REGIONAL CHANGES OF HYDROGEOLOGICAL CONDITIONS EFFECTED BY DEWATERING OF "BEŁCHATÓW" LIGNITE OPEN PIT

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ABSTRACT

Opencast mining operations in the Bełchatów Open-pit are carried out under protection of extensive and deep dewatering arrangements made and operated in advance. The deep dewatering results in changes of hydrogeological conditions in the surroundings of the pit. Their ranges and sizes are connected with the geological structure of the lignite basin region.

HYDROGEOLOGICAL CONDITIONS OF LIGNITE BASIN AND ADJACENT AREAS

The Bełchatów Lignite Basin was deposited in the narrow, East-West running tectonic rift valley of Kleszczów having width of 0.5 - 2 km. It crosses the main structural lines of Mesozoic base in which it was created. The part of rift valley explored so far is several dozens kilometers long and its maximum depth amounts to 500 m. The Mesozoic base is formed by Jurassic and Cretaceous rocks. There are aquifers such as fractured limestone, marls and sandstones. The non-aquifers such as mudstones and claystones occur only in the wings of the small structure - Łękińsko anticline.A potential hazarc to the water purity is produced by the Dębina salt dome in the central part of rift valley that divides the lignite basin into the Bełchatów field and Szczerców field. The complex tectonics of the Kleszczów rift valley is connected surley with halotectonic processes (8).

The Tertiary formations within the rift valley can be divided into three principal series with regard to the hydrogeology:

- under lignite series, mostly sandy ones
- lignite seam with minute amount of sand
- overburden with considerable amount of sand.

All series are in the direct contact with mezozoic formations and at the northern part with the deep Quaternary burried valley (1). The maximum proved depth of this valley and thickness of mostly sandy formations amonut to 300 m. The width of this valley is about 500 m and its length is greater than proved length of the basin. The aquifers occuring in the particular stratigraphic series have many connections so the whole complex of the permeable rocks create one huge and heterogenous aquifer in the whole region. Its saturation begins right below land surface. Before drainage had been started it was recharged with precipitation infiltrating to the groundwater on average rate 172 mm/year. The water table of this aquifer was concordant with the shape of terrain surface and inclined toward North-West so the groundwater runs off was in the same direction. Some characteristic data concerning the aquifers are as follows:

- Quaternary aquifer - depth about 90 m, contents of sand-gravel about 70 percent and 30 percent of clays, the average coefficient of permeability for sand-gravel series is about 20 m/d
- Tertiary aquifer occur in the Kleszczów rift valley at the depth 90-400 m, and can be devided into the under lignite and over lignite series; permeable sand strata have the coefficient of permeability about 1-3 m/d and are about half of all Tertiary formations; the other half are clays and lignite (both impermeable).
- Mesozoic aquifer - occur at the depth about 40-100 m around the rift valley, but within the rift valley at the depth of about 400 m, the average coefficient of permeability for this fissured aquifer is about 5 m/d, but is very diversified; the highest permeability occurs in karslified limestones.

The lignite basin and surroundings are in the Widawka River basin which is the left tributory of the Warta River. The Widawka River flows in general from SE to NW, but in the area near the lignite basin the river runs nearly S-N on the length of about 18 km and crosses the lignite basin perpendicularly. Below this section the Widawka River runs parallel to the basin to Szczerców and then above it in NW direction. The lignite basin and its surroundings were originaly drained by smaller water-courses tributory to Widawka: Świętojanka, Struga Złobnicka, Jeziorka and their tributory rivers (Fig.1). The original groundwater table was the most shallow in the river valleys and local terrain depressions without run-off. The waterlogged meadows in the river valleys and dips took a considerable areas. The water balance for the Widawka River basin up to Słok village before dewatering of the mine i.e. from 1963 to 72 was following (9).

Table 1

Elements of balance mm	Half-year XI-IV	Half-year V-X	Year
precipitation P	235.3	404.8	640.1
run-off H	109.6	70.0	176.6
evaporation E	95.2	365.3	460.5
P-H	125.7	334.8	460.5
retention DR	+30.5	-30.5	0

It results from this table that for total sum of precipitations feeding upper and lower Widawka River basin run-off has taken 28.8 percent but 71.2 percent has been evaporated. During winter half-year some part of precipitation was retained in form of groundwater seasonal rise, but high evaporation during summer occured at the cost of winter retention.

