Water Protection in the Region of Bełchatów Surface Mine of Lignite Against Salt Diapir Impact

By Zbigniew GODLEWSKI[1], Jacek LIBICKI[1], Ludwik SEWERYN[1], Boguslaw WOJTKOWIAK[1]

[1]POLTEGOR Engineering
53-332 Wroclaw, Powstańców Śląskich 95, Poland

ABSTRACT

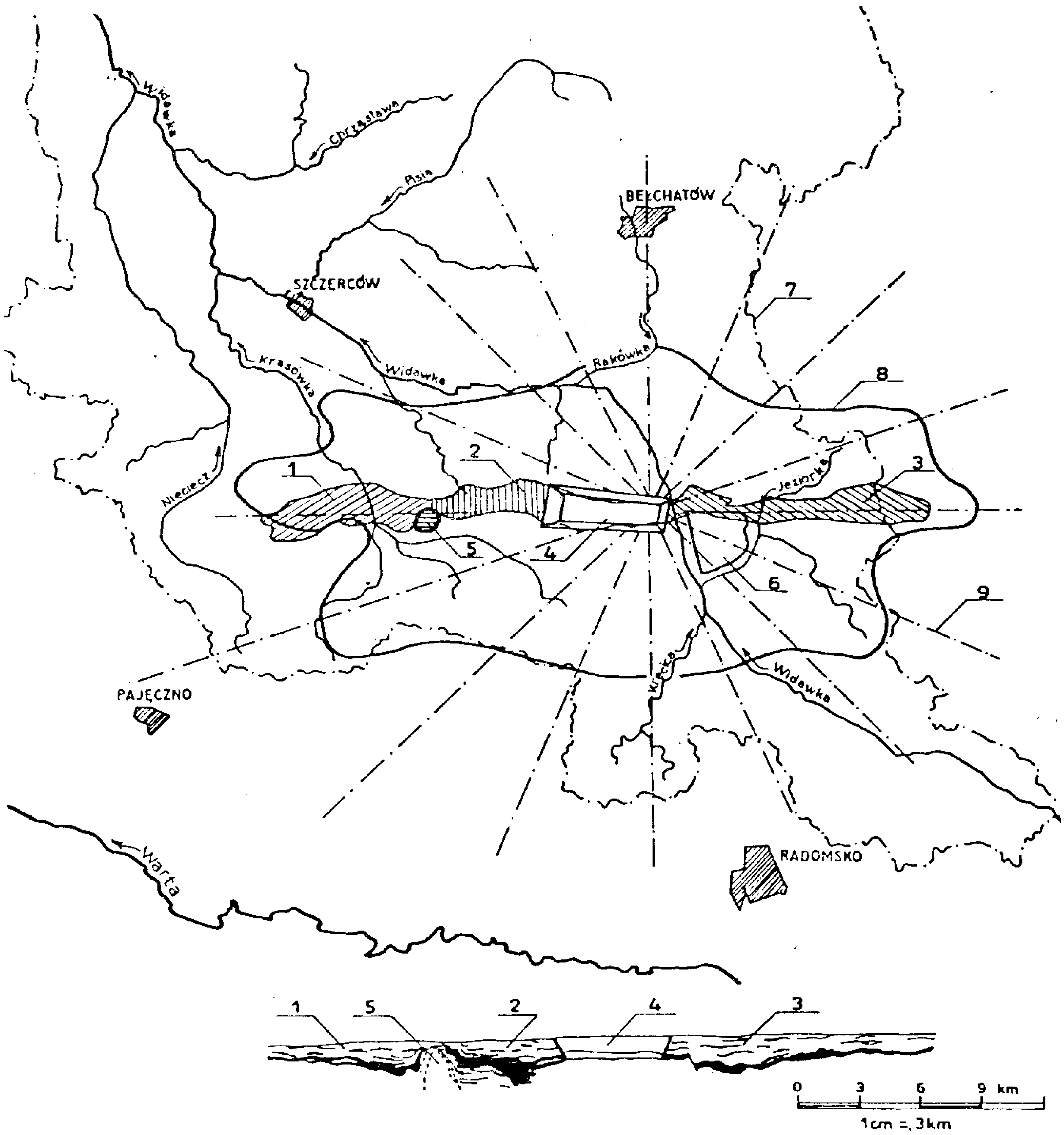
The paper presents hydrogeology of Bełchatów Lignite Basin including salt intrusion "Dębina" and consequent hazard for mine waters to be salted due to dewatering operations. Description is also given for methods of mine water protection against salinization, and ground surface subsidence which could occur as a result of salt washout by the ground water stream. A barrier of balanced depression wells is presented as protection methods. Measures of neutralizing brine are also handled as planned to be undertaken, if full efficiency of the wells barrier could not be achieved.

