HYDROGEOLOGICAL CRITERIA OF LIGNITE BASINS DEVELOPMENT IN POLAND

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ABSTRACT

Different criteria are used when taking decision on development of a lignite basin and opencast mine construction. Among others the hydrogeological criteria have to be taken under consideration. The hydrogeological criteria can be divided into:
- technical feasibility of dewatering
- environmental impact of dewatering
- economical judgement.

Some examples of lignite basins in Poland neglected due to hydrogeological criteria have been presented.

INTRODUCTION

In Poland, there are more than 100 lignite basins that have very various geological structure and hydrogeological conditions. Among those 100 basins 11 ones is in operation or prepared for mining operations, 14 basins are relatively good proved reserves, 15 ones are basins that are not proved enough but having considerable reserves. The others are small or very small basins that are proved with different mostly small accuracy.

A given lignite basin is considered as potential for future mining operations and for detailed exploration with use of different criteria. The main criteria are following:

- overburden vs. lignite ratio, its maximum value is determined as 12 to 1, but in practice, it is smaller and does not exceed 10 to 1;
- reserves are considered in the aspect of utilization of lignite f.ex. in power plant;

- quality of lignite discussed from the point of view of its use (in most cases burning in a power plant) in the way that can be accepted from the environmental view point;
- distance of the basin from lignite consumer (of mostly from operating power plants);
- presence of objects, with which a mine can be in a collision (f.ex. cities, National Parks etc.);
- protection of environment and of well cultivated and highly efficient farm land;
- hydrogeological conditions discussed in technological and economic aspect of water control in a possible mine as well as its impact on environment;
- economy of project.

Among the criteria mentioned above the hydrogeological criterion is not the most essential, however it can have substantial impact on devision-making to construct or not to construct an open pit.

ELEMENTS OF HYDROGEOLOGICAL CONDITIONS DECIDING ON CONSTRUCTION OF AN OPENCAST MINE

Presence of groundwater that,table must be lowered before development and mining operations commence. It concerns all lignite basins in Poland. That is why this criterion is not of primary range when decision making in Poland. However, it can be the main criterion in other countries, where a possibility of optional selection does exist.

Confined or free groundwater table also, is not the main criterion, because, in Poland, both confined or free table aquifers occur everywhere. It results from very differentiated geological structure. Moreover, in most cases within the basins or right outside their boundaries hydraulic contacts occur. That causes that all aquifers create one system of connected vessels.

Share of permeable formations - the greater part of permeable formations, results in greater volume of groundwater inflow and construction of greater number of dewatering arrangements and also higher cost of groundwater control. In Poland the share of permeable formations in overburden of lignite basins varies from 20 to 75 percent.

Thickness of aquifer - is essential for hydrogeological conditions. It determines the volume of groundwater inflow to the pit, and the number of required dewatering arrangements as well as cost of groundwater control. It concerns firstly the aquifers in the overburden that must be drained entirely, but also, thickness of aquifer underlying lignite seam has influence on inflow volume and number of dewatering arrangements. Very essential is the thickness of particular layers of permeable formations, f.ex. in two basins, in overburden there are 50 percent of permeable formations that are 30 m of saturated sands. However, in one case those sands can occur as one aquifer that can be drained quite easily, but in other case those sands can occur in 10 thin layers each 3 m thick intercalated by clays. In this latter case dewatering is much less effective and more expensive.

Permeability - is one of the most significant elements of hydrogeological conditions that has influence on feasibility and economy of groundwater control. The high permeability results in great volume of groundwater inflow and extensive development of cone of depression outside. It rises costs of drainage because a great amount of water must be pumped and a mine is obliged to compensate damages in the large surroundings of the operations. However, on the other hand, drainage arrangements are efficient and operate without breakdowns. The low permeability results in small volume of water inflow and also, the cone of depression outside the mine is rather small. Therefore, the costs of water pumping and compensations for damages are low. However, low permeability results in low output of particular arrangements(pumping wells) and considerable requirements for their construction to avoid migration of fine grains of sands to the well. This phenomenon causes colmatation of filter coat, quick wear of submersible pumps and their frequent breakdowns.An effective drainage of slightly permeable aquifer is difficult. Some groundwater, rest among drainage arrangements. It results in taking into account presence of water, when slope stability is calculated. This causes slopes more gentle and in sequence overburden versus lignite ratio becomes worse. The most favourable permeability should be assumed to average value 5-15 m/day. Such value enables effective drainage with relatively reasonable costs both of groundwater pumping and compensations for damages around. A very significant is heterogenity of permeability. The most unfavourable conditions can be met, when in one basin high and low permeable formations adjoin one another and especially when high permeable aquifer lays on low permeable one. It is quite frequent case, because Quaternary aquifers are almost always more permeable than lower Tertiary ones. Similar unfavorable conditions occur when basins are cut by Quaternary burried valleys (often filled with gravel) continously recharging low permeable aquifers in overburden or under the lignite seam. To sum up, the most unfavourable conditions are when in one basin direct contacts have numerous high permeable aquifers with numerous low permeable ones.