MINE DEWATERING SYSTEM

At Bełchatów lignite mine groundwater is controlled by largediameter pumping wells system. The wells are placed in the barriers protecting open-pit, draining its forefield and taking static waters within the pit. The depth of pumping wells depending on their location and tasks varies from 100 m to 350 m. The main task in groundwater control is to lower both the free level of groundwater and to reduce pressure in arterian aquifers down to the bottom of the openpit that enables safe mining operations (Fig. 2) to be performed. With regard to the fact that the deposit occurs in the rift valley formed in the Mesozoic aquifer it is necessary also to lower orginally confined) the groundwater table in the slopes of the rift valley and in its bottom. The pit construction required also the dewatering of Quaternary burried valley running along the Northern boundary of lignite seam. The dewatering operations started in 1973. The total number of wells drilled so far is about 900, and 600 ones are operated at present. The groundwater inflow ranged from 180 m^3/minute at the beginning, has its maximum 450 m^3/minute The total volume of pumped water from the begining to the end of 1986 is 2 139 million m^3. The maximum lowering of natural groundwater table in the eastern part of the pit and is 215 m, and average within the mining operations is about 200 m.

CONE OF DEPRESSION

The dewatering operations result in lowering of groundwater table not only in the openpit area but also in its surroundings. The lowering of free groundwater table and reduction of pressure in the confined aquifers create cone of depression around the open-pit. The drainage of the Mesozoic bed as well as of wide-spread and deep Quaternary burried valley where, as it has been mentioned above, the hydraulic water contact of Quaternary, Tertiary, Cretaceous and Jurassic aquifers occurs, results in wide spreading of drainage effect, To monitor and control the external effects of drainage, i.e. lowering of groundwater table and development of the cone of depression, the system of external piezometers has been developed. They are located along 16 lines runing radially from the drainage centre to the distance of 21 km. The spacing between piezometers are from 1 to 3 km. Total number of piezometers is ab. 200, and they are monitored in 1 to 3 months intervals.

SHAPE AND LIMITS OF THE CONE OF DEPRESSION

The shape of cone of depression is effected by the geological structure of the region and drainage progress in the particular aquifers. The drainage of the Quaternary burried valley effected from the very beginning of dewatering operations has resulted in especially intensive development of the cone of depression along this structure. The fastest development of groundwater table drawdown in this structure has been influenced by high coefficient of permeability of the formations filling it. Until 1982 the cone of depression was developing more less regularly in Eastern and Western direction. Later as a result of drainage development toward the West the range of the cone of depression was stabilized on East side and was here about 20 percent smaller than its range in the Western direction. The range of cone of depression toward South is related to draining of upper Jurassic limestones. These limestones occur at the peripheries of the Lekinska anticiline which Eastern wing has more gentle dipping and therefore,it has here greater horizontal range. The maximum yearly advance of the cone of depression in this structure was in 1978 when the Southern boundary of limestones was reached.Because this structure runs towards SE since 1980 the intensive development of the cone of depression just in this direction has been observed. It was connected with more intensive drainage of those limestones by new deep draining wells.

The smallest cone of depression can be observed toward North. The Cretaceous formations occur here in the bed of Quaternary. They have smaller permeability than upper Jurassic limestones in South. Besides,smaller volume of water is pumped from them because drainage wells are located in the axis and in the southern part of the Quarternary burried valley and drain mostly this structure.

Similarly the small cone of depression can be observed in the SW direction from the open-pit. At the first period only Eastern wing of the Lekinska anticline was drained intensively. Non permeable mudstones surrounding the nucleus of anticline built from lias sandstones isolate structures situated Western from anticline from drainage effects. This protected from development of the cone of depression towards SW. Recently the drainage system has comprised limestones of Western wing of the anticline. It influences the development of the cone of depresion toward WSW. The range of the cone of depression in SW constitutes only 50 percent of range in the W, E and SE directions.

To determine the range of the cone of depression the definition of its univocal boundaries is required. During the first period of drainage the attempts were made to find the zero (0) contour of groundwater table drawdown. However, taking into account that seasonal variations of groundwater table amount to 1.0 m, and sometimes even 2 m periodically and locally (9) it has been assumed that the limit of cone of depression is the contour of groundwater drawdown 1.0 m. It allowed the variations of boundaries of the cone of depression resulting from the seasonal of precipitation to be eliminated.