INTRODUCTION

The Bełchatów Lignite Basin is located in the Central Poland. The yearly precipitation varies here from 360 to 800 mm, and average is about 600 mm. The long-shaped basin laying evenly with a parallel of latitude has total length of about 38 km and width between 1.5 - 2 km. Lignite deposits occur in a graben of average depth approx. 400 m, and is divided into three fields:

- Szczerców field on the Western side,
- Bełchatów field in the middle, and
- Kamieńsk field on the Eastern side.

The natural boundaries for basin division into a/m fields represent the salt intrusion "Dębina" between Szczerców and Bełchatów fields (Fig. 1) and Widawka River fault between Bełchatów and Kamieńsk fields.



1 – Szczerców Field
2 – Bełchatów Field
3 – Kamieńsk Field
4 – Bełchatów Open Pit
5 – Salt Diapir „Dębina"
6 – Spoil Disposal of Bełchatów Open Pit
7 – Boundary line of Widawka river watershed
8 – Cadius of depression cone of Bełchatów Open Pit in 1990
9 – Ground-water observation line

Figure 1. Map of Bełchatów Lignite Basin

The geological structure of the region incorporates the following formations:

Mesozoic sediments represented by the Jurassic and Cretaceous formations are a continuous substratum for Tertiary and Quaternary ones. The Mesozoic roof depth varies from about 80 m below ground level on the Southern side of to some 200 m on the Northern side, and it is approx. 300 - 600 m within area of the graben. The Jurassic sediments are mostly represented by the Malm limestones and marls which are characterized by strong fissures and well developed Karst. The Cretaceous formations are represented by the Upper Cretaceous marls, limestones and sandstones of different fissuring rate. The Tertiary formation is limited to the area of graben and three characteristic series are here represented. The lowermost, sandy series mostly is of average thickness approx. 60 m; and the uppermost one is clayey-silty-sandy series of thickness approx. 20 m. The depth of lignite roof in the axis of seam varies from about 130 to above 200 m.

The Quaternary formations are encountered within area of coal basin and outside this area, where they are mostly seated directly on the Mesozoic substratum. The average thickness of the Quaternary within area of lignite is about 100 m and outside this area, about 10 m. The sandy-gravel formations are prevailing while clays and silts are encountered in smaller amounts.

The important elements in the structure of Bełchatów Basin are tectonic phenomena within Mesozoic base along with the Karst within Upper Jurassic formations and also, a burried valley running in parallel to the main fault. Sands and gravels are deposited here directly on the Mesozoic formations (Cretaceous, Jurassic) and have average thickness 200 to 300 m.

Owing to well developed hydraulic contacts, the groundwaters occurring in the Quaternary, Tertiary and Cretaceous-Jurassic formations represent one common, but lithologically diversified aquifer. The primary, free aquifer was originally encountered at a depth from 1 to about 5 m below ground level. The permeability for Quaternary and Tertiary and Mesozoic formations are 20 m/d, 2 m/d and 5 m/d, respectively on the average. The water quality in specified subaquifers is similar. They are characterized by a low TDS content, mostly below 300 mg/m^3 and also, by high total iron content (up to several mg/dm^3). Despite the salt intrusion in natural hydrogeological conditions the chlorides content does not exceed 50 mg/dm^3 and most frequently, it varies from 7 to 10 mg/dm^3. Only seldom, an increased TDS content was found in few places and in single wells made close to some faults in the Szczercow field (west from salt intrusion).