Boundary conditions are very various and can play a very important role when feasibility and costs of drainage are considered. The most favourable conditions occur when basin is surrounded by geological structure limiting groundwater flow, f.ex. surroundings is built from clay formations. Dynamic inflow of groundwater is relatively small and also the spread of cone of depression is limited. The most unfavourable conditions occur when in the intermediate vicinity of lignite basin, are the contours of continuous recharge such as rivers, lakes or large highly permeable groundwater reservoirs.

High and continuous groundwater inflow is the greater the greater part of circumference of the basin is surrounded with the contour of continuous recharge and also, the greater is permeability of layers between recharge and drainage contours.

I n f i l t r a t i o n of precipitation water is one of the minor factors affecting the inflow volume. Infiltration factor depends on morphology of terrain surface permeability of superficial soils and flora. The convex forms sloping down from the centre toward the basin limits are favourable to increased surface water run-off and decreased ground percolation. The contrary situation can be observed when a basin creates concave form (valley). Superficial impermeable layers cause increased surface run-off and small ground percolation. Superficial permeable soils result in the opposite effect. Also, richer flora has influence on increased evapotranspiration.

Q u a l i t y o f g r o u n d w a t e r that must be pumped out is a very essential factor, that influences the possibility and costs of water control. Clean mine drainage water that meets the standards can be discharged to lakes or streams. Dirty water (f.ex. with salt contents), can be discharged only after treatment or have to be batched in such a way not to change the original water quality in the receiver. This is sometimes difficult even impossible to be met. It is one of the most important hydrogeological criteria that influences more and more the decision-making.

H y d r o g e o l o g y R e l a t e d C r i t e r i a . Among the hydrogeology related criteria of decision-making on feasibility and economy of mine water control at opencast mines three (3) groups of problems should be identificed:

1. Technological feasibility.
2. Environmental aspects.
3. Economy.

T e c h n o l o g i c a l f e a s i b i l i t y of dewatering exists almost in every case. Though special cases may happen when reasonable range of dewatering operations is not able to drain overburden in such a degree that guarantees slopes stability. Such a situation may be met when near draining contour (f.ex. drilling well barrier along slopes of open pit) is a contour of intensive aquifer recharge (f.ex. river flowing in the post-glacial valley filled with gravels). When deep drawdown (f.ex. 160 m) is required and only narrow safety pillar (f.ex. 300 m) is economic hydraulic gradients can have so high values, that is impossible to intake all groundwater with pumping wells. It is possible then to cut-off water flow by sealed screen. However, the maximum depth of sealed screen made in narrow-space ditch filled with impermeable material amounts to 70 m. A deeper screen could be made with injection method, however, for considerable and various permeability of aquifer it would not be tight. So such a case can be qualified as case for which there is no technological feasibility of drainage in the degree that ensures slope stability. It is also almost impossible in practice, to drain silty aquifer of permeability below 1 m/day when is recharged continuously laying over or adjoining wide spread aquifers of permeability 100 m/day. In such aquifers it is impossible to cut off the groundwater flow efficiently. Then the number of drainage arrangements in such aquifer has to be absurd high.

E n v i r o n m e n t a l a s p e c t s can exclude from the point of water protection feasibility and economy of mine drainage. It is a case when damages caused by development of cone of depression in the opencast mine surroundings cannot be accepted, f.ex. there is a National Park in this area. A cone of depression could change the habitat of protected plants, their disapperance or deterioration of vegetation conditions. It can effect also ,disapperance of natural springs water reservoirs, or streams. Sometimes, it concerns of natural mineral water springs or waters of therapeutic properties. Also drying up good quality farmland of high efficiency, or drastic drop of crops within a cone of depression can be an environmental criterion against planning of mining operations. The other such criteria could be drying up of recreation water reservoirs, that have a great socialim ortance. The group discussed above comprises quantitive impact on water in the open pit vicinity.

The other group of environmental aspects is connected with protection of original water quality in receivers of mine drainage water. Sometimes, it may happen, (f.ex. in Central Europe several such cases are known) that lignite basins accompany salt diapirs. Then salty water can appear in mine dewatering system. Such water cannot be discharged to rivers or lakes without desalinization. However, there are some techniques of salt removal, but the problem is with a great volume of water when salt concentration is relatively low, however, not meeting the permitedstandard. Other pollutants of mine water (f.ex. pH or suspended solids) can be changed or removed in easier way but, they increase the cost of drainage, but almost in such degree that crosses out economy of mine development.

