IDENTIFICATION OF HYDROGEOLOGICAL PARAMETERS FOR MODELLING OF A LIGNITE BASIN. (WITH DRMNO LIGNITE FIELD AS AN EXAMPLE).

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ABSTRACT

The paper presents the identification of hydrogeological model parameters of the Kostolac Lignite Basin (Drmno lignite field) in Yugoslavia which is intended to be mined with an open pit. Against a background of an inverse problem solution, a model identification is presented using several methods for different phases of hydrogeological exploration.
It was found that a lignite basin where complex hydrogeological conditions are encountered, and a computing procedure which has been determined for such an area, is advisable to be represented in a numerical model.

INTRODUCTION

The identification of hydrogeological parameters of a lignite basin is a system-oriented control and verification of data obtained from different exploration and investigations. Its aim is to create an uniform model. This method was used to design dewatering system of an open pit within Drmno lignite field in Yugoslavia. A reason were complex hydrogeological conditions and a considerable water hazard caused by the close huge rivers, i.e. Danube River and its tributaries, particularly after they have been swollen by the Djerdap dam. The developed model of hydrogeological conditions, as that being suitably represented in a computational scheme and adjusted to the monitoring in situ, ensures a correct prediction of hydrogeological phenomena during mine dewatering.

LOCATION, MORPHOLOGY, HYDROGRAPHY

The Drmno lignite field is situated on the right-hand riverside of Danube, some 60 kms to the East of Belgrade close to the Mlava River mouth. It is South-Eastern part of the big Kostolac Lignite Basin. The terrain is here flat with dipping to NW. Its Western boundary is a meridional hill range called Pozharevatzka Greda and the Eastern boundary is another hill range, and the Northern one - the Danube River valley (Fig. 1). The elevations vary from +180 asl on the hills to +71 and +68 m asl in the Danube River valley. The Danube River flows to the North-west at a distance of some 4 kms away from the planned open pit openning. In parall to the main river-bed of Danube, the Dunavac Channel is running which is now the cut off old river bed portion where water level is controlled by a pumping station. The Mlava River flows from the South across the Western portion of lignite field along a foot of Pozharevatzka Greda hill range. Down portion the river, was relocated and regulated. The Danube River swell at the Iron Gate results in 2.5 m increase of water level in this river where it flows in the vicinity of Drmno coal field, and its back flow reaches, in the Mlava River, the area of opening cut.

GEOLOGICAL STRUCTURE AND HYDROGEOLOGICAL CONDITIONS

Within Kostolac lignite basin Tertiary and Quaternary formations have been found. The Tertiary lignite series dips monoclinally to the North-West underneath Danube River. Four lignite seams have been identified in there and among these seams, the seam III 15-20 thick is of economical importance in the Drmno field (fig. 2). On the NW-SW hydrogeological crossection, subsequent layers of lignite bearing series are visible from SE to NW, beginning from the oldest to youngest ones. In the floor of lignite seam III, clays and loams occur with lenses and patches of fine sands which, however, don't form a continuous aquifer. Above lignite seam III, the series of fine and very fine sands transiting into dust to the North occur. The share of dusts and their thickness increases towards NW. The outcrops of seam III are Southern boundary of the lignite field Drmno. This outcrop strikes along SW-NE (fig. 1). At a distance of 2.5-3 kms parallel to the autcrops of lignite seam III, the outcrop of several metres thick seam II is running towards NW. In the roof of seam III, the series of Tertiary clays is encountered.
Over Tertiary formations the Quaternary 10-15 m thick gravel series occurs discordantly decreasing down to several metres towards SE. The gravel series occurs almost horizontally. This series is covered by a loess layer 20 to 30 m thick outside the river valleys and several metres thick in the Mlava and Danube River valleys. Ground water from sand-gravel aquifer is in a direct contact with of Tertiary aquifer within area between the outcrops of lignite seams II and III (figs. 2 and 3). Aquifers are recharged in the SW portion of the lignite basin, and drained in the river valleys towards N and NW.
In the SE part of Drmno lignite field groundwater table stabilizes at +90 m asl (at a depth of over a dozen metres below terrain surface). A general original direction of groundwater outflows with dipping 1.5o/oo to 2o/oo is towards the Mlava River mouth. During high water periods, the aquifers are recharged from the rivers at bifurcation of Mlava and Danube Rivers.

