IAH 2010 Krakow
BIULETYN PAŃSTWOWEGO INSTYTUTU GEOLOGICZNEGO 441: 167–174, 2010 R.

RECLAMATION OF POLISH LIGNITE OPEN PITS BY FLOODING

JACEK SZCZEPIŃSKI[1], JANUSZ FISZER[2], ZBIGNIEW STACHOWICZ[1], PAWEŁ SZCZEPANIK[1]

Abstract. This paper presents reclamation of post-mining lignite open pits by flooding in Poland. Besides, it provides some data on hydrogeological conditions of Polish lignite mines. Reclamation by flooding is presently used in post-mining voids in the Adamów Lignite Mine and the Konin Lignite Mine, and it is anticipated to be used in the future, in the case of large-space abandoned open pits in the Turów Lignite Mine and the Bełchatów Lignite Mine, whose volume will exceed one billion cubic meters. Pit lakes in Poland are formed deliberately as a planned part of the after-use of lignite surface mine voids and they are used as wildlife habitats, fisheries, water sports venues or other forms of amenity. In each case the mine voids are flooded by natural groundwater inflow, water pumped out from dewatering system and water from rivers and courses. In the existing and abandoned Polish lignite open pits there are favorable conditions in terms of water quality formation, so the water in pit lakes is of a good quality. However, the studies indicate a potential threat to the water quality in pit lakes, where they are recharged only by groundwater. Therefore, additional recharge the void with surface water or water pumped out from dewatering wells reduces the probable pit lakes deterioration.

Key words: pit lakes, lignite open pits, hydrogeological conditions.

INTRODUCTION

The reclamation and management of post-mining excavations in rock quarrying is not a big issue in Poland due to the inconsiderable size of open pits. Much more essential problems concern reclamation of the abandoned lignite open pits, sometimes with a volume of billion cubic meters. The most rational method is flooding. Such a way of reclamation is preferred across the world and it is used also in Poland. Lignite pit lakes are formed deliberately as a planned part of the after-use of a lignite mine voids, for where the water quality is appropriate they can be used as wildlife habitats, fisheries, water sports venues or other forms of amenity (Younger *et al*., 2002).

Reclamation by flooding is currently used in post-mining voids in the Adamów and Konin lignite mines, and it is anticipated in the case of large-space abandoned open pits in the Turów and Bełchatów lignite mines.

HYDROGEOLOGICAL CONDITIONS OF POLISH LIGNITE MINES

The thickness of lignite in Polish lignite mines varies from 5 to 60 m and the thickness of overburden is from 30 to 240 m. The overburden constitutes Neogene and Quaternary formations consisting of silt and clays (30–75%) and sands (25–70%). All lignite deposits are below the natural groundwater table that occurs most frequently right under the terrain surface. Annual precipitation in the regions of lignite basins varies from 500 to 700 mm/year, the climate is moderate with the average annual temperature about 8°C. Groundwater is drained by deep wells with submersible

[1] Poltegor-projekt Sp. z o.o., Wyścigowa 56f, 53-012 Wrocław, Poland; e-mail: j.szczepinski@poltegor.pl, z.stachowicz@poltegor.pl, p.szczepanik@poltegor.pl

[2] Wrocław University of Technology, Faculty of Geoengineering, Mining and Geology, pl. Teatralny 2, 50-051 Wrocław, Poland; e-mail: janusz.fiszer@pwr.wroc.pl

pumps. The main lignite deposits being presently under exploitation are of the Neogene age. They occur in the Adamów, Konin, Turów and Bełchatów lignite seams and have different hydrogeological conditions (Libicki, 1987; Fiszer, Sawicki, 2003).

In **the Adamów Lignite Mine** three open pits are presently active – Adamów, Koźmin and Władysławów (Fig. 1). The hydrogeological conditions are characterized by four aquifers – two over and two below the lignite seam. The first aquifer of free water table consists of the sands and gravels just below the terrain surface. Its thickness is mostly up to 10 m and permeability of 5 m/day, but sometimes in old buried valleys it reaches thickness of 40 m and permeability of 50 m/day. The second aquifer occurs in sandy lenses within the clays. The groundwater is under pressure of 1 to 3 Ba. The third aquifer is located in the fine widespread Neogene sands underlying the lignite seam. Its thickness varies from 2 to 30 m and permeability from 1.5 to 4.0 m/day. The fourth aquifer occurs in the fissured Cretaceous marls underlying Neogene sands with permeability from 2 to 45 m/day. Groundwater in the Neogene and Cretaceous aquifers occurs under confined conditions. The total volume of groundwater pumped out from the pits amounts to 130 m^3/min, when groundwater drawdown is 25–40 m. The cone of depression around the open pits in the Quaternary aquifer is very irregular and depends on thickness and geological structure. It varies from 1 to 5 km. The cone of depression in the Neogene and Cretaceous aquifer has a more regular shape and ranges from 4 to 7 km.