RANGE OF CONE OF DEPRESSION

The greatest increments of the cone of depression were observed during the first year of dewatering, when, additionally to the efficient operation of dewatering wells it was a drought during the summer 1976. The development of cone of depression is illustrated by the average values presented in the following table together with the precipitation rates. The direct relations of depression cone to the precipitation rate is clearly visible.

Table 2

Year	Average radius of cone of depression km	Yearly increment km	Precipitation rate mm
1	2	3	4
1975	3.3	3.3	520.0
1976	6.3	3.0	517.2
1977	6.7	0.4	757.0
1978	7.9	1.2	577.3
1979	8.1	0.2	569.9
1980	9.3	1.2	662.7
1981	9.2	-0.1	713.1
1982	10.1	0.9	483.1
1983	12.0	1.9	512.0
1984	12.1	0.1	527.0
1985	11.9	-0.2	670.0
IX 1986	12.1	0.2	597.5

The greatest increments of the cone of depression occured at the beginning of dewatering (1975 and 1976) and in 1978, 1980 and 1982 especially in 1983 when it increased by almost 30 percent. Since December 1983 the cone of depression has been stabilized. The Fig. 3 presents the development of cone of depression area, average radius related to volume of water pumped out. The area of cone of depression in 1983-85 was stabilized but the precipitation rate differed from 512 mm in 1983 to 670 mm in 1985. The output of the mine water did not change considerable during that period. However, the continuous drawdown of groundwater was observed, which enabled the open-pit to be deepened from +29 m above sea level in 1983 down to +1 m above sea level in 1985.
The increments of the average drawdown in two drainage areas (Northem and Southern) within the open-pit is showed below.

Table 3

Year	Area	
	N	S
1983	15.2 m	28.3 m
1984	4.3 m	12.4 m
1985	4.8 m	4.9 m
Total	24.3 m	45.6 m

WATER BALANCE OF AREA INFLUENCED BY MINE DEWATERING

In 1986 in the Centre for Hydrogeological Research and Mathematical Modelling in Poznań the changes of water balance in the cone of depression for years 1983-84 and for 1985 (10,11) have been calculated. The water balance of upper part of the Widawka River basin to Szczercow and Chabielice was following in years 1983-85.

Table 4

Elements of balance	Years					
	1983		1984		1985	
	mm	percent	mm	percent	mm	percent
P	512	100	527	100	662	100
H	138	27	107	20.3	175	26.5
$E + E_w$	374	73	420	79.7	480	72.5
R	-	-	-	-	7	1

The percentage of the balance elements in 1983 and 1985 does not differ from the calculated values for the period before drainage had been started.
The elements of useful balance has been calculated, as well applying the following formula:

$$P = E + E_w + H_p + W_i + R$$

where:
P - precipitation;
E - actual evaporation(evaporation from the near surface zone and infuenced by drainage);
E_w - disappearance of evaporation from the ground zone equivalent to losses of evapotranspiration increasing percolation in cone of depression;
H_p - run-off divided into infiltration from water-courses into the groundwater in cone of depression and superficial (river) run-off beyond the drainaged area;
W_i=Hg - effective infiltration of precipitation within the mine drainage system equivalent to ground run-off from the basin of Bełchatów Open-pit;
R - instantaneous surface retention.

Table 5

Useful balance of the Widawka River basin to Szczerców and Chabielice in years 1983-85 in percent

Element of balance	1983	1984	1985
P	100	100	100
E	51.5	62.0	52.6
E_w	21.5	17.7	19.9
H_p x	6.7 x	4.0 x	5.1
W_i	20.2	16.3	21.3
R	-	-	1.1

x) - in 1983 to 1984 the instantaneous retention R is included in inflow H_p.

The calculated inflow balance to the mine drainage system in 1983 to 85 allowed the sources of inflows and their relations with useful balance elements of the river basin to be determined. The balance of inflows to the drainage system of the pit can be presented by the formula:

$$Q = Q_s + Q_d + Q_{ew} + Q_i$$

where:

Q = output of groundwater drainage system
Q_s - inflow from of static resources
Q_d - dynamic inflow
Q_{ew} - additional dynamic inflow as a result of decrease of loss for evaporation by lowering of the groundwater table within the cone of depression
Q_i - water infiltration directly from water courses under influence of drainage system.

