The work of the well barrier around Dębina salt diapir for the protection of the water environment in the area of Bełchatów lignite mine, effects and methodology of the apprisal of its effectiveness

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Abstract: Bełchatów open pit is presently some 200 m deep and its target depth is some 280 m. The amount of water pumped out from its drainage system is some 350 m^3/min. In the vicinity of lignite basin, at the depth of some 2,000 m, there is a Permian deposit of salt. The "Dębina" salt dome divides the Bełchatów lignite basin into two fields: Bełchatów and Szczerców. The structure of diapir consists of: a body of salt (with the salt level culmination at the depth of 170 m), anhydrite and gypsum overlay and breccia formations. As the result of the drainage of Bełchatów open pit, the well barrier around the diapir was created. The water level in the barrier is always lower than in the vicinity. Presently the centre of some 200 m depression is located some 5000 m east of the diapir and the future centre of 280 m depression will be located some 1000 m away from the diapir.

The groundwater flow through the diapir structure is a threat for the groundwater quality in the area of the mine. The way of the protection of the water environment that relies on a groundwater controlled drainage around the diapir zone has been functioning for 7 years. Presently are used 28 wells that create protective barrier around the diapir. The present depression at the barrier perimeter is some 115 m and a total discharge varies between 12 and 14 m^3/min. The protection of the diapir from washing out will have to function for about 50 years, i.e. till the time of the completion of the lignite production and preparation of Bełchatów and Szczerców open pits for their reclamation as water reservoirs.

This paper presents the natural conditions of that area, the ways of the protection of the water environment in the area of the diapir and describes the up-to-date effects and methodology of the appraisal of the effectiveness of the protective barrier.

1 NATURAL CONDITIONS OF THE SALT DIAPIR AND THE WAYS OF THE PROTECTION OF THE NATURAL ENVIRONMENT

Bełchatów lignite deposit runs parallelwise (Seweryn L., 1994). Its total length is 38 km and its width is 1.5 ÷ 2 km. The deposit is located in Kleszczów fault trough which average depth is some 400 m. The natural boundaries of the deposit division are: salt diapir "Dębina" that is located between Szczerców and Bełchatów open pits and Widawka fault separating Bełchatów Field and Kamieńsk Field. (Figure 1).

The geological structure of the deposit area consists of Permian limestone, Jurassic, Cretaceous, Tertiary and Quaternary formations. In all of the above formations a common aquifer system exists. The salt diapir, Dębina, in a horizontal plane, resembles an irregular ellipse of an elongated axis in the direction N-S and measurements of 500 x 650 m with an eccentrically moved culmination of the salt water level. In a vertical plane the diapir is of the shape of a trunk raising from N W and E under the angle of 70^o to 85^o.