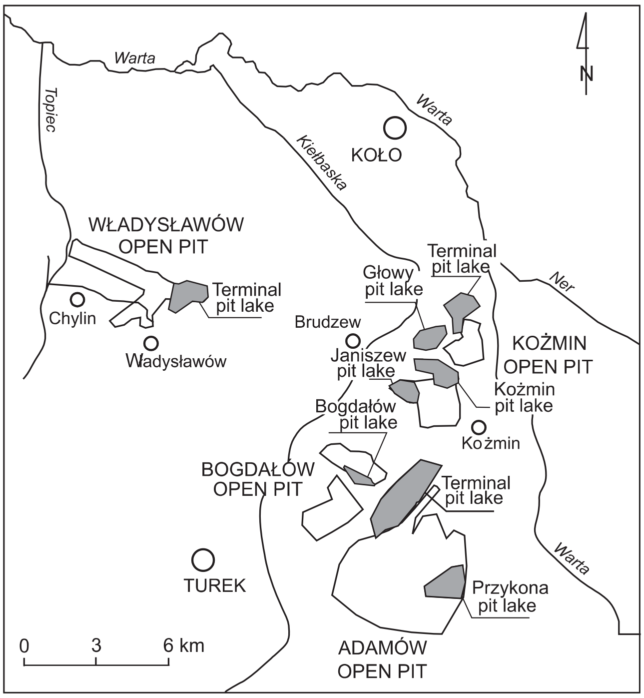

Fig. 1. Current and proposed location of pit lakes in the Adamów post-mining area (courtesy of the Adamów Lignite Mine)

In **the Konin Lignite Mine** three open pits are presently active – Kazimierz Północ, Jóźwin, Drzewce (Fig. 2). The open pit Lubstów finished lignite production in 2009. In the future, it is planned to start lignite production in Tomisławice, Piaski and Ościsłowo lignite deposit areas. The hydrogeological conditions are characterized by four aquifers – two over and two below the lignite seam. The first aquifer of free water table occurs in the Quaternary sands and gravels. Its thickness varies from 0 to 20 m and permeability averages about 10 m/day. The second aquifer with groundwater under confined conditions is located in sandy lenses within clays and its permeability varies from 2 to 10 m/day. The third aquifer occurs in the widely spread Paleogene and Neogene sands underlying the lignite seam. Its thickness ranges from 20 to 70 m and permeability from 3 to 4 m/day. It contains groundwater under confined conditions with the pressure of 1–5 Ba. The fourth aquifer is located in the fissured Cretaceous marls. The groundwater table is under the pressure similar to the Paleogene and Neogene sands. Its permeability varies from 1 to 45 m/day, on average 3 m/day. The water inflow to the particular open pits varies from 20 to 70 m^3/min and the total volume of groundwater pumped out from all the pits is 180 m^3/min (2008), when groundwater drawdown ranges from 25 to 80 m. The cone of depression around the open pits in the Quaternary aquifer is very irregular and depends on thickness and geological structure. It varies from 1 to 2 km. The cone of depression in the Paleogene, Neogene and Cretaceous aquifer has more regular shape and ranges from 4 to 9 km. The total area of the cone of depression is about 280 km^2.

The Turów Lignite Mine is located in the geological structure having the shape of a real basin (tectonic depression) and covering an area of about 100 km^2 (Fig. 3). The bed consists of impermeable Paleozoic rocks filled with the Neogene formation at the centre. Its thickness ranges from 50 m on the boundary to 300 m at the centre of this structure. It consists of clays (50–80%) and sands (20–50%) depending on the basin region. Sands occur in form of closed lenses from 1 to 30 m thick and extend from several hundreds meters up to 3 km. They contain groundwater under confined conditions with the pressure of 2–20 Ba depending on depth. At the west side along the open pit contour, the Nysa Łużycka River flows. Its valley with depth from 5 to 20 m is filled with gravel. Groundwater is drained by underground galleries and pumping wells. The recharge from the Nysa Łużycka River is cut by cut-off wall. The total water inflow on average 32 m^3/min, depends on the amount of precipitation. The groundwater inflow is stable and amounts to 18–20 m^3/min.