The following relations can be determined among the elements of inflow balance and useful balance.

$$P = E + H_p + E_w + W_i$$

$$Q = Q_s + Q_i + Q_{ew} + Q_d$$

These relations emphasize the close relations between water balance of the Widawka River basin above Szczerców and water inflow balance of the mine drainage system. There is lack of any relations between evaporation from the surface zone E and pumping of static resources Q_s. There is no also clear relation between precipitation P and drainage output Q.

The percentage of the particular elements of inflow balance to the drainage system of the mine is given in the table below (10, 11).

Table 6

Year	Q	Q_s	Q_d	Q_{ew}	Q_i
1983	100	45.4	22.2	23.7	8.7
1984	100	50.6	20.5	22.2	6.7
1985	100	28.9	31.7	30.6	8.8

The areaof the cone of depression increases exclusively as a result of exhaustion of static groundwater resources. The inflow from those resources Q_s in "dry" years is predominant element of the balance of inflow to the drainage system (45.4 - 50.6 percent in years 1983-84). For the "wet" years the dynamic elements $Q_d + Q_{ew} + Q_i$ are predominant. Their partion increases from 49.5 percent of inflow in "dry" year up to 71.7 percent in "wet" year. Therefore, the area of cone of depression develops mainly during dry years. Despite of close relation between elements of water balance and inflow balance:

$$W_i - Q_d; \quad E_w - Q_{ew}; \quad H_p - Q_i$$

there is no direct relation P - Q (precipitation - drainage system output). The regulators of this relation are groundwater drawdown on the drained area and area of cone of depression.

CHANGES OF HYDROGEOLOGICAL CONDITIONS AND SOME EFFECTS OF DRAINAGE

Decreasing of static resources on the area of cone of depression resulting in lowering of groundwater table brings about changes of run-off regime and character of groundwater circulation including thermic and chemical changes.

Influence of the cone of depression on the river run-off brings about decrease of river flow, even their periodical or total disappearance. Water percolating down from river-beds is one element of drainage system inflow balance to the Q_i. The volume of this percolating water is variable during one year and between years. It is greater during wet years and during freshets because at that time the surface increases. Because both groundwater and surface water percolate from the river valleys, their volume depends on river valley recharge. The down run-offs from river-beds of the Widawka River (above the mine) and Jeziorka and Kręcica Rivers were (10, 11):

in 1984 0.31 m^3/s
in 1985 0.54 m^3/s

in this from

	1984	1985
Widawka River	58 percent	52 percent
Jeziorka River	25 percent	37 percent
Kręcica River	15 percent	11 percent.

In order to keep flow in the water-courses and to decrease the water inflow to the drainage system of the mine the rivers beds and and water-courses were sealed in the mine vicinity. Such sealing resulted in changes of the natural flow and thermic characteristics of flowing water. The leak-proof river-beds separated flowing water from the underlaying aquifer. It can be observed in the Widawka River above the sealed section above the mine that the flow decreases because of losses. But seasonal variations characteristic for the natural flow are observed too. The Widawka River below the mine contains above 80 percent of water discharged from the mine drainage system. The flow value depends here on the operation of mine drainage and does not show considerable variations. The temperature of flowing water also does not change here during the year period. It is equal to the average temperature of groundwater discharged from drainage system. The TDS content in the river water below the mine depends also on TDS of groundwater pumped from drainage wells. During the first decade of drainage operation the water quality below the mine water discharged places was better than in the natural river. In general, water drained meets requirements for potable water except for the iron and manganese contents that exceed the standard values. During the last year as a result of considerable lowering of groundwater table within the open-pit, in the Cainozoic and upper Jurassic formations and also due to occurance of non permeable Dogger formations, the groundwater of higher temperature are obtained from the drainage wells taking water from Upper Jurassic or Cretaceous formations but localized near faults. The maximum water temperature pumped from the those wells is up to 30°C. However, the number of such wells in the whole system is rather small, but they cause a slight temperature rise of discharged mine water. In the 1975-76 this temperature varied from 9-11°C but at present is 11-14°C.