In view of salt diapir impact on the water environment, the hydrogeological exploration in its region allows to say that:

- highly isolated salt body under naturally stabilized conditions prevented effectively waters against salinisation,
- extensive open pit drainage carried out closer and closer to the salt intrustion will result in an increased groundwater flow rate and in washing out its structure and consequently, in mine waters salinisation and can lead also to the land subsidence as a result of salt dissolution.

The mining operations are carried out by a parallel advance system from the East to the West, with yearly face advance between 300 and 500 m. They were started with overburden stripping in 1977 and lignite mining in 1981 at a distance of 11 km away from the salt structure. The crawler mounted bucket wheel excavators and belt conveyors have been employed for in-and off-pit operations. The lignite production rate is approx. 38 mill. tons per year, and the overburden stripping volume is 120 mill. m^3 respectively. Almost all lignite is fired in the 4320 MW (12 x 360 MW) Bełchatów Power Plant.

The open pit drainage is made by deep (down to 350 m) and large-diameter (up to 1,2 m) drilling wells arranged in outer and inner barriers.
A subsidiary function is performed by the auxiliary dewatering facilities installed within the open pit, namely:

- pumping wells,
- overfall-pumping and recharged wells,
- drainage ditches and trenches,
- pumping stations within the open pit.

The dewatering operations were started in 1975. A total volume of water pumped in the drainage system is now about 350 m^3/min., but it come up to 500 m^3/min. to a maximum (in 1985). From the beginning, 2.9 bill. m^3 of water has been pumped out, and total number of wells drilled is 1230. The average radius of depression cone around the open pit is 14 km.

To monitor drainage effects and to determine impact of operations on the adjacent terrains, the following is effected:

- meteorological survey,
- groundwater level monitoring in 750 piezometric tubes at open pit and within area of depression cone,
- water quality examination,
- control of efficiency of drainage system elements,
- observations of drainage effects (land deformation, agriculture - forestry growing rate).

HYDROGEOLOGY OF SALT DIAPIR

Geological structure

At the turn of Miocene/Pliocene, a local upfolding of Permian salt seposit has occurred to form salt dome called "Dębina" now. The structure of intrusion incorporates:

- salt body,
- anhydrite-gypsum cap,
- breccia formations.

In the horizontal projection, the intrusion looks like an irregular ellipse of elongated axis towards N-S and sizes 500 x 650 m, with eccentrically displaced culmination of salt table drilled at a depth of 170 m. In the vertical section, the diapir is shaped as a plug rising from N, W and E at a dip from 70° to 85°. From S, the inclination of walls is not so steep and varies from 55° to 60°.

The salt body is covered by an anhydrite-gypsum cap of thickness from 25 to 70 m. On the slopes, the cap thickness is reduced to some 10 m. The outer portion of diapir is breccia zone built from crushed and mixed Jurassic, Cretaceous and Tertiary rocks of max. thickness approx. 60 m, but considerably reduced even to several meters on the steep walls of diapir.

The spatial shape of diapir has been determined with a high probability to a depth of about 500 m basing on the comprehensive analysis of geological and geophysical exploration with the use of computer for three-dimensional gravimetric interpretation.[1] Recently made test holes, observations wells and first dewatering wells have generally proved its predicted shape.

Within area adjacent to the diapir, there are encountered steeply upward-sloped Jurassic-Cretaceous formations and Tertiary lignite-bearing sediments.

Hydrogeological conditions

Within area adjoining the diapir, three aquifers occur having hydraulic connections. This is evidenced both by a position of original-ground water table which has been stabilizing almost evenly at a depth from 1 to 5 m below ground level (4) and now, as a result of dewatering operations, at a depth of 15 to 35 m.[2]

Quaternary aquifer sands and gravels of thickness 30 to 60 m, has free water-table only locally confined by overlying patches of clays and silts. Relatively high although variable permeability (1.6 to 20 m/d) has been found from pumping tests. The considered aquifer is seated above the diapir on breccia formations, from the West-on Cretaceous formations, within remaining area - on sandy Tertiary formations.