The following issues were to be examined in detail:

- rate of recharge from the Mlava River, or permeability of the river bed, especially in a new section,
- structure and recharge regime of an area adjoining the Drmno lignite field from E, SE and S,
- variation of transmissivity of gravel aquifer determined on the grain-size analysis,
- possible lowering of groundwater table below the gravel series by pumping out from the Tertiary high-anistropy sands considering their low permeability being 50 or even 100 smaller than that of gravels,
- intensity of hydraulic contacts on the Quaternary gravels floor and Tertiary sands roof,
- effect of 2.5 m swell of Danube River on the inflow to the open pit and waterlogging of its slopes.

The hydrogeological investigation of the lignite basin was carried out for many years to increase the knowledge of the discussed questions:

- till 1959, preliminary exploration was carried out including pumping tests from three wells with piezometers and on this basis, the lignite field Drmno was considered as impossible to be dewatered effectively,
- till 1969, a general geological exploration was complemented, and a simultaneous pumping 10 wells was carried as an example part of designed dewatering barrier,
- till 1974, exploration of structures was extended outside the original lignite field, i.e. on to its foreland, by a series of hydrogeological drillings (B),
- till 1979, the aquifers were ultimately explored, and permeability of Mlava River bed and old Danube River bed as well. Pumping tests and simultaneous pumpings from 14 wells enabled to determine permeability separately for Quaternary gravels and Tertiary sands.

SOLUTION OF INVERSE PROBLEM

The Drmno lignite field is a good example how much the technical evaluation of hydrogeological conditions of a open pit can be changed depending on the accuracy of hydrogeological exploration. This exploration should be extended by observations of natural flow, results of simultaneous pumping tests, and even preliminary phase of open pit dewatering. The method consists in a solution of inverse problem, i.e. basing on the hydrostatic heads distribution, flow rate and time, the transmissivity of aquifers (T) and their specific yield (u) could be found. Optionally the boundary conditions within a given area can be known or, they can also be unknown value.
A general equation of filtration model is as follows:

$$T \times h/t/ + Q/t/ = u \frac{dh}{dt} \quad . \qquad (1)$$

$$\text{but usually} \quad Q/t/ = Q/t/ + w/t/ \quad . \qquad (2)$$

where: T - transmissivity, h - hydrostatic head, Q - flow yield, w - surface recharge, e.g. infiltration from precipitation, or constant percolation from other sources, μ -specific yields.

It can be seen from equations (1) and (2) that the solution can be obtained directly by adoption of the infiltration (w) adequately distributed over the whole surface. If, however, w should be assumed as a value determined a priori then, the solution h = f (a) is obtained explicitly only for linear or radially symmetrical schemes, as is the case in pumping tests in single wells. When, however, differentiated transmissivity and various boundary conditions are encountered within a wide area the inverse problem is solved with a considerable error, and it is not explicit. In case of steady flow, the equation (1) becomes simplified:

$$T \times \bar{h} = \bar{Q} \qquad (1')$$

A number of independent solutions of this equation can be obtained and besides, the result depends on the adopted boundary conditions (3). Much better effects are obtained by adopting T (x, y) and verifying the results.
In case of non-steady flow, the equation becomes more complex due to searching for an additional parameter - μ. The solution depends now on the errors in determining T (x, y), h (x,y) and Q (x,y,t) in several time states. As yet, no algorithms are known to solve inverse problems for the non-steady flow.

MODEL IDENTIFICATION

To solve problems covering a large area the hydraulic, electrical, continuous or discrete analog models were used, many years ago. Now numerical ones replaced them. In models, the direct solution is searched by adopting, on a trial basis, the values T(x,y), u and w and differentiating them within a discussed area. The solutions obtained in this way are compared to the independently estimated intervals of values of unknown parameters, and to the variation of flow in time as well. For the lignite basin under consideration, models were developed many times at different accuracy of hydrogeological exploration and using different methods (1).
First Model was developed in 1970 by a method of electrical analogy in an electrolytic tank. The steady flow was assumed. The recharge from precipitation and pumping of static groundwater reserves were neglected. The boundary conditions determined as H=const. were assumed in rivers and places where probable aquifer outcrops have been anticipated to be found. The T-value was accepted to be a sum of vertical transmisivities, assuming a full hydraulic contact between aquifers. The model did not represent the morphology of lignite floor, The water heads - h were represented by a square function. The model adjustment was limited to the selection of water heads on the boundary. The transmissivity was corrected only by a change of mapping scale. It was found that local changes in T-value have no effection either the water heads distri-

bution or on the flow rate. This one was very high. It was a result of close contacts with the rivers, and of a high transmissivity as well.