Due to the small thickness and isolation from deeper aquifers, the cone of depression in the Quaternary aquifer occurs close to the open pit. The cone of depression in the Neogene aquifer reaches outcrops of the rocks, which form the basement of the basin (about 2 km). In the south and west directions the range of the cone of depression can extend further.

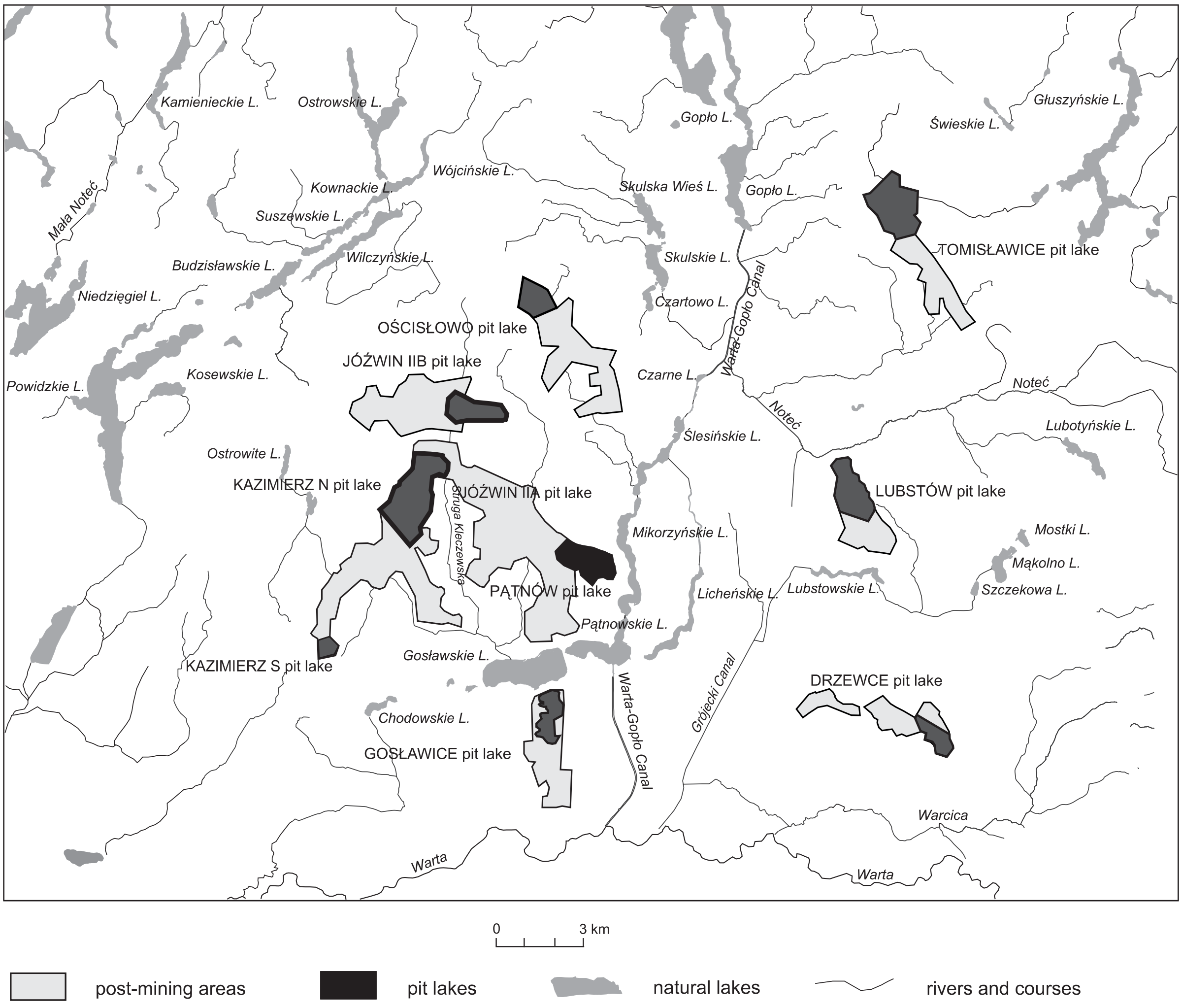

Fig. 2. Current and proposed location of pit lakes in the Konin post-mining area

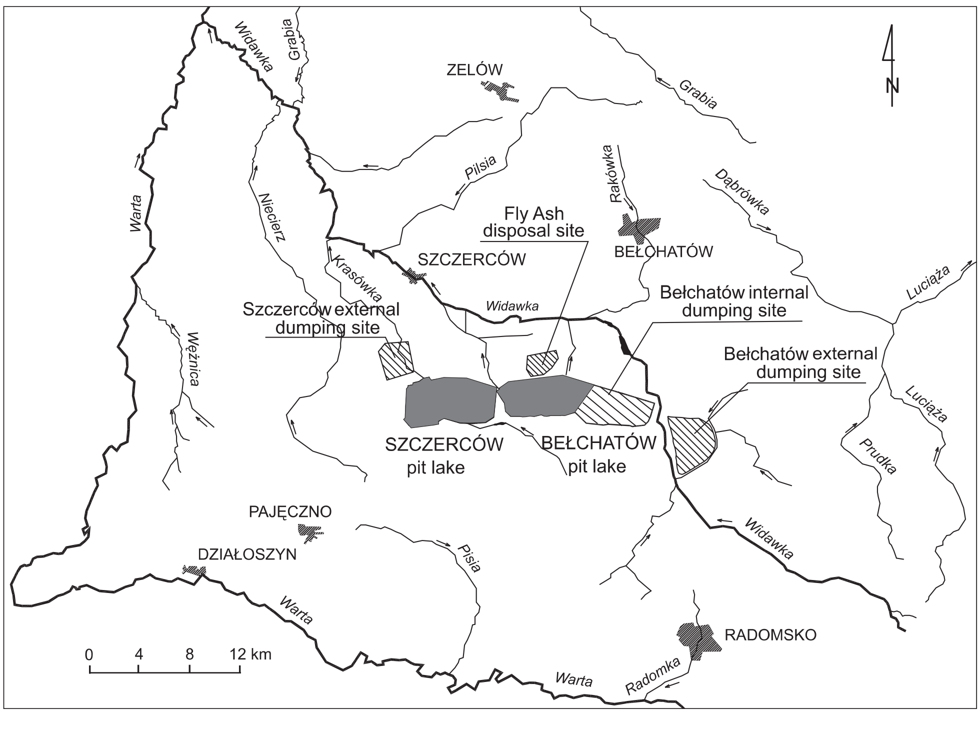

Fig. 3. Proposed location of pit lakes in the Bełchatów post-mining area (modified from Szczepiński, 2004)