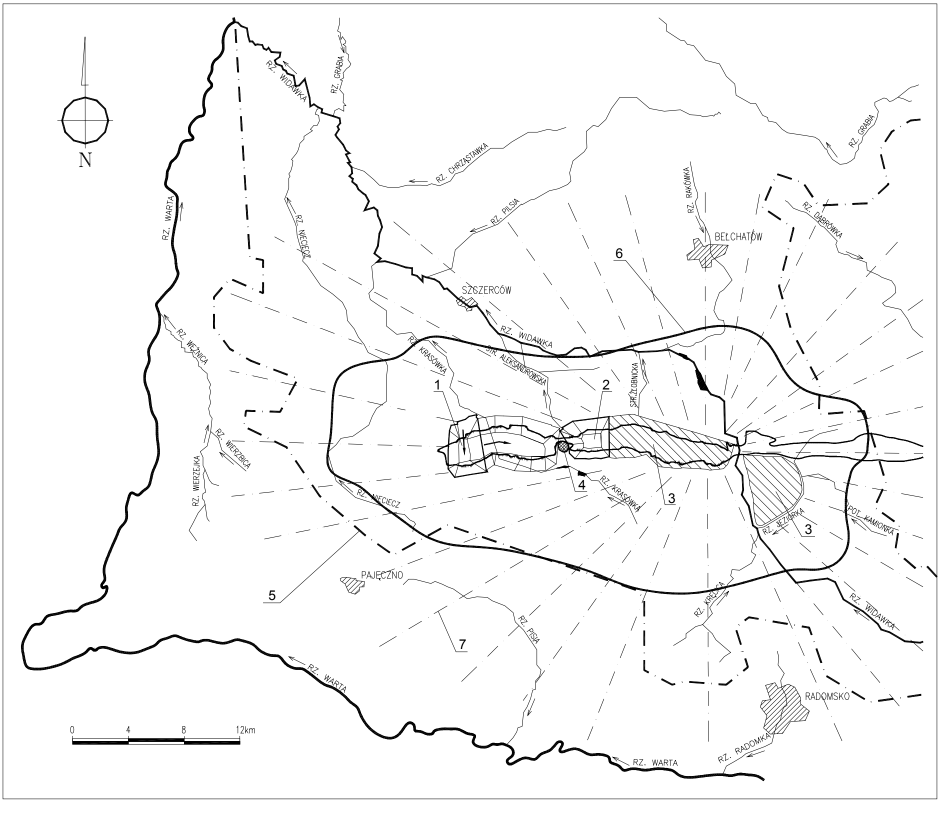

Figure 1 Map of Bełchatów mine region
1– Szczerców open pit, 2– Bełchatów open pit, 3 – overburden disposal area, 4– Dębina salt stock, 5– boundary of Widawka river catchment basin, 6– Bełchatów open pit cone of depression, 7– lines of piezometers of monitoring system

The soil over the diapir of the ordinate of 190 m above the sea level is somewhat raised comparing to its surroundings.

The body of salt is covered with an anhydrite and gypsum overlay of the thickness of 25 m to 70 m; on the slopes the thickness is reduced to some 10 m. An exterior part of the diapir is a zone of breccia formations built out of crushed and mixed Jurassic and Cretaceous rocks and Tertiary formations of a maximum thickness of some 60 m; that thickness is reduced to even a few meters at the steep walls of the diapir.

In the surroundings of the diapir there are sharply raising Jurassic and Cretaceous formations and Tertiary coal-bearing sediments. In the vicinity of the diapir there are three basic aquifer:

- Quaternary, in sand and gravel formations of the thickness of some 70 m where the hydraulic conductivity is about 2 to 20 m/d,
- Tertiary, in fine and dust sands of the hydraulic conductivity of some 2 m/d with a sub-artesian water level,
- Cretaceous and Jurassic (Mesozoic), in cracks of limestone and marl with its hydraulic conductivity of 3 to 14 m/d, sub-artesian. In the vicinity of the diapir groundwater is mostly fresh, two-ion of a HCO_3-Ca, of a weakly basic reaction. The content of dissolved substances is mostly between 200 and 300 mg/dm^3. The content of chlorides is mostly below 20 mg Cl/dm^3 and sporadically to some 200 mg Cl/dm^3; the content of sulphates, from 10 to 20 mg SO_4/dm^3 and maximum of some 50 mg SO_4/dm^3. The deeper it gets the content of dissolved substances is, in general, higher; for the Quaternary aquifer it is, on average, 210 mg/dm^3, for the Tertiary aquifer located below, an average of 260 mg/dm^3 and for the Cretaceous aquifer located the deepest, an average of 380 mg/dm^3.

Several anomalies were observed, especially within the Tertiary and Mesozoic aquifer that are in contact with the structure of the diapir where the content of dissolved substances varies between 1500 to 4900 mg/dm^3 and the content of chlorides, from 470 to 820 mg Cl/dm^3.The waters that are in breccia, that constitutes an exterior part of the diapir structure, have a diverse chemical composition of the type of Cl-SO_4-Na and Cl-Na (salty waters and brines). The content of dissolved substances varies from 1610 to 54800 mg/dm^3, and content of chlorides from 39 to 32300 mg Cl/dm^3 (Godlewski Z. et al.,1990).

The hydrogeological survey of the diapir area (when it comes to its influence on the existing areas and water environment) shows the following:

- a high level of isolation of the salt diapir in naturally stabilised conditions was effective in the prevention of the mineralization of water,
- an intensive drainage of the open pit taking place ever closer to the diapir would cause an increase in the intensity of the groundwater flow and washing out its structure. As a consequence, the salinity of mine water and ground settlement and subsidence resulting from the dissolution of salt.