E c o n o m i c f e a s i b i l i t y - is always the final factor deciding on mine development. Here, both capital investment costs and running costs are decisive. The main part of capital investments costs of lignite opencast mine in easily accessible area comprises the costs of main machinery and equipment and digging of development cut.That reaches mostly about 50 percent of total investment costs. The costs of mine drainage in Poland are placed secondly and they comprise from 10 to 20 percent of total investment costs. Running costs of drainage are from 5 percent (when, about 10 m^3 water per ton of lignite is pumped) up to 11 percent of running cost (when above 20 m^3/t is pumped). It is certain simplification because not only volume of water but also a method of drainage plays here a very important role, however,for general estimation such assumption could be adopted. Under present economic conditions and prices of electric energy in Poland (96 percent of lignite is burned at power plants) it seems that maximum investment costs for mine drainage that can be accepted for otherwise economic mine construction is 50 percent of total costs in case of "cheap" operations and 35 percent for "expensive" ones.

EXAMPLES

In Poland, there are three cases for which hydrogeological criteria have decided on neglecting mining of lignite basins, that have other favourable parameters (such as depth, overburden vs. lignite ratio etc.).

Cybinka Lignite Basin - is located in the meander of the Odra River (second largest river in Poland). It flows around the lignite basin from the South and West side. So above 50 percent of circumference of open pit, would be continuously recharged at the distance of about 300 m from the drained open pit slopes when drawdown depth would be 75-120 m. The hydraulic gradient would be here from I = 0.25 to 0.40. Quaternary aquifers filling the Odra River valley and other erosive washouts (burried valleys) cutting the lignite basin have permeability about 15 m/day, when fine sands and silts over upper and between two lignite seams have permeability 0.5 - 3 m/day. Moreover,the lignite seam is also an aquifer of permeability 3-11 m/day, so it could not be a base for a cut-off sealed screen. The lower lignite seam is also underlaid by an aquifer of fine sands (permeability 0.8-2 m/day) with groundwater under pressure of 9-12 Ba. It has been found that it is practically impossible, to drain very low permeable fine sands and silts both in the overburden and between lignite seams enough effectively to ensure slope stability. It was also found that percolation water from Odra River will be to high to be efforded (fig. 1).

Rogoźno Lignite Basin is located on a salt diapir (Permian Age). Salt diapir creates a nucleus of anticline, in which cover the Mesozoic rocks occur. The salt roof is at the depth of 230-600 m below terrain surface. Salt is covered with gypsum anhydrite formation 13 to 280 m thick. Very differentiated morphology of diapir cover surface is effect of karstic phenomena developed as a result of salt leaching. Such phenomena took place during upheaval of diapir, when sedimenting of lignite in the basin, and it may be assumed that they have been continued so far, however, less intensive. Formations in diapire cover have permeability 0.2-12 m/day (average 3.2 m/day). Tertiary sands-silts having thickness several to dozens meters lays on the diapir cover. They fill mainly karst funnels, and create an aquifer under pressure up-to 22 Ba and permeability from 0.4 to 4 m/day. This aquifer is recharged from underlying Permian limestone aquifer.

On these formations, lower lignite seam 19 m thick in average (ranges from 0 to 44 m) lays. It is strongly fissured and cut with number of trough-type faults. Such a structure makes possible also groundwater circulation through the lignite seam. The lower lignite seam is covered by Tertiary interseam sands 70 m thick. These sands are fine and silty ones and contain artesian groundwater under pressure of 10-15 Ba and permeability 0.1 - 4.0 m/day (on average 0.8 m/day). This aquifer is recharged both from underneath (through lower lignite seam and outside its boundaries) as well as from above (through upper lignite seam from Quaternary overburden aquifer). Especially intensive recharge can be encountered within Quaternary deep erosive washout (burried valley of high permeability), where all aquifers have a contact. On this series upper lignite seam lays. Its thickness is also 19 m (extremes 0-53 m) and its permeability is from 0.01 to 1.7 m/day (average 0.44 m/day). Over upper seam sandy-clay series lays and its average thickness is 85 m. Aquifers occur here under boulder clay (its thickness 30-40 m and permeability about 30 m/day), in lenses within boulder clays (permeability 8 m/day) and right under terrain surface (thickness 10-15 m, permeability 60 m/day). A very essential factor is here quality of groundwater. Under natural conditions when Quaternary groundwater are not moved by drainage operations their quality is good, however, Tertiary groundwater (interseam and underseam ones) and Permian groundwater are strongly mineralized.

