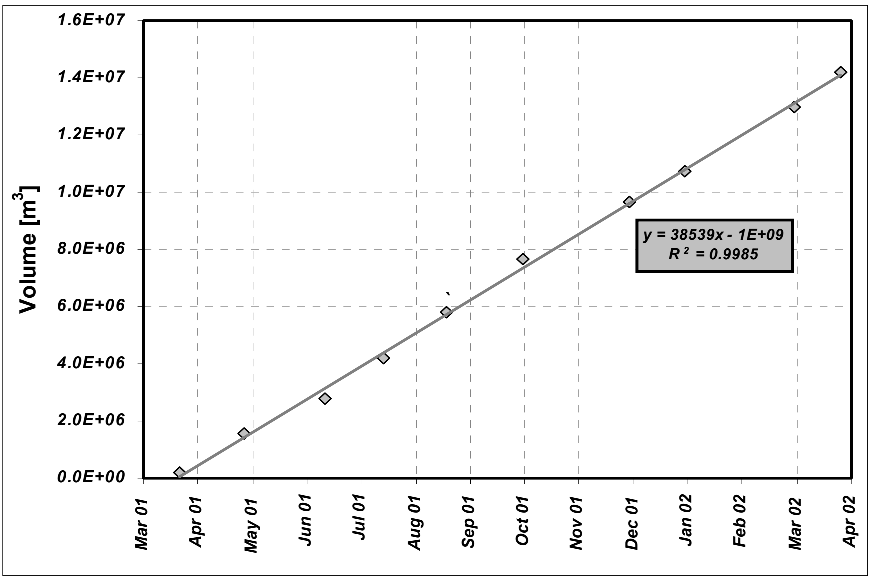

Fig. 3. The total volume of water changes in Patnow reservoir

Water quality

The water level drawdown induced by the dewatering of open-pit leads to the artificial expansion of unsaturated zone. The availability of oxygen from air initiates the weathering process of less-stable minerals. The oxidation of ferric sulphides (pyrite and marcasite-FeS_2) process is one of the most dangerous processes to the environment. The oxygen and water initiate the decomposition of mentioned minerals and it results in a change of sulphur redox form from S(-II) to S(+VI). Sulphate ions and hydrogen cations are formed. The process of ferric sulphide oxidation consists of a few connected chemical reactions. (Singer, Stumm 1970). The summary stoichiometric reaction is shown below.

$3FeS_2 + 8O_2 + 8H_2O \longrightarrow 3Fe^{2+} + 6SO_4^{2-} + 16H^+$

The process of pyrite oxidation and the process of environment acidification are connected closely. They are both associated with the excavation of sulphide metallic ores and hard and brown coal. Ferric sulphides are located within coal and metal deposits because they were formed under reducing conditions, which support pyrite and marcasite formation. There are many key studies showing how the process of ferric sulphide oxidation determines the chemical composition of groundwater within post-mining areas. (Fernandez-Rubio 1986, Smith et al. 1994; King et al. 1995; Kropka 1995, Rogoż 1996, Banks et al. 1997, Deutsch 1999, Motyka et al. 1999, Adamczyk A.F. et al. 2000, Iribar et al. 2000, Razowska 2000, Czop et al. 2001, Hidalgo 2001, Marszałek and Wąsik 2001, Steven et al. 2001). It is well known, the oxidation of pyrite from hard coal and waste rock causes pollution and has a negative influence on surface water and groundwater and causes environment aciditation (Anderson and Youngstrom 1976, Davis and Boegly 1981, Yu 1996, Foos 1997, Schüring et al. 1997, Geldenhuis and Bell 1998, Deutsch 1999, Szczepańska and Twardowska 1999, Brake et al. 2001, ab Kim et al. 2002).

In the area surrounding Patnow open-pit the conditions supporting ferric sulphide oxidation processes have been created. It is because the coal deposit consists of total sulphur in 1,5 - 1,8% and it is connected with the presence of ferric sulphide (Osika et al. 1970). In addition there is the significant amount of organic matter within Miocene sands under the bottom of brown coal deposit. There is ferric sulphide in organic matter as well. There are pyrite weathering processes occurring within all open-pit cone of depressions in Konin region.

As the brown coal deposit was exhausted the open-pit was abandoned and flooding process started. The open-pit is recharged with water coming from an easterly direction. Water from Quaternary aquifer flows to the Miocene sands and inflows into the open-pit. The well barrier takes over the role of discharge and it is directed into the reservoir. The water has low electrolytic conductivity on average ca. 505 μS/cm. In the water there are: calcium – 82 mg/L, magnesium – ca. 18 mg/L and small amounts of sulphide ions, on average 40,7 mg/L.