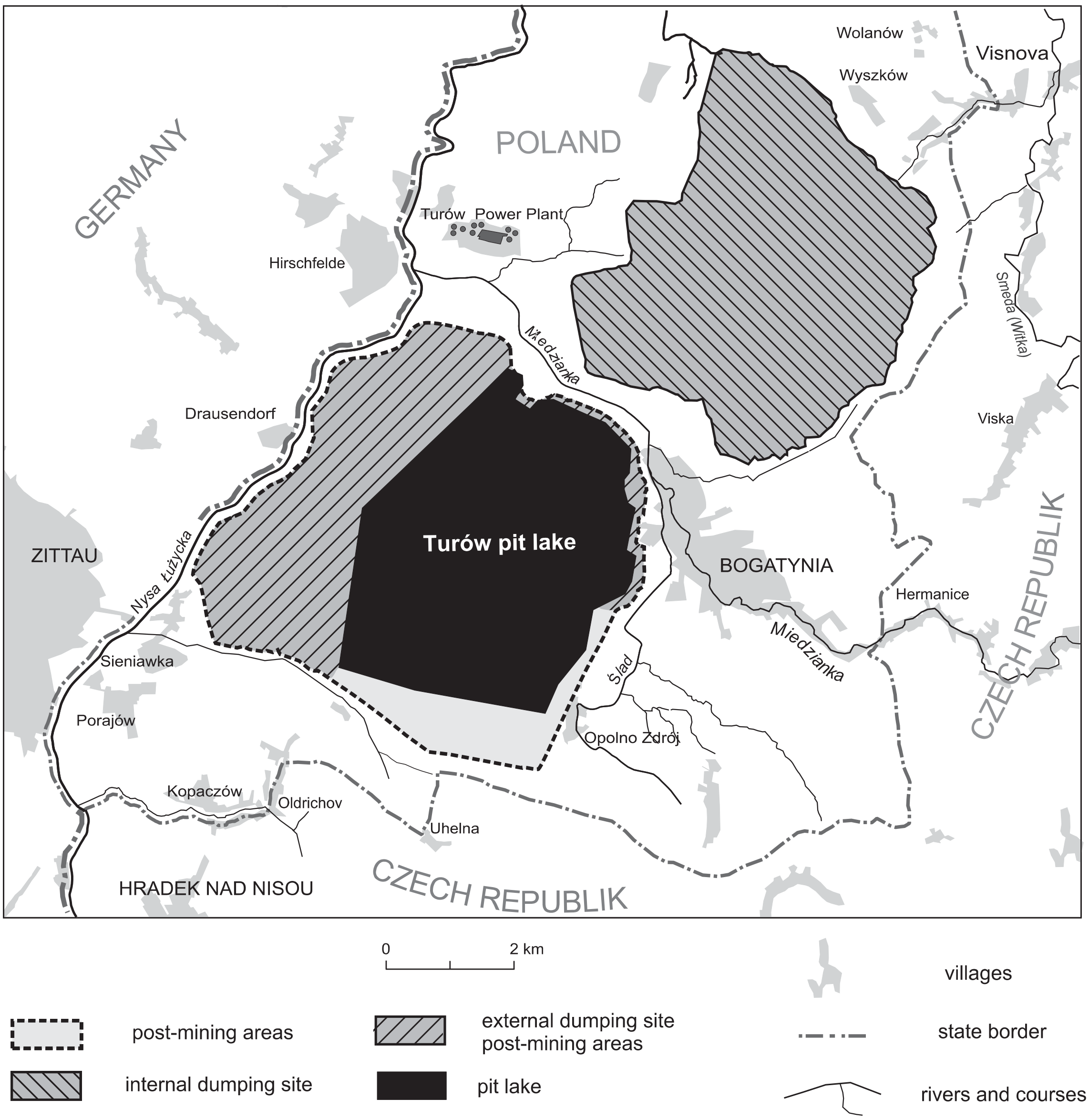

Fig. 4. Proposed location of pit lake in the Turów post-mining area

In **the Bełchatów Lignite Mine** two open pits are active – the Bełchatów and Szczerców open pits (Fig. 4). The lignite seam is deposited in the tectonic rift valley having the length of 60 km and width of 0.5–2.0 km. Its maximum depth reaches 500 m. The Mesozoic base is formed by Jurassic and Cretaceous rocks. Mesozoic aquifers are: fractured limestone, marls and sandstone. This aquifer is located at the depth of about 40–100 m around the rift valley, but within the rift valley at the depth of about 400 m. The average hydraulic conductivity for this fissured aquifer is about 5 m/day, but is very diversified; the highest permeability occurs in karstified limestones (Szczepiński, Libicki, 1999). The Paleogene and Neogene formations are located within the rift valley at the depth of 90–400 m. Permeable sand strata have the hydraulic conductivity of about 1 to 3 m/day and are about half of these formations. The other half consists of clay and lignite, both impermeable. Quaternary formations occur in the whole area. Their maximum depth reaches 300 m in the northern part of the Bełchatów open pit in the post-glacial buried valley. In the other parts of the region the depth of the Quaternary formation is about 90 m. It consists of about 70% of sand and gravel and 30% of clays. The average hydraulic conductivity for sand-gravel series is about 20 m/day. The aquifers occurring in this particular stratigraphic series (Mesozoic, Tertiary and Quaternary) have many geological and hydraulic connections, so the whole complex of the permeable rocks creates one huge and heterogeneous aquifer in the whole region. The dewatering system in the Bełchatów Lignite Mine has been operating since 1975. The mine water inflow for two open pits amounts to 500 m^3/min. The groundwater table is lowered to about 300 m within the area of mining operation, and the radius of the cone of depression is 3–9 km. It effects the cone of depression of about 730 km^2 (2008).