Tertiary aquifer encountered in fine and medium-grained sands and silty sublignite series. In general, these are confined waters of subartesian pressure (0.9 MPa), and confining beds are usually silt lenses and lignite seam. The coefficient of permeability "k" from pumping tests varies from 0.17 to 2.5 m/d. This aquifer is in contact with the diapir structure from N and E.

Cretaceous - Jurassic aquifer occurs in the limestones and marls and less frequently in sandstone. These are confined fissure waters of subartesian pressure (1.7 MPa), and the confining beds are clay and silt patches on the hanging wall of substratum and also, underlying discontinuous siltstone and claystone beds. The permeability of those formations is extremely diversified. The highest values (k = 7 up to 14 m/d) have strongly fissured and cavernous Jurassic limestones and the lowest values prevail for Kimmeridgian marls (k less than 1 m/d). The Jurassic formations adjoin the diapir structure from SW. The Cretaceous formations are in contact with the diapir within remaining area.

Hydrogeology of salt structure

When drilling the anhydrite-gypsum cap and breccia the fissuring and caverning were found, particularly in the breccia zone, being manifested by flushing decay and low and even none core recovery. From pumpings low values of permeability coefficient have been obtained varying from 0.006 to 0.13 m/d.[4]

Groundwater quality

Waters encountered within area adjacent to the diapir are mostly fresh, mainly two-ion type HCO_3 - Ca, slightly alkaline reaction, soft to medium-hard (9 - 14°h), with a prevalence of carbonate hardness. The TDS content varies mostly from 200 to 300 mg/dm^3, and up to 600 mg/dm^3 to a maximum. In most cases, the chlorides content is less than 20 mg Cl/dm^3 and up to about 200 mg Cl/dm^3 in few cases. The SO_4 content varies from 10 to 20 mg/dm^3, and up-to some 50 mg/dm^3 to a maximum. As depth becomes greater an increase in TDS content is observed in general, which for the uppermost Quaternary, underlying Tertiary and lowermost Cretaceous aquifers is 210 mg/dm^3, 260 mg/dm^3 and 380 mg/dm^3 on the average, respectively.

Besides, a number of anomalies has been found, particularly within Tertiary and Mesozoic aquifers being in contact with the diapir structure where TDS and chlorides content was varying from 1500 to 4900 mg/dm^3 and from 470 to 820 mg Cl/dm^3, respectively.

The groundwater in breccia have different chemical composition situated between Cl-SO_4 - Na and Cl - Na types (salt waters and brines). The TDS and chlorides content varies from 1610 to 54800 mg/dm^3 and from 39 to 32300 mg Cl/dm^3, respectively.[(3)]

PREDICTION OF SALT DIAPIR IMPACT ON MINE WATER QUALITY

In natural conditions, the salt diapir was kept in the hydrochemical equilibrium with adjacent fresh groundwater. However, the dewatering approaching from the East will bring an increased groundwater flow rate from the diapir area towards dewatering wells at open pit and an increased hydraulic gradients, as illustrated in Fig. 2a.

The drawdown within area of salt diapir, which is now about 15 m, will increase there up-to some 180 m in final phase. The prediction of groundwater table on both sides of the diapir between 1995 and 2015 and relevant values of hydraulic gradient are shown in fig. 3a.

The increased groundwater flow rate within area of the diapir will produce an important hazard for washing-out its structure. A minimum value of hydraulic gradient equal to $i = 0.004$ which initiates washing process will be 4 times as high in 1995 and 32 times as high in 2015.

Volumes of groundwater flowing through the diapir, as calculated from mathematical model, will vary from 3.59 m^3/min. in 1995 to 7.18 m^3/min. in 2015. Assuming TDS of those waters to be between 15 and 25 g/dm^3 (as estimated in physico-chemical tests on water samples taken from the diapir structure), the total volume of salts washed out from the diapir till 2015 would amount to 1,090.000 tons. Such a large volume of brine would result in increased pollution of rivers receiving mine waters. The increase in TDS and sulphates in Widawka River would amount to approx. 300% while that in chlorides would be as high as more then 1600 %, which is not allowed according to environmental standards.