Total TDS Content in interlignite aquifer is from 2000 to 10 000 mg/dm^3 (extremely 65 500 mg/dm^3), chloride content from 700 to 3500 mg/dm^3 (maximum 4640 mg/dm^3) and sulphate contents is from 100-800 mg/dm^3 (maximum 4640 mg/dm^3). In the aquifer underlaying lower lignite seam total TDS content is from 13 000 to 78 000 mg/dm^3, chloride contents from 700 to 34 200 mg/dm^3 and sulphates from 2000 to 5000 mg/dm^3. Groundwater inflow to a planned open pit was calculated to be about 150 m^3/min. and average parameters of mine water are following:

TDS	4000 - 7500 mg/dm^3
chloride	2300 - 4200 mg/dm^3
sulphate	400 - 5500 mg/dm^3.

In conclusion it was found that both criteria of technological feasibility of drainage (high pressure and low permeability) and very bad quality of mine water that would result in very high salinity, exclude practical feasibility of mine construction (fig. 2).

W i e l k o p o l s k i L i g n i t e B a s i n is the greatest among known lignite basins in Poland. Its proved reserves are estimated at about 5 billions tonnes. Lignite seams 28-38 m thick are covered by overburden, 195 to 235 m thick overburden vs. coal ratio amounts here from 5 to 7:1. Overburden is in fifty/fifty permeable and unpermeable layers (sand and clays). This basin has elongated shape in N-S direction 2 to 3 km wide and about 70 km long. It crosses the region having soils of very good quality and known from the most efficient agricultural production in Poland. In Northern part, the basin boundary reaches the National Park and runs near groundwater intakes for the Poznań City (population 600,000). The prefeasibility study showed that here, it would be possible economical mining of lignite ,but from the point of view of mining technology. However, when social and ecological (encluding also water management) criteria, are considered such exploitation was found irrational. So this basin has been excluded even from far reaching plans of mining. In hydrogeological aspect was found that:

- Some surface water reservoirs (lakes, ponds) and streams on the area of National Park could dry up;
- Soils on the part of Park terrain could be dried which could be dangerous for plants (mainly trees) under protection because, their natural habitat may be changed;
- Natural conditions of water intakes for Poznań City could be disturbed;
- Hydrographic network would have to be reconstructed and relocated on the areas of future open-pits and overburden disposals,,which can effect existing melioration systems;
- During the longer period of time the natural moisture of highly efficient farm land soils in the vicinity of open pits could change considerably.

Those criteria, but not only - additionally, economic and sociological impact-have been considered including social defiance and other factors,have influenced considerably on the final decision to exclude Wielkopolski Lignite Basin from development plans until 2020.

SUMMARY AND FINAL CONCLUSIONS

1. Decision making on development of lignite basins and surface mining planning shall be preceded by the feasibility study discussing wide range of technological, economic, and ecological criteria.
2. Hydrogeological criteria are very significant and cannot be ommited because it may happen that they are decisive, though in most cases they are merely auxiliary.
3. Hydrogeological criteria comprise among others:
   - criterion of technical feasibility of dewatering
   - criterion of environmental impact
   - criterion of economy of dewatering operations.
4. Hydrogeological problems shall be considered at earliest stages of planning process. It helps to avoid costs of geological exploration of those basins, that could be excluded relatively early as imposible or non-economic for development.

Fig. 1. CYBINKA LIGNITE BASIN

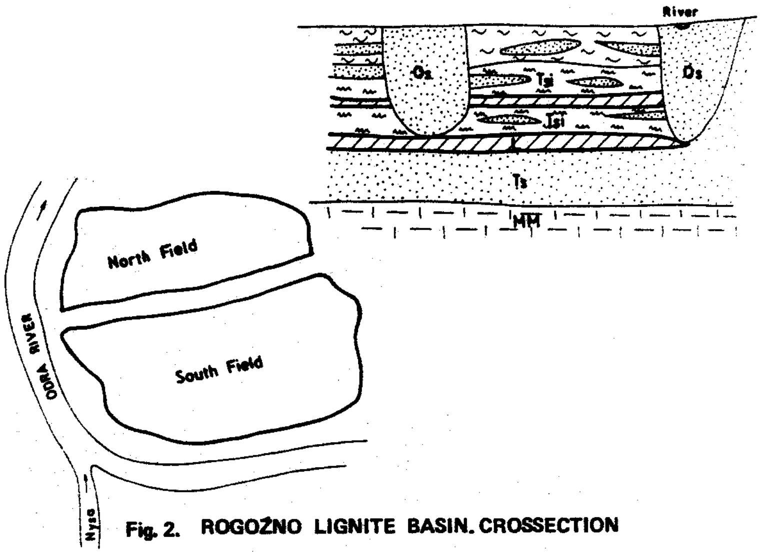

Fig. 2. ROGOŹNO LIGNITE BASIN. CROSSECTION