RECLAMATION BY FLOODING IN THE KONIN AND ADAMÓW LIGNITE MINE AREA

The final reclamation of abandoned lignite open pits in the Konin and Adamów lignite mine area has faced no major problems as yet owing to:

– the small depth and size of open pits changed into water reservoirs (between 15 m and 40 m);
– the possibility of their complete or partial backfilling by the overburden from the adjacent open pits;
– a relatively simple water regime.

Adamów Lignite Mine Area. In the Adamów region the water reservoirs have been a part of the post-mining areas (Fig. 1). In the non-backfilled part of the abandoned Bogdałów open pit a small pit lake was formed, covering an area of about 10.8 ha and having a depth of about 8 m. In the eastern part of the inner dumping area of the Adamów open pit, the Przykona pit lake having a volume of 7.3 mln m^3 was established in 2000 (Table 1). Another example of such a reclamation is the Janiszew pit lake covering an area of 60 ha and a volume of 4 mln m^3, formed in 2007 in the post-mining area of the Koźmin open pit (Szwed, 2008). The water in pit lakes is of a good quality.

In the near future, more pit lakes are planned to be constructed. In the post-mining area of the Koźmin open pit three others pit lakes will be established – Koźmin, Głowy and Terminal, with a total area of about 290 ha and a volume of 58 mln m^3. In the Władysławów post-mining pit void, a pit lake with a volume of 20.4 mln m^3 will be formed. After the cessation of lignite production in the Adamów open pit, in its post-mining excavation a pit lake with a capacity of 161 mln m^3 will be established. The flooding of the voids in the Koźmin and Władysławów post-mining areas is likely to take 2–3 years, but in the case of the Adamów voids 15–20 years (information from Adamów Lignite Mine SA). In each case the surface mine voids are flooded by natural groundwater inflow, water pumped out from dewatering of the neighboring open pits and water courses.

Konin Lignite Mine Area. In 1953 and 1961, the Morzysław (15 m deep) and Niesłusz open pits (24 m deep) were abandoned, respectively (Table 2). In the final excavations of both these pits the pit lakes were established. In the post-mining area of the Gosławice open pit operated until 1974, a water reservoir and ash disposal site sprang up covering an area of 32.5 ha and having a capacity of 390,000 m^3 (Fig. 2). In 1997, the Kazimierz Południe open pit (55 m deep) was abandoned. Its post-mining excavation is now being backfilled with overburden from the adjacent open pit and on the top crown of the internal dump site, two pit lakes were established covering an area of 35 and 65 ha and having the total capacity of about 3 mln m^3. The process of flooding the Pątnów void has been finished in 2009. Recently the Lubstów open pit has been under the process of flooding. Its post-mining pit lake will have an area of 346 ha and a volume of 83.5 mln m^3. There will be no problems with reclamation of the other open pits having an average depth from 50 to 80 m. Modeling studies reveal that the flooding of post-mining excavations in the Konin Lignite Mine by natural groundwater inflow is likely to take about 30 years and it will finish in the late 1970s of XXI century (Fiszer ed., 2009). To speed up this process, like in the case of Pątnów and Lubstów mine voids, the water from dewatering of neighboring open pits and water from rivers and courses is planned to be used.

Table 1

Reclamation of abandoned lignite open pits by flooding in the Adamów Lignite Mine (courtesy of the Adamów Lignite Mine)

Open pit	Completion of lignite production	Pit lake	Area [ha]	Volume [thousands m^3]
Bogdałów	1991	Bogdałów	10.8	600
Władysławów	2011	Terminal	103.0	20,400
Koźmin	2020	Janiszew	59.6	4,050
		Koźmin	108.5	6,100
		Głowy	64.5	17,700
		Terminal	116.1	34,090
Adamów	2023	Przykona	139.7	7,300
		Terminal	462.0	161,700

Table 2

Reclamation of abandoned lignite open pits by flooding in the Konin Lignite Mine (Michalski, 2004, modified)

Open pit	Completion of lignite production	Area [ha]	Volume [thousands m^3]
Morzysław	1953	2.5	20
Niesłusz	1961	18.5	148
Gosławice	1974	32.5	390
Pątnów	2000	346	83,500
Kazimierz Południe	1997	100	2,980
Lubstów	2010	475	144,000
Kazimierz Północ	2011	360	190,000
Józwin IIB	2021	420	147,180
Drzewce	2022	125	12,500
Tomisławice	2030	300	83,200
Piaski	2036	630	~22,0000
Ościsłowo	2037	300	84,000

FUTURE RECLAMATION BY FLOODING IN HUGE ABANDONED LIGNITE OPEN PITS

The reclamation of final excavations of the Turów Lignite Mine in southwestern Poland and the Bełchatów Lignite Mine in central Poland will be much more difficult. The effect of lignite mining in these areas will be large-space abandoned open pits whose volume will exceed one billion cubic meters. The most rational method for reclamation is filling of these huge mine voids with groundwater and surface water.