In natural conditions the salt diapir was created in hydrochemical equilibrium with fresh groundwater that are in its vicinity. The drainage system getting closer from the east would cause an increase in the intensity of the groundwater flow from the diapir to the mine drainage system and an increase in hydraulic gradients; that is illustrated on Figure 2. A depression in the vicinity of the salt diapir will increase to some 180 m in the final phase of the drainage of Bełchatów open pit.

An intensification of the groundwater flow through the diapir zone would create a serious threat of washing out its structure. The amount of water flowing through the diapir could be some 3.5 m^3/min in 1995 to some 7 m^3/min in 2015. By assumed general mineralization of those waters from 15 to 25 g/dm^3 (based on the physical and chemical testing of water sampled from the diapir structure) the total amount of salt washed out from the diapir till 2015 would be 1080 thousand of Mg. Such a large amount of salt would cause an increase in a pollution in surface waters and deterioration in the cleanliness of the rivers to which the mine waters are dumped.

An expected increase in a general mineralization and amount of sulphates in Widawka river that takes all of the waters from Bełchatów open pit would be some 300% and an increase in chloride ions over 1600%. That is unacceptable. Moreover, a washing out of the salt diapir could lead to the creation of cavities and, then, to the creation of sink holes in the area.

In order to select a proper solution for the protection of the water environment from the influence (impact) of the salt diapir, several ways of elimination or limitation of the groundwater flow through the diapir were analysed. The best one was considered a solution utilising a ring barrier of depression wells (Seweryn L. & Wojtkowiak B., 1995).

The goal of the barrier is:

- elimination of the groundwater flow through the diapir zone and prevention of the washing out of the structure of the salt diapir,
- protection of the mine water from the pollution by salty water from the diapir area,
- protection of the area from the creation of sink holes resulting from the dissolution of the salt diapir.

The wells around the diapir play the role of a hydraulic protective barrier. This solution is based on the elimination of the groundwater flow through the diapir. Created is such a hydrodynamic system where the depression between the wells is slightly bigger than the depression created by the open pit drainage system. Its effectiveness is to maintain an equal depression on the perimeter of the protective barrier. In a new hydrodynamic system clean groundwater flowing to the barrier from outside of the ring, mineralised water that are within the diapir and water located between the diapir and the barrier are taken in by its wells and transferred to the outside. The idea of the work of the system is illustrated on figure 3 (Seweryn L, 1988).

As the result of the work of the protective barrier the water salination will be eliminated or it will be reduced to the level not causing a catastrophic or huge negative impact on the environment.

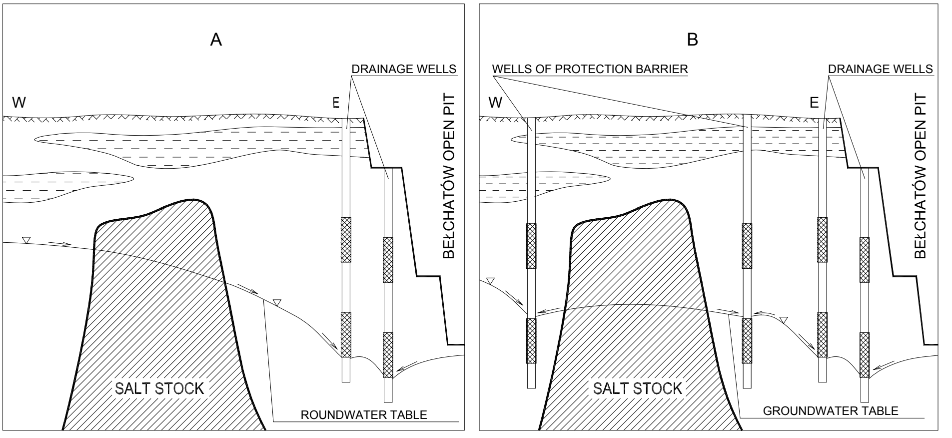

Figure 2 Scheme of groundwater flow through Dębina salt stock
A – without protection barier, B – with protection barier

2 IMPLEMENTED PROTECTIVE SYSTEM

The design of the protective barrier was drawn-up by Poltegor-engineering of Wrocław in the years 1990-91. The location and depth of the wells were adopted to the geological survey of the salt diapir area that was inferior to the present one. The designs did not include the contemporary assumptions concerning the mining in Szczerców open pit.