Protecting drainage around the diapir, will reduce volumes of brines and will vary from 0.36 m^3/min. in 1995 to 1.25 m^3/min. in 2015. The total volume of salt washed out from the diapir till 2015 will amount to some 162,000 tons.[(3)] Moreover, when protecting drainage should fail, salt washing, if any, could lead to the surface subsidence. Eliminated or limited groundwater flow through the diapir, owing to the use of a barrier of balanced drainage wells, shall prevent those phenomena.

HOW TO PROTECT WATER AGAINST SALINIZATION

To select the best option for protection of water against pollution many ways were considered:

- surrounding sealed cut-off walls made by different methods,
- sealing of salt body cover itself or gypsum-clay cap,
- barrier of drainage wells,
- barrier of recharge wells,
- full exploitation of salt.

The preliminary studies of hydrogeological conditions and technical aspects have shown that the only two options i.e. sealed cut-off wall to be made with grouting method, and the barrier of drainage wells are feasible.

Many alternative concepts for those measures have been developed, and techno-economic comparison analysis has been made.

The main parameters of grouting cut-off wall would be as follows(6):

- length of wall approx. 3000 m (ring round the diapir at a distance of some 100 m away from a max. radius of the dome cap,
- number of injection holes (spaced every 3 m) about 1000 nos.,
- average depth of injection 425 m (total drilling length - 420,000 m),
- volume of sealed rock mass 3,600.000 m^3,
- injection medium - for sealing sands and weak sandstones - water glass solution with hardening agent, for Jurassic and Cretaceous formations - clay - cement materials with fly ash (estimated total volume of sealing medium - 1,908.000 m^3),
- necessary additional tests - 50 holes to be drilled to a depth of about 500 m, and laboratory, field and model tests to determine filtration parameters of sealed rock, injection technique and injection medium composition.

The parameters of drainage wells are given further on.

The option with a surrounding drainage wells barrier has been admitted to be most favourable. The alternative with cutt-off wall was declined because it would be an experiment from the viewpoint of sizes and sandy formations to be sealed at depth without parallel so far. It could be followed by a substantial hazard that such a screen would not be sufficiently effective. But first of all cost would be three times as high as that of well barrier.

DEWATERING WELLS BARRIER

The barrier is to:

- avoid water flow within area of the diapir and to prevent the salt structure from being washed out,
- protect mine waters against being polluted by brines from the diapir area.

The wells will serve as a hydraulic curtain.

How is the barrier to operate?

It will be created such a hydraulic scheme where the depression between wells will be somewhat higher than the open pit drainage impact. It will be effective on condition that an even depression is provided along the line of whole barrier. In the new hydrodynamic scheme pure waters flowing to the barrier from outside and brines occurring within the diapir, and waters between the diapir and barrier as well, will be captured by the barrier-forming wells and pumped to the outside. The alternative is illustrated in a schematic diagram as shown in Fig. 2b.