The resaturation of the zone where the sulphide mineral oxidation processes took place has followed the groundwater recovery. The groundwater stream dissolves the products of sulphide mineral decomposition. It results in the increase of calcium, magnesium and sulphates concentration and the decrease of pH value. In long term above mentioned process could result in the aciditation of reservoir water and in the worsening of its quality due to the concentration of sulphides, magnesium, iron, aluminium and microelements. This phenomena is observed in abandoned open-pits in East Germany (prior DDR; Luckner 1997, Hurst et al. 2002).

The Table 1 presents the chosen physical and chemical indicators of water in the open-pit. They confirm that the quality of reservoir water is much worse than the quality of water pumped by wells barrier. The biggest differences are observed in the sulphide ion concentration. The changes of water quality are observed in the reservoir as well. For example the samples taken in June and November 2001 show the doubling of sulphides average concentration (Table 1).

Table 1. The average of chosen physical and chemical indicators of water in wells barrier and Patnow reservoir.

Sample location		pH	γ [μS/cm]	Ca [mg/L]	Mg [mg/L]	SO_4 [mg/L]
Wells barrier		8.41	505.11	81.86	17.69	40.71
Reservoir	Average	8.20	750.86	117.74	27.08	174.73
in open-pit	June 2001	8.44	679.33	114.05	24.01	125.37
	November 2001	8.01	804.50	120.50	29.38	211.75

The process of weathering minerals dissolving will go on and follow the groundwater recovery in the unsaturated zone. It might cause the further worsening of water quality in Patnow reservoir and reduce ability to restore water biology.

Leakage has the main influence on the chemistry of reservoir water. The scale of changes to the quality of groundwater might be estimated on the basis of the quality of leakage above the water level in reservoir. Some analysed leakage had pH value of 3-4. Its sulphide concentration reached 2000 mg/L. A high concentration of iron, aluminium, silica, strontium and manganese was observed as well. The chemical composition of leakage is probably the result of sulphuric acid buffering through the decomposition of clayey minerals from boulder clay.

Conclusions

Natural processes could have a negative influence on the environment in the vicinity of flooding open-pits. The rate of water level recovery in the open-pit can have an influence on the chemistry of water in the artificial lake. Hydrostatic pressure increase in aquifers could change conditions of open-pit slopes stability. Flooding processes aided by dewatering systems in Patnow open-pit reduces the negative effects of processes connected with groundwater level recovery. The pumping of unpolluted groundwater reduces the amount of water migration trough the weathered soils. It also lowers hydrostatic waters pressure on scarp of the artificial lake. An increase in pumping rate could help reduce the flooding time, which is important from a foreshore abrasion point of view.

References

Anderson W C, Youngstrom M P (1976) Coal pile leachate – quantity and quality characteristics. J. Environ. Eng., Div. ASCE 102:1239 – 1253.

Banks D, Younger P L, Arnesen R-T, Iversen E R, Banks S B, 1997 - Mine-water chemistry: the good, the bad and the ugly. Environmental Geology 32 (3): 157-174.

Brake S S, Connors K A, Romberger S B, (2001 b) A river runs through it: impact of acid mine drainage on the geochemistry of West Little Sugar Creek Pre- and postreclamation at the Green Valley coal mine, Indiana, USA. Environmental Geology 40 (4-5): 1471 - 1481.

Brake S S, Dannelly H K, Connors K A, (2001 a) Controls on the nature and distribution of an alga in coal mine-waste environments and its potential impact on water quality. Environmental Geology 40 (4-5): 458 - 469.

Czop M, Motyka J, Szuwarzyński M (2001) Sulphates in groundwater inflowing to the Zn–Pb Trzebionka mine (south Poland). In: Proc. of the Conf. Modern Problems of Hydrogeology, Vol. X/1: 291-299 (in Polish)

Davis E C, Boegly W J (1981) A review of water quality issues associated with coal storage. J. Environ. Qual. 10:127 – 133.

Deutsch W J (1999) Groundwater geochemistry, fundamentals and applications to contamination, Lewis Publishers, New York, 226pp.