The construction of the barrier took place in the years 1990-92 and its start-up in October 1992. The protective barrier consisted then of:
- 37 pumping wells around the diapir with a gravitational discharge of water,
- 107 piezometers,
- the posts for the continuous supervision and recording of the salinity of the pumped out water.

The operation of the system is, in general, in accordance with adopted assumptions. Slight departures from the design assumptions, when it comes to the planned depressions, were corrected by differentiation of the output of the wells and drilling of the new ones. Also the observation network is being improved by the addition of new observation wells.

Presently the protective barrier consists of (Figure 3):
- 41 wells,
- 138 piezometers.

The depths of the wells are between 200 m and 320 m. These are the wells of large diameters; the smallest filtration columns have the diameter of 356 mm and drilling diameters of 670 mm.

The observation wells have the depths of up to 395 mm. The piezometric pipes of the diameters of 89 mm to 168 mm are installed both in the Cainozoic and Mesozoic aquifers. Those wells were divided into two groups depending on their location. In those groups the frequency of the measurements of the water level varies. Also the importance of the results of the measurements for the appraisal of the effectiveness of the barrier varies.

Group I (the wells on the perimeter of the barrier):

- measurements, once a day (24 hours),
- presently under observation are: 26 piezometers in the Tertiary aquifer and 26 piezometers in the Mesozoic aquifer,

Group II (the wells inside the barrier):

- measurements, twice a week,
- presently under observation are: 3 piezometers in the Tertiary aquifer and 8 piezometers in the Mesozoic aquifer,

Group III (the wells on the outside of the barrier in the distance to 400 m from the barrier):

- measurements, twice a week,
- presently under observation are: 6 piezometers in the Quaternary aquifer, 19 piezometers in the Tertiary aquifer and 9 piezometers in the Mesozoic aquifer.

Group IV (the wells on the outside of the barrier in the distance of over 400 m from the barrier):

- measurements, once a month,
- presently under observation are: 10 piezometers in the Quaternary aquifer, 16 piezometers in the Tertiary aquifer and 15 piezometers in the Mesozoic aquifer.

The supervision of the work of the barrier is conducted on the ongoing basis and consists of:

- measurements of the location of the water level within the barrier and its surroundings,
- measurements of the salinity of the groundwater pumped by the barrier pumps,
- measurements of the quality of the groundwater in the vicinity of the diapir,
- measurements of the quality of the groundwater within the area between the diapir and the system of the drainage of Bełchatów open pit,
- measurements of the quality of groundwaters pumped using the wells within the drainage system of Bełchatów open pit.

The basic operating parameters of the barrier in the period from October 1992 to December 1999 are shown in the Table 1, and the changes in the effectiveness of the barrier and an average content of Cl^- ions in the pumped out water are shown in the Figure 4.

Table 1 Selected parameters of the protective barrier

YEAR	NUMBER OF WELLS IN THE BARRIER		DISCHARGE OF A WELL [m³/min]		TOTAL DISCHARGE OF THE BARRIER [m³/min]	AVERAGE WATER LEVEL WITHIN THE BARRIER [m above the sea level]	AVERAGE CONTENT OF Cl^- IONS IN THE PUMPED-OUT WATER [mg/dm³]
	total	operating	min.	max.			
1992	37	25	0.15 - 2.3		24.6	165	32.3
1993	37	26	0.04 - 1.7		13.6	155	39.6
1994	39	29	0.03 - 2.5		12.7	130	56.8
1995	39	22	0.04 - 3.2		12.0	122	51.2
1996	40	23	0.02 - 4.5		13.6	105	47.2
1997	40	28	0.02 - 4.5		13.4	90	56.1
1998	40	28	0.02 - 4.2		13.6	80	53.4
1999	41	28	0.01 - 3.1		12.9	65	84.7

3 WORK RESULTS AND THE WAYS OF THE APPRAISAL OF THE BARRIER EFFECTIVENESS

The implemented (Poltegor-projekt sp. z o.o., 1999 a, b) way of the protection of the water environment in the area of Dębina salt diapir seems to be effective when there is no washing of the structure of the diapir by the groundwater and, at the same time, eliminated is the threat of the flow of grounwater through the structure of the diapir. Such an effect should be achieved at possibly smallest lowering of the groundwater level of the around the diapir by the well barrier.