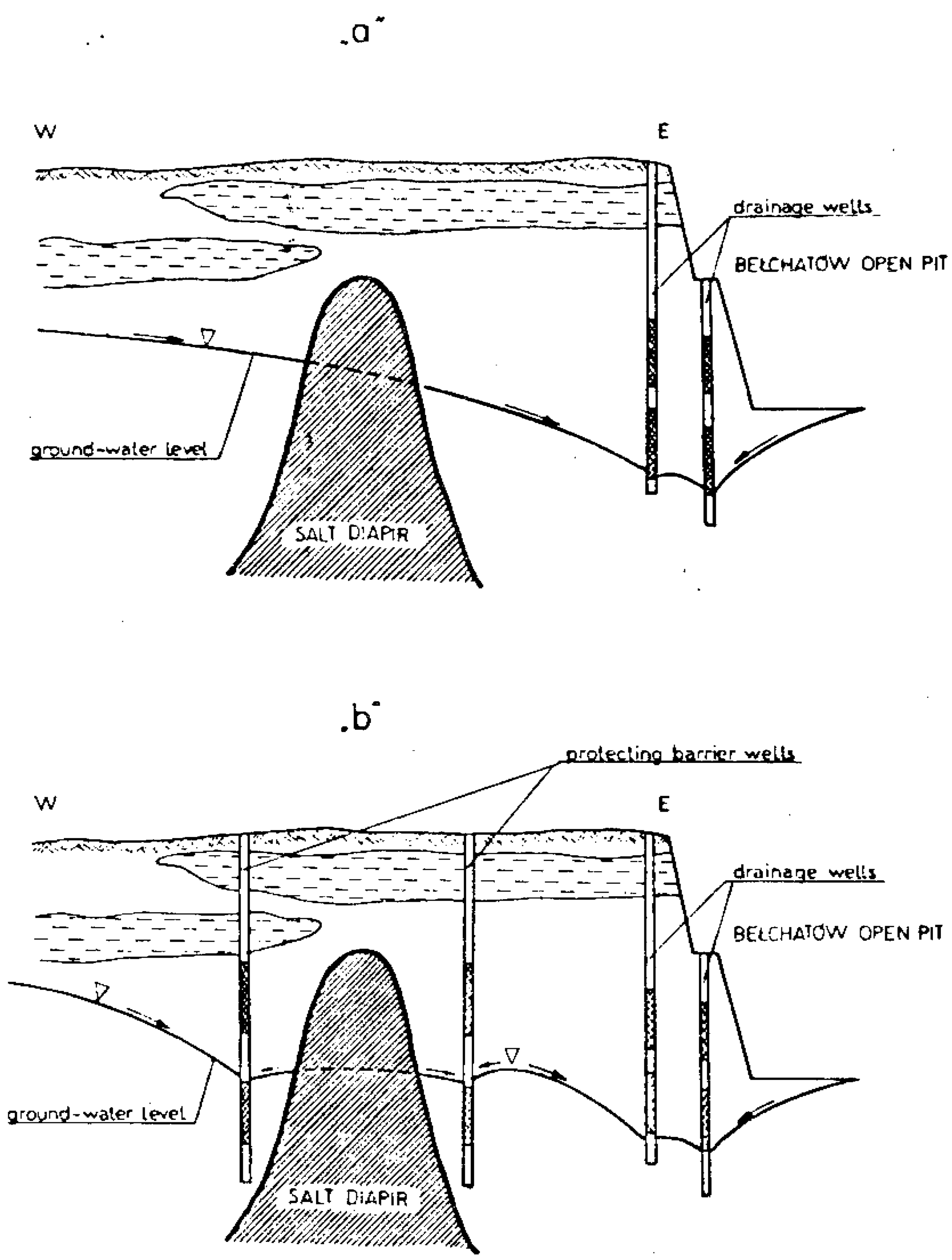


Figure 2. Scheme of Ground-water Flow Through Salt Diapir "Dębina"
"a" - without protecting barrier
"b" - with protecting barrier

A preliminary hydrodynamic model based on the three-dimensional mathematical analogue has been made with reference to the protecting barrier. The inflow rate to the barrier has been estimated at 23 to 40 m^3/min. The results have testified to a satisfactory efficiency of the barrier till the end of open pit life and also, to a stability of the area where underground water stream flows in different directions round the protecting drainage.

The predicted depth of groundwater pumping level in the barrier between 1995 and 2015 is shown in Fig. 3b.