The other very important problem is pollution of the shallowest aquifer by antropogenic factors on the boundary of cone of depression, that locally leads to pollution of the small rest of water in this aquifer. The detailed research carried out in the Kręcica River basin (5) shows that essential part here plays ignorance of people, who are not aware of results of making use of dried up wells as septic tanks and garbage storage. The similar part plays also a large pig farm, on the periphery of the cone of depression. Dung, which was very good fertilizer, at present because of quicker water percolation (also polluted) pollutes groundwater by nitrates.
The problem that had to be solved on the area of cone of depression is to supply communities with potable water. The old wells dried. Water is supplied from new deeper water wells by pipelines. Such water intakes within the cone of depression and especially close to its boundaries, when static resource decreases, have additional effect on the deepening of cone and some local depression cones are created.
The problem of local cones is very essential because of mine responsibility for damages. The local cones of depression arise also around the municipal water intakes independent of the mining operations, but located close to mine influence area. The application for compesations are directed only to the mine. It should be pointed out here that there are no piezometers in the neighbourhood of the municipal intakes for observation of their operation effects. Municipal authorities don't install those devices and preffer accuse the mining company for damages. From the beginning of drainage operations research on influence of cone of depression on agriculture have been conducted. So far, the research has been carried out and financed by the Agriculture Department and has not indicated the negative influence on crops especially when proper agrotechnique is applied. The research performed so far on influence of the Bełchatów Mine cone of depression on environmental conditions is still continued.

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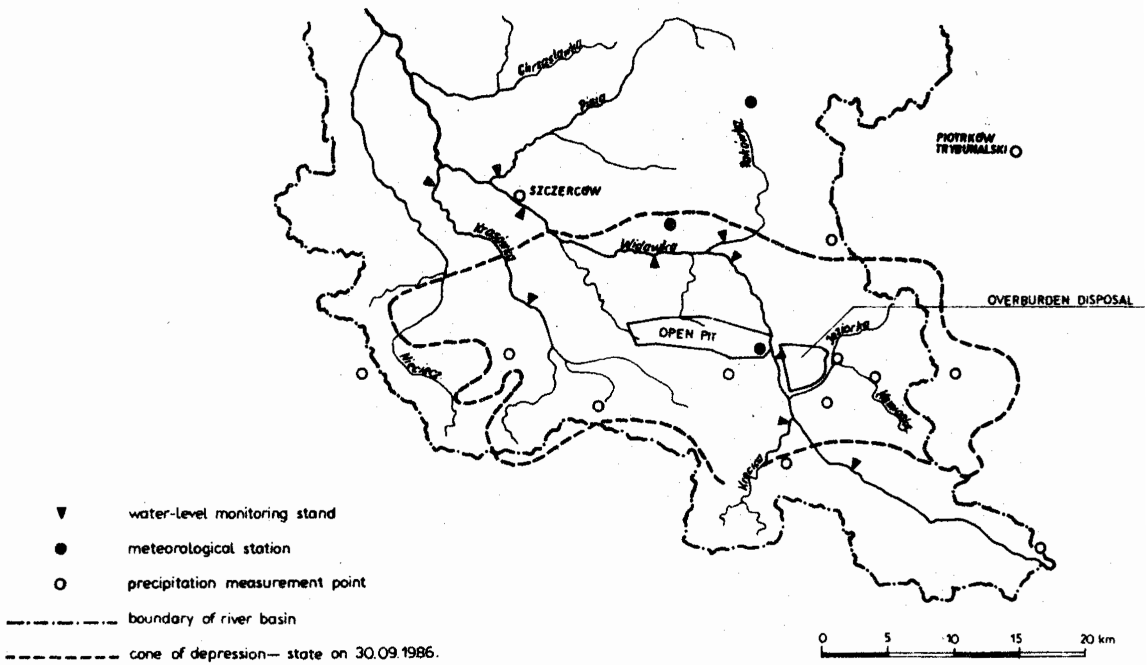