Bełchatów Lignite Mine Area. In 2019, it is planned to cease lignite production in the Bełchatów open pit. Lignite production at the adjacent Szczerców open pit will be completed in 2038. The final excavations of both open pits immediately after completion of the lignite production, will have an area of about 39 km^2 and a depth of 280 m (Table 3).

A general concept of the reclamation of both abandoned pits is to shallow them with overburden and fill them with water (Fig. 3). The preparation of both voids for flooding will be completed in 2026 for the Bełchatów open pit and in 2048 for the Szczerców open pit. As a result the Bełchatów and Szczerców reservoirs will be formed, with an area of 16.9 and 22.0 km^2, a depth of 205 and 165 m and a volume of 1.3 and 1.8 bln m^3, respectively. The process of filling the post-mining excavations with water in the Bełchatów void will start in 2027 and in the Szczerców void it will start in 2049. Two conceptions of flooding have been taken into consideration (Kasztelewicz, ed., 2008). For the first one the assumption was that the water reservoirs will be filled with groundwater inflow and by additional recharge with water from the well barriers located around the open pits. Groundwater pumped out from the dewatering wells will be discharged to the canals and then it will be transported by pipes into the voids. Calculations reveal that the process of flooding will be finished after 2100. In the second conception the assumption was that the voids will be filled with groundwater inflow with additional recharge from the Warta

Table 3

Reclamation of abandoned lignite open pits by flooding in the Bełchatów Lignite Mine (Kasztelewicz *et al.*, 2005)

Open pit/pit lake	Completion of lignite production in open pit	Area [ha]	Volume [mln m^3]
Bełchatów	2019	1690	1300
Szczerców	2038	2200	1800

Table 4

Variants of the post-mine excavation reclamation in the Turów Lignite Mine (Fiszer *et al*., 2005)

Variant	Depth [m]	Area [ha]	Volume [mln m^3]
A	105	1690	1220
B	200	1690	1480
C	200	1865	1600

and Widawka rivers at a rate of 2.25 or 4.00 m^3/s. The results of calculations have shown that the flooding will last until 2072 and 2062 respectively. The water level in the both pit lakes will be the same. Water from the pit lakes will discharge into the Widawka River.

Turów Lignite Mine Area. Lignite production in the Turów Lignite Mine is planned to be ceased in 2040. The preparation of void for flooding will be completed in 2050. Three variants (A–C) related to the final excavation formation have been considered (Fiszer *et al*., 2005). In each one the area and depth of the reservoir were different (Table 4).

In order to estimate the time of flooding the void the following assumptions have been made:

– the reservoir will be flooded only with surface water from the Nysa Łużycka and Miedzianka rivers at a rate of 3.87 m^3/s;
– groundwater inflow into the void (in average 20 m^3/min) will not be possible; water in the post-mining reservoir will cause excess of hydrostatic pressure on the groundwater in the vicinity of the voids; groundwater inflow will be renewing static resources in the aquifer surrounding the void;
– precipitation on the pit lake surface supplements the losses associated with evaporation.

The calculations made for average hydrological conditions reveal that the time of filling the void with water will reach 10 years for option A, 12 years for option B and 13 years for option C. Therefore the reclamation by flooding will finish between years 2060–2063 (Fig. 4).

At the steady state condition, the pit lake will be recharged from the Nysa Łużycka River in the amount of 0.075 m^3/s, in order to compensate for evaporation losses. Water from the pit lake will discharge into the Miedzianka River.