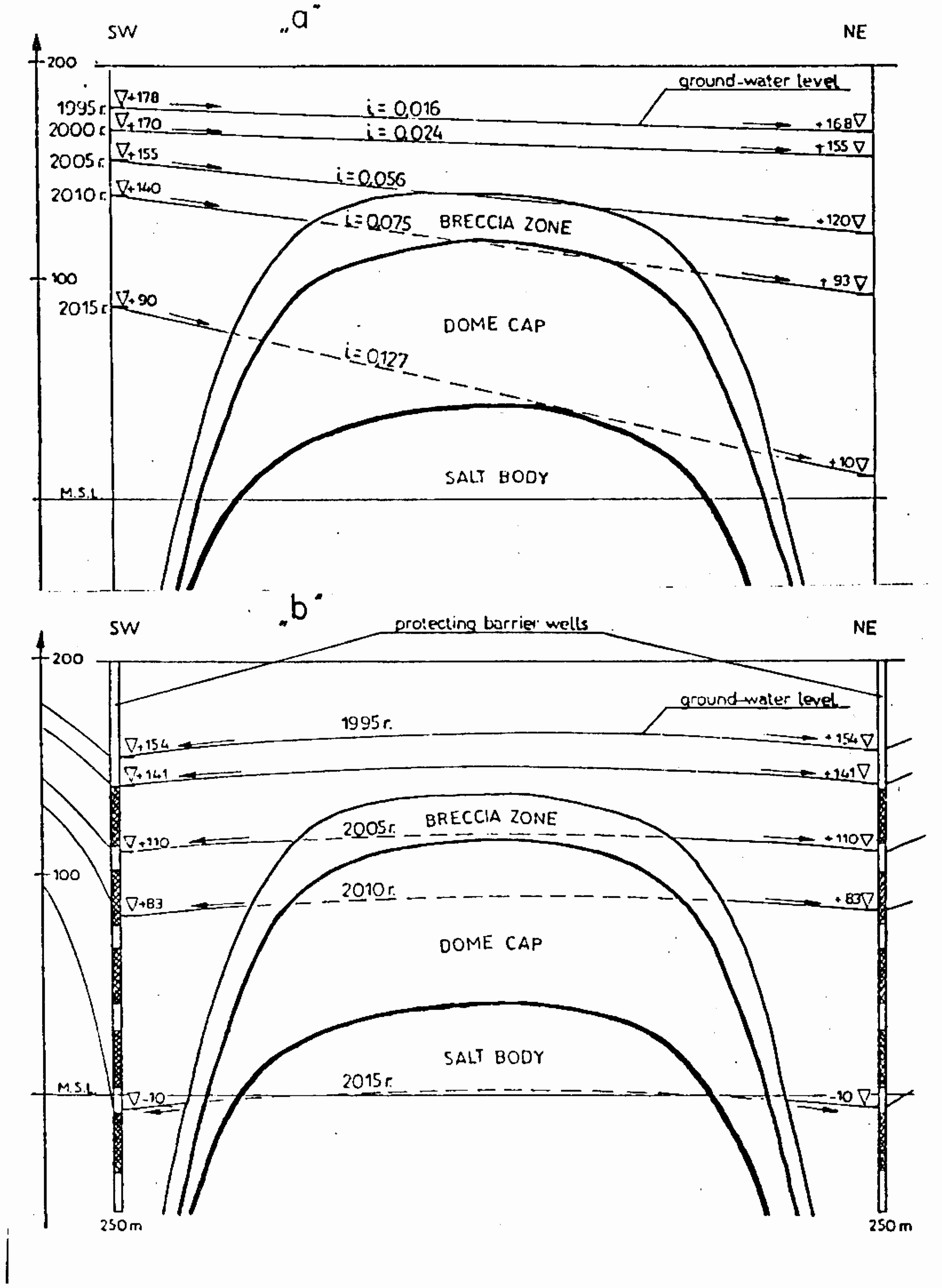


Figure 3. Prediction of Ground-water Level Within Area of Salt Diapir "Dębina" between 1995 and 2015
"a" - without protecting barrier
"b" - with protecting barrier

Parameters of protecting barrier

- barrier wells - 37 pcs., depth from 220 to 260 m,
- pilot holes for barrier wells - 21 pcs. depth from 310 to 350 m,
- observation holes - 40 pcs., depth from 60 to 265 m, in this: inside the barrier - 10 pcs, between wells - 19 pcs., outside - 11 pcs.,
- water evacuation - western and Eastern ditches (2 nos.), and gathering ditch.

Barrier operation

The operation planned to be started in May, 1992 will be carried out to create and to maintain such a hydrodynamic system where the groundwater flow through the salt diapir will be avoided with, however, a highest admissible pumping level in the wells and between them. So, a depression will be produced in the wells step by step to a depth not larger than that necessary to form a desired arrangement of streams in the diapir region. Hence, it will be necessary to keep strictly time-varying pumping of the drainage system in relation to the increasing impact of open pit dewatering operations on the considered area. The operation of all wells will be under strict control and will require the following main conditions to be satisfied:

- continuous operation of wells,
- pumping of wells at a rate assuring precisely defined position of water table to be maintained between wells,
- when an individual well is put out of operation necessary correction of pumping in neighbouring wells,
- when a group of wells is put out of operation in emergency, necessary correction of pump regime in all other wells,
- from two latter conditions, it results that pumps are needed to be installed in the wells, so as to provide a corresponding margin of yield in case a correction of well regime should be necessary.