Fig. 1 Map of Widawka River Basin

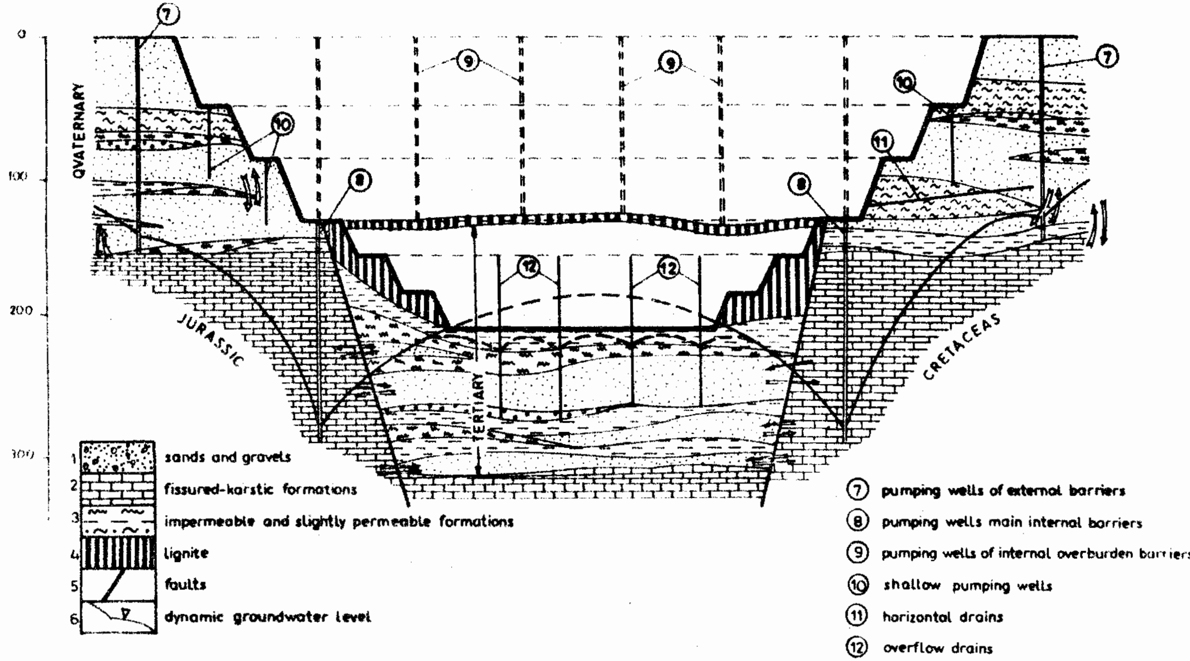

Fig. 2 Cross-section of the Bełchatów Open-pit Mine Drainage System

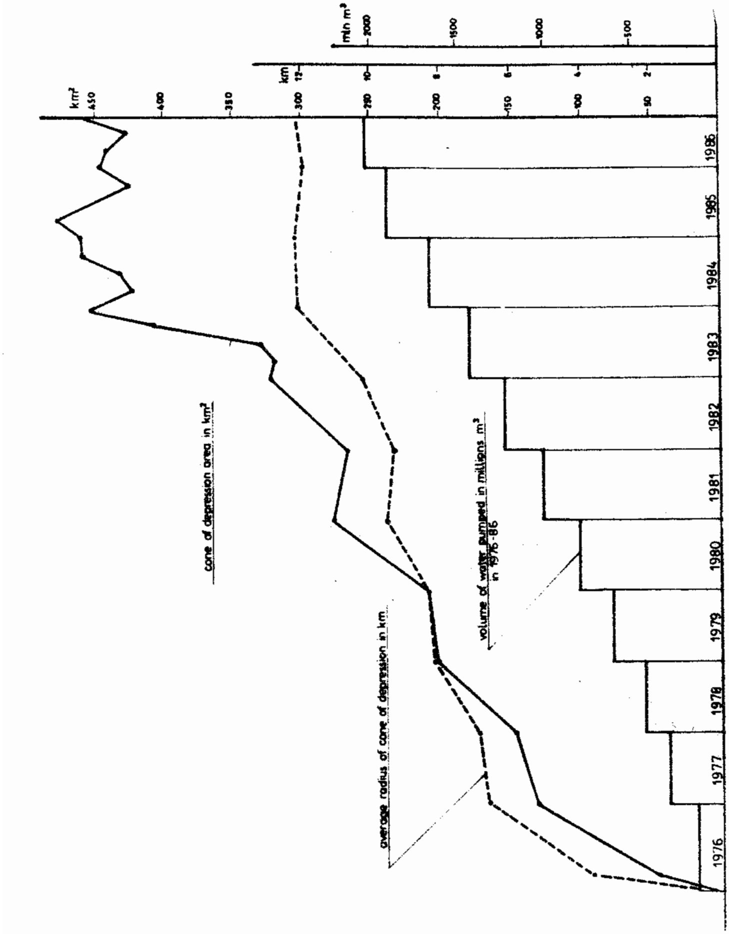

Fig. 3 Bełchatów Open Pit Cone of Depression Development