So far, during the barrier operation, in the area of the diapir a desired hydrodynamic system has been maintained. Presently (31.12.1999) the location of the groundwater piezometric level in the vicinity of the diapir is shown on the Figure 3. On that drawing shown are also the variables occurring during the operation of the barrier till today and the location of groundwater divide between the centre of the depression in Bełchatów open pit and protective barrier. That barrier moves to the west but its location is always in accordance with the design assumptions.

An appraisal of the effectiveness of the protective barrier work is based on the following elements:

1. The measurements of the water table in the wells and in observation wells in the barrier. The analysis of the results is conducted after each series of the measurements. Every quarter groundwater contours map are prepared and is apprised the hydrodynamic situation around the diapir.
2. Supervision of the groundwater quality pumped out by the barrier wells. The water quality is controlled in the transfer ditch on an ongoing basis with the recording of the results. The water quality in each well is controlled once a day (24 hours).

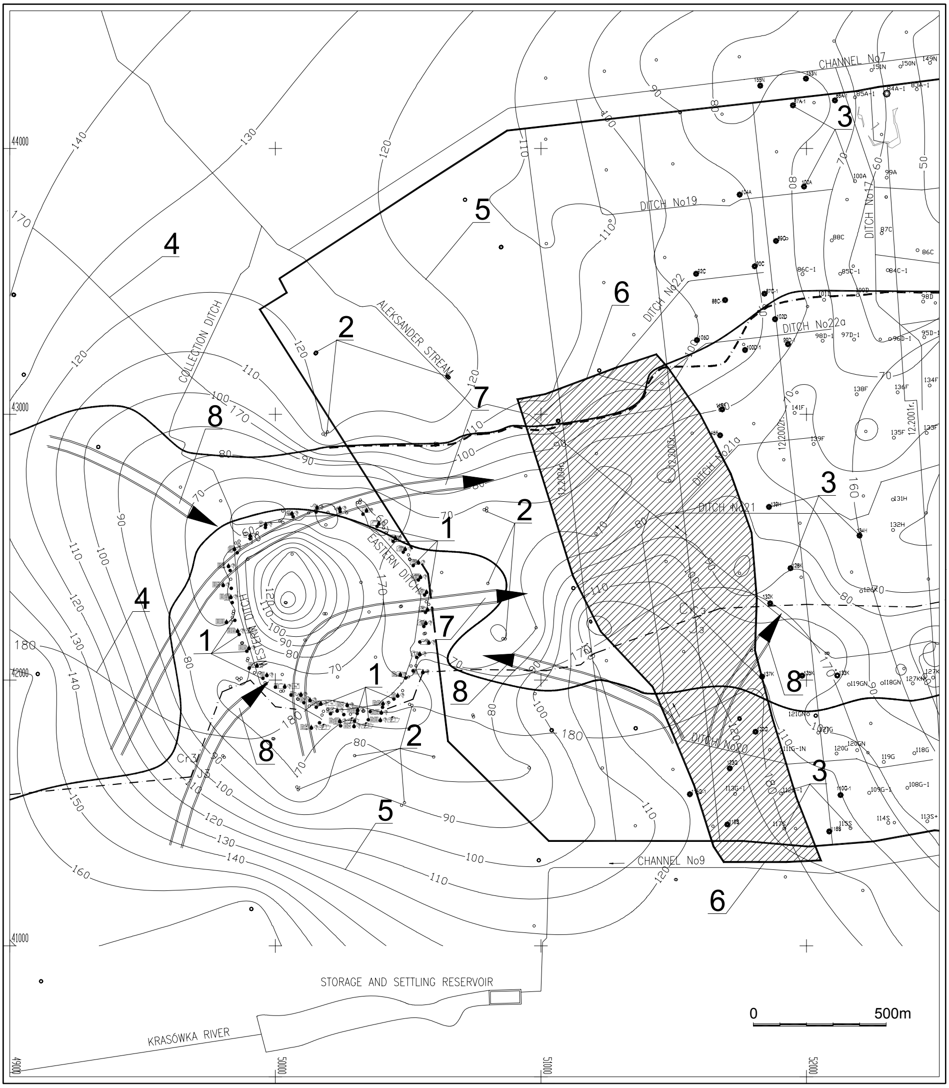

Figure 3 Map of Dębina salt diapir zone.

1- barrier wells, 2- observation wells (groups I, II, III, IV), 3- drainage wells, Bełchatów open pit 4- groundwater level contour, the state before the activation of the barrier 1992, 5- groundwater level contour as of December 1999, 6- the zone of the water flow split in the years of 1993-1999, 7- the directions of groundwater flow before the activation of the barrier, 8- the directions of groundwater flow after the activation of the barrier, the state as of 1999

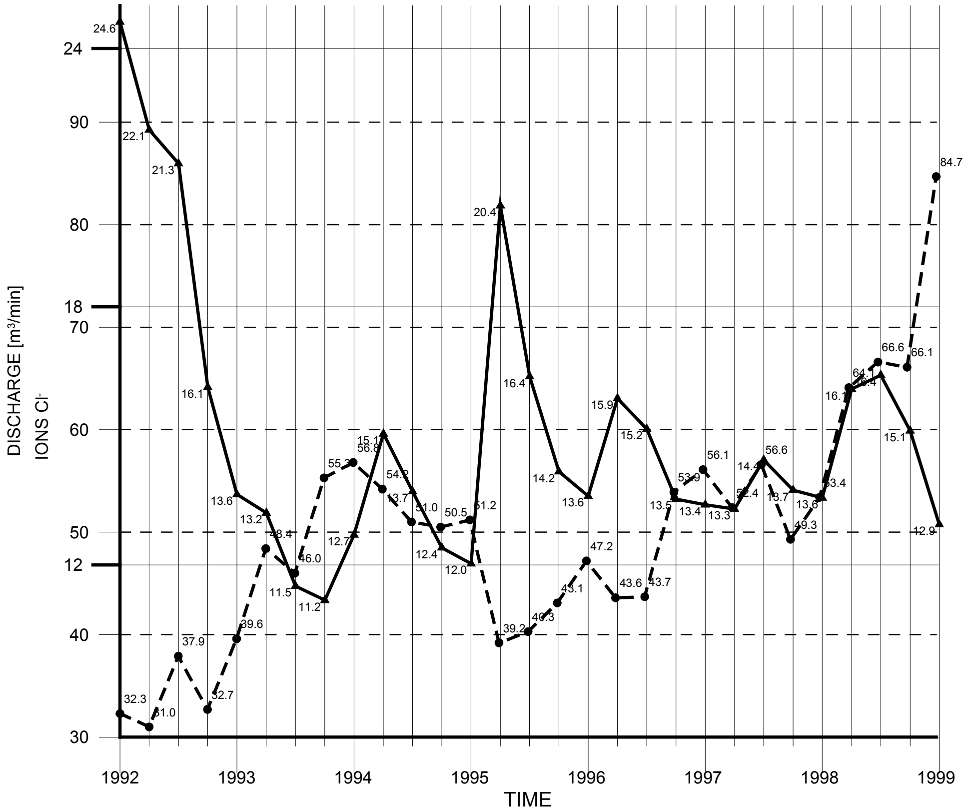

Figure 4 The graph of the barrier effectiveness and an average content of Cl^- ions in pumped out water

Recorder are: water temperature, concentration of chlorides and general mineralization. Moreover, once a quarter are tested the physical properties and content of macroelements in the waters in each well. The appraisal of the results is conducted on an ongoing basis. The changes in the water quality that are noticed are subject to an additional, detailed analysis.