WATER QUALITY IN PIT LAKES

The main danger to the quality of groundwater feeding the pit lakes is the occurrence of easily oxidizable minerals such as pyrite in the rock mass. Due to the groundwater rebound in the rock mass subjected to oxidation, a process of dissolution of oxidized pyrites takes place. Pyrite weathering that produces sulfate also releases soluble iron and acidity. The groundwater flowing through the area of depression cone into the excavation can lead to accumulation of pollutants in the flooded voids. As a result the deterioration of water quality, especially in the lower part of the pit lakes, is possible. However, the research studies indicate that in lakes which are prone to acidify low pH and elevated concentrations of ecotoxic metals preferentially occur during the short period of initial pit lake filling and briefly thereafter (Shevenell, 2000). Only those pit lakes in which the terminal water level is in contact with a rock unit rich in pyritic sulphur are likely to remain acidic in the long term (Bowell *et al*., 1998). Additionally, because of the high values of "relative depth" the phenomenon of evapoconcentration in pit lakes is less important than in nearby natural lakes (Younger *et al*., 2002).

It should be noted, that in the existing and abandoned Polish lignite open pits there are favorable conditions in terms of water quality formation (Polak, 2004). An analysis of geological profiles in the Pątnów open pit indicates the occurrence of the carbonate rocks and low content of pyrite in the overburden. The result is that acidic water is largely neutralized. However, there is a potential threat to the water quality in voids, where they are directly recharged only by groundwater. In many cases, what is crucial for the chemistry of the pit lakes, is flooding the voids with additional recharge from surface water or even water pumped out from dewatering wells. It can reduce the probable pit lakes deterioration. The acidic pit lakes should be the focus of a remedial action.

REFERENCES

BOWELL R.J., BARTA J., MANSANARES W., 1988 — Geological controls on pit lake chemistry. Implication for the assessment of water quality in inactive open pits. *In*: Proc. of the IMWA Congress. "Mine Water & Environmental Impacts". Johannesburg, 7–13th September 1998: 375–386.

FISZER J. (ed.), 2009 — Numeryczny model hydrogeologiczny dla KWB Konin w zasięgu oddziaływania systemu odwadniania wraz z bilansem wodno-gospodarczym. Arch. PWroc., Wrocław.

FISZER J., BATOG A., TOMASZEWSKI J., 2005 — Wstępna koncepcja napełniania zbiornika wodnego w wyrobisku poeksploatacyjnym kopalni „Turów". BUHiKAŚ „HYDROS". Arch. KWB Turów S.A., Turoszów.

FISZER J., SAWICKI J., 2003 — Hydrogeologia polskich złóż kopalin i problemy wodne górnictwa. *In*: Hydrogeologia złóż i problemy wodne górnictwa węgla brunatnego (ed. Z. Wilk). Uczelniane Wyd. Nauk-Dydakt., Kraków.

KASZTELEWICZ Z. (ed.), 2008 — Koncepcja rekultywacji i zagospodarowania wyrobisk końcowych Zakładu Górniczego KWB Bełchatów. Arch. AGH, Kraków.

LIBICKI J., 1987 — Hydrogeological conditions of lignite basin in Poland and their changes caused by dewatering lignite open pits. *In*: Proc. of the IMWA Symp. Hydrogeology of Coal Basin, Katowice: 525–536.

MICHALSKI A., 2004 — Zagospodarowanie terenów pogórniczych. *Węgiel Brunatny*, **47**, 2: 33–37.

POLAK K., 2004 — Zagrożenia jakości wód w zbiornikach poeksploatacyjnych kopalń węgla brunatnego. *Tech. Poszuk. Geol., Geosynoptyka i Geotermia*, **43**, 3: 29–38.

SHEVENELL L.A., 2000 — Water quality in pit lakes in disseminated gold deposits compared to two natural, terminal lakes in Nevada. *Envir Geol*, **39**: 807–815.

SZCZEPIŃSKI J., LIBICKI J., 1999 — Modelling of the Bełchatów open pit impact on the groundwater environment. *In*: Proc. of the IMWA Congress. "Mine, Water & Environment". Sevilla, 13–17th September, 1999: 69–77.

SZCZEPIŃSKI J., 2004 — Problems of water management in abandoned open pits in Poland. *In*: Sustainable post-mining land management, Wrocław (eds. C. Heberstreit *et al.*): 193–200. ROMA-POL, Kraków.

SZWED L., 2008 — Budowa zbiornika "Janiszew" w KWB Adamów SA. *Węgiel Brunatny*, **64**, 3: 10–12.

YOUNGER P.L., BANWART S.A, HEDIN R.R., 2002 — Mine water hydrology, pollution, remediation. Kluwer Acad. Publ., Dordrecht.