Making use of drilling results and pumping experiments, a computer modell will be developed before starting with operation. It will enable to simulate the barrier regime and to determine:

- necessary depressions between the wells and in selected observation holes outside the barrier,
- yield of individual wells corresponding to those depressions,
- necessary corrections in the yield of neighbouring wells when scheduled stoppage of individual wells is the case,
- necessary corrections in the instantaneous capacity of the whole barrier when emergency stoppage of a group of wells is the case,
- correction in the operating conditions of wells when increased salinity of water pumped from such a well is the case, if any.

The first phase of barrier operations, i.e. till the end of 1992, should be considered as an experimental period. At that time, test stoppages of individual wells and their groups shall be carried out to verify the model. The results obtained will be used to verify the model for subsequent control of current operation and will enable the supervising persons to make adequate decisions when scheduled and emergency stoppages of wells are the case.

Hydrogeological monitoring

To maintain steady operating conditions of the wells and its running control it will be necessary to run the following measurements and surveys:

- measurements of water level in the wells and piezometers,
- measurements of volume of water pumped from the wells in Western and North-Western ditches, and in the collecting ditch as well,
- water quality control and tests in each well and cumulatively in the ditches,
- water quality control and tests in the piezometers.

SALT WATER MANAGEMENT

However, it is not unlikely to disclose other, apart from the salt diapir "Dębina", salt water sources not identified until now. Most of all, such a hazard can occur after the drainage depth has been increased to make possible mining operation in the deepest portions of lignite seam. In some wells, the deep-circulation waters can occur then being in contact with deeper salt structures, if any. If the pollution of some mine waters exceeds standards of purity in the receivers special measures will be undertaken. The procedure will be adjusted to the volume of brine and degree of salinity. The following methods are considered to be used as alternatives:

- controlled water discharge to the receivers in a way so as to provide an adequate dilution with pure waters,
- making use of brine in the hydraulic storage of ash from the neighbouring Power Plant,
- recharge brine into the deep rock mass,
- water desalting.

Those problems are now a subject of studies to be completed in 1991. The next phase will be feasibility study of particular options to select a most favourable method.

CONCLUSIONS

1. As result of Belchatów open pit drainage, a hazard can be produced for washing the salt body "Dębina" and mine water pollution as well. A possible salt washout could also effect the land subsidence.
2. To avoid or to limit those hazards it is necessary to realize a program of preventive measures. Many alternatives have been studied.
3. Basing on the multialternative analysis, a method has been selected consisting of balanced pumping wells barrier.
4. A computer modell has been made to simulate functioning of such a barrier and control of its operation.
5. If the barrier efficiency should not be sufficient or the other salt sources should be disclosed it will be necessary to realize a program fro management of brines.

REFERENCES

1. Bobowska M. et al.: Geological Structure in the Region of Salt Diapir Dębina as Based on Geological and Geophysical Surveys Made So Far. Cracow. CHEMKOP 1988/89 (not published).
2. Dziedziak J. Et. al.: Report I of Hydrogeological Survey Round Salt Diapir Dębina. Wroclaw: PG. 1991 (not published).
3. Godlewski Z., Seweryn L., Wojtkowiak B.: Refined Forecast of Dębina Salt Diapir Impact on Mine Water Quality and Concept of Protecting Barrier Arrangement. Wroclaw: POLTEGOR 1990 (not published).
4. Overall Geological Documentation of Belchatów Lignite Basin-Bełchatów Field. Collective work. Wroclaw: PG 1983 (not published).
5. Seweryn L. et al.: Method for Protection of Underground Waters against Unfavourable Water Flow through Pollution Source. Patent application in Polish Patent Office. 1987.
6. Study of Sealing Technique for Dębina Salt Diapir. Collevtive work. Warsaw. Krosno, Cracow: PRWIG, IGNIG, AGH 1986 (not published).