3. Supervision of the groundwater quality. It is conducted via periodic chemical analyses of the waters sampled from the observation wells in the vicinity of the diapir, in the area between the diapir and Bełchatów open pit and from the drainage wells located in the western part of the drainage system of Bełchatów open pit. The analysis of the hydrochemical condition of the salt diapir area and the groundwater quality inflow to the drainage system of Bełchatów open pit is conducted once a year.

4 SUMMARY

- A high level of isolation of the salt diapir in the stabilised, natural hydrogeological conditions before the start of the drainage of Bełchatów mine was effective in the prevention of the water mineralization.
- An intensive drainage of Bełchatów open pits taking place ever closer to the slat diapir would cause the increase in the groundwater flow and washing out of the diapir's structure. As a consequence, that would lead to the salination of the mine water and to the settlement or sinking of the ground as the result of the dissolution of the salt.
- The operation of the barrier (up to 1992), taking into account the ways of the monitoring presented in this paper, confirms the assumed effectiveness of this solution.

REFERENCES

Godlewski Z., Seweryn L., Wojtkowiak B., 1990. *Uściślona prognoza wpływu wysadu solnego Dębina na jakość wód kopalnianych i koncepcja układu bariery zabezpieczającej* . Unpublished Report. Wrocław, Poltegor-projekt sp. z o.o.

Poltegor-projekt sp. z o.o., 1999 a. Bełchatów open pit. *Analiza i ocena pracy bariery wysadu solnego za okres 01.11.1998-31.10.1999.* Unpublished Report.

Poltegor-projekt sp. z o.o., 1999 b. Bełchatów open pit. *Eksploatacja bariery wysadu solnego.* Unpublished Report.

Seweryn L., 1994. *Ochrona wód kopalnianych przed ujemnym wpływem wysadu solnego Dębina.* In: Kozłowski Z. *(ed) Proc. of the First International Congress of Open Pit Mining* (in Polish). Prace Nauk. Inst. Górn. PWr 74, 217 - 224.

Seweryn L. at all, 1988. *Sposób zabezpieczenia wód podziemnych przed ujemnym wpływem przepływu wody przez źródło zanieczyszczeń.* Patent No. 273440 executed on 29.06.1988 and awarded on 28.10.1991 by the Patent Office of Republic of Poland.

Seweryn L.& Wojtkowiak B., 1995. *Hazards to water quality and water protection in the region of Bełchatów lignite mine*. In: Szczepański A. (ed) *Proc. of Conf. of Contemporary Problems of Hydrogeology* (in Polish).T VII, nr.2,193-200.

Działanie bariery studni wokół wysadu solnego Dębina dla ochrony środowiska wodnego w rejonie KWB „Bełchatów" - efekty i metodyka oceny skuteczności

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Streszczenie: Odkrywka Bełchatów ma aktualnie głębokość około 200 m, a docelowo głębokość ta wzrośnie do około 280m. Ilość wód pompowanych z systemu odwadniania kopalni wynosi około 350 m^3/min. W rejonie złoża, na głębokości około 2700 m występuje permskie złoże soli. Lokalne wyniesienie tego złoża w postaci wysadu (wysad Dębina) rozdziela złoże Bełchatów na pole Bełchatów i pole Szczerców. Przepływ wód podziemnych przez strukturę wysadu stanowi zagrożenie dla jakości wód podziemnych rejonu kopalni.

Zrealizowany sposób ochrony środowiska wodnego, który polega na kontrolowanym drenażu wód wokół strefy wysadu, funkcjonuje od 6 lat. Obecnie w eksploatacji znajduje się 28 studni tworzących barierę wokół wysadu. Aktualna depresja na obwodzie bariery wynosi około 115 m, a sumaryczna wydajność studni waha się w przedziale 13 - 15 m^3/min. Ochrona wysadu przed rozmyciem funkcjonować będzie musiała jeszcze około 50 lat, tj. do czasu zakończenia eksploatacji złoża oraz przygotowania wyrobisk poeksploatacyjnych odkrywek Bełchatów i Szczerców do rekultywacji wodnej. Artykuł prezentuje sposób ochrony wód podziemnych w otoczeniu wysadu oraz zawiera omówienie dotychczasowych efektów i metodyki oceny skuteczności działania bariery ochronnej.