Dmitruk S, Hawrysz M, Batog A (1998) Slopes stability in phase of liquidation open –pit mine, In: Proc. of the Conf. XXI School of stratomechanics, p. 61-70 (in Polish)

Fernandez-Rubio R, Fernandez Lorca S, Esteban Arlegui J (1986) Abandono de minas. Impacto hidrologico. Inst. Geol. y Minero de Espana E.T.S. de Inguenieros de Minas, Madrid, 267 pp.

Foos A (1997) Geochemical modeling of coal mine drainage, Summit County, Ohio. Environmental Geology 31 (3/4): 205 - 210.

Geldenhuis S, Bell F G (1998) Acid mine drainage at a coal mine in the eastern Transvaal, South Africa. Environmental Geology 34 (2/3): 234 - 242.

Hajdo S, Klich, Polak K (2000) – Hydrogeological conditioning of slopes stability during the process of liquidation based on Patnow open-pit example. In: Proc. of the Conf. Reclamation and derelict land management in land degraded by mining activity (in Polish)

Hidalgo MC, Benavente J, (2001) Controls on groundwater chemistry in the Linares lead-copper abandoned mines (Spain). In: Seiler K.-P., Wohnlich S. (eds.) - New Approaches Characterizing Groundwater Flow: 1199-1202.

Hurst S, Schneider P, Meinrath G (2002) Remediating 700 years of Mining in Saxony: A Heritage from Ore Mining. Mine Water and the Environment 21 (1): 3-6.

Iribar V, Izco F, Tames P, Antiguedad I, da Silva A, (2000) Water contamination and remedial measures at the Troya abandoned Pb-Zn mine (The Basque Country, Northern Spain). Environmental Geology 39 (7): 800-806.

Kim J J, Kim S J, Tazaki K (2002) Mineralogical characterization of microbial ferrihydrite and schwertmannite, and non-biogenic Al-sulfate precipitates from acid mine drainage in the Donghae mine area, Korea. Environmental Geology 42:19–31.

King T V V (ed.) (1995) Environmental considerations of active and abandoned mine lands. Lessons from Summitville. Colorado. U.S. Geological Survey Bulletin 2220, 40pp.

Kropka J (1995) Zinc and lead in the water from Zn-Pb mines of Bytom region (Silesia, Poland). In: Proc. of the Conf. Modern Problems of Hydrogeology, Vol. VII/2: 87-92 (in Polish).

Luckner L (1997) Bedeutung der Fremdwasserflutung für die Wiedernutzbarmachung der vom Braunkohlentagebau beanspruchten Flächen. Glückauf, v 133, 5.

Marszałek H, Wąsik M (2001) Hydrogeochemical anomaly in waters of pyrite deposit area in Wiesciszowice (Western Sudetes Mts., SW Poland). In: Seiler K.-P., Wohnlich S. (eds.) - New Approaches Characterizing Groundwater Flow: 1031-1034.

Osika R (ed.) (1970) Geology and mineral resources of Poland, Geological Publishers. Warsaw, 878 pp.

Razowska L (2000) Hydrogeochemical changes in Czestochowa region (south Poland) induced by iron mine flooding. Biul. PIG (Polish Geological Institute) 390: 35-96 (in Polish).

Rogoż M (1996) Impact of the mine cessation on water environment. In: Archives of mining sciences. 41 (1): 105-130 (in Polish).

Schüring J, Kölling M, Schulz H D (1997) The potential formation of acid mine drainage in pyrite-bearing hard-coal tailings under water-saturated conditions: an experimental approach. Environmental Geology 31 (1/2): 59 - 65.

Singer P C, Stumm W (1970) Acid mine drainage: the rate - determining step. Science, v. 167: 1121 - 1123.

Smith K S, Plumlee G S, Ficklin W H (1994) Predicting Water Contamination from Metal Mines and Mining Wastes. U.S. Geol. Survey, Denver CO, Third Int. Conf. on the Abatement of Acidic Drainage, Workshop 2, April 24, 112 pp.

Steven N M, Badenhorst F P, Harris C, Spath A (2001) An integrated hydrogeological and water chemistry study at the Navachab Gold Mine, Namibia. In: Seiler K-P, Wohnlich S (eds.) - New Approaches Characterizing Groundwater Flow: 1297-1301.

Szczepanska J, Twardowska I (1999) Distribution and environmental impact of coal-mining wastes in Upper Silesia, Poland. Environmental Geology 38 (3): 249-258.

Yu J-Y (1996) Pollution of Osheepcheon Creek by abandoned coal mine drainage in Dogyae area, eastern part of Samcheok coal field, Kagwon-Do, Korea. Environmental Geology 27 (4): 286 - 299.