Second Model was developed basing on the new hydrogeological data investigated until 1975. The electrical resistance grid RR was used to simulate the non-steady flow. A changes in the interpretation of the geological structure of the lignite basin were taken into account. A continuity of sand aquifer was assumed between lignite seams II and III and also, their recharge as far away as from beyond the Danube River. The other boundaries have been adopted unchanged. The model did not represent a configuration of the aquifers floor. Model adjustment was carried out in the steady flow regime by adopting boundary conditions and recharge through infiltration. The inflow rates to the open pit predicted with use of this model were very large and had very doubtful spatial distribution.

Third Model was developed basing on the data investigated till 1979. A numerical method of finite elements was used for the non-steady plane flow regime. In the model, the aquifer, in the Mlava River and Danube River valleys were represented, as well as Quaternary gravel aquifer and Tertiary sand aquifer, the latter being in full contact with Quaternary one above the lignite seam II.

The sandy aquifer within area covered by seam II was neglected. As distinct from the previous models, the Western boundary was moved to the West of Pozharevatzka Greda at assumption that Mlava River and Danube River get in contact with the groundwater indirectly and can become detached from the latter during groundwater drawn in the open pit. Among the rivers, only Danube River was considered as a boundary with a fullfilled condition H = const. An important feature of this model was that morphology of the active aquifers floor was taken into account, including a monoclinal dipping and threshold produced by the outcrop of lignite seam II. The transmissivity T was calculated depending on groundwater table position. The permeability which was considered to be most controversial has been adopted basing on the hydrogeological computations, and it was excluded from model adjusting (veryfying). Veryfying was carried out for boundary conditions and active hydraulic contacts with the rivers. The results obtained were quite different from the previous ones. This was caused by correction of hydrogeological conditions concerning structural geology of the basin and permeability, as well as by the modelling method. The inflow from inter-lignite aquifer has been eliminated; the influence of Mlava River has been reduced to the infiltration through its bottom; maximum hydraulic gradients from Danube and Mlava have been reduced to a value conditioned by a configuration of the floor of active aquifers; the transmissivity was becoming gradually reduced as groundwater table has been lowered.

The flow rate to the open pit from particular directions was conformable to the estimations obtained after pumping tests in well barrier portion. A reduction of the total inflow to the opening cut was substantial, being between 57 and 61 % in successive years to compare with previous forcasts .

The Mlava River valley came to be the main groundwater recharge source. So, inflows from SW and N and, initially, from static reserves were found to be predominant. The influence of Danube and Dunavac River became reduced to be of minor importance (fig. 1). The possibilities of veryfying the analog and numerical models are different, which in the discussed case led to some differences in obtained results. The analog models, and the used numerical model as well, represented the flow in plane. However, as distinct from the latter, they do not represent two essential factors, i.e. reduced transmissivity of aquifers when groundwater table is lowered during dewatering with regard to vertical differentiation of permeability and configuration of the aquifer floor. When veryfying the numerical model, more parameters can be selected, thus providing more possibilities but making this model difficult for control. On the basis of veryfying, more than one set of parameters can be obtained to solve the inverse problem. The idenfication of model parameters consists in the selection of one of above sets.

SUMMARY

1. Under complex hydrogeological conditions of a lignite basin exemplified by the Drmno lignite field, an insufficient exploration leads often to the development of incorrect model. The geological structure is here of major importance. The expensive examination of parameters by pumping in individual wells provides only point information, which only slightly explain flow regime within the whole area.
2. In case of the discussed lignite basin, the following questions were most important for changes in the prediction of dewatering effects: exclusion of a direct contact of Danube River with the Tertiary sand aquifer and reduction of the effect of this river through the edge of lignite seam II, and reduction of percolation from Mlava River due to the river-bed resistance taken into account as well.
3. The real, effective hydrogeological parameters are possible to be identified well only when using models because they allow to make such a correction as these parameters are conformable one to another in different states of open pit dewatering and in time. Local, even important errors of the transmissivity are not so important for the picture of the whole model.
4. A necessary condition to achieve a correct identification is the use of a numerical model which covers all important issues for given hydrogeological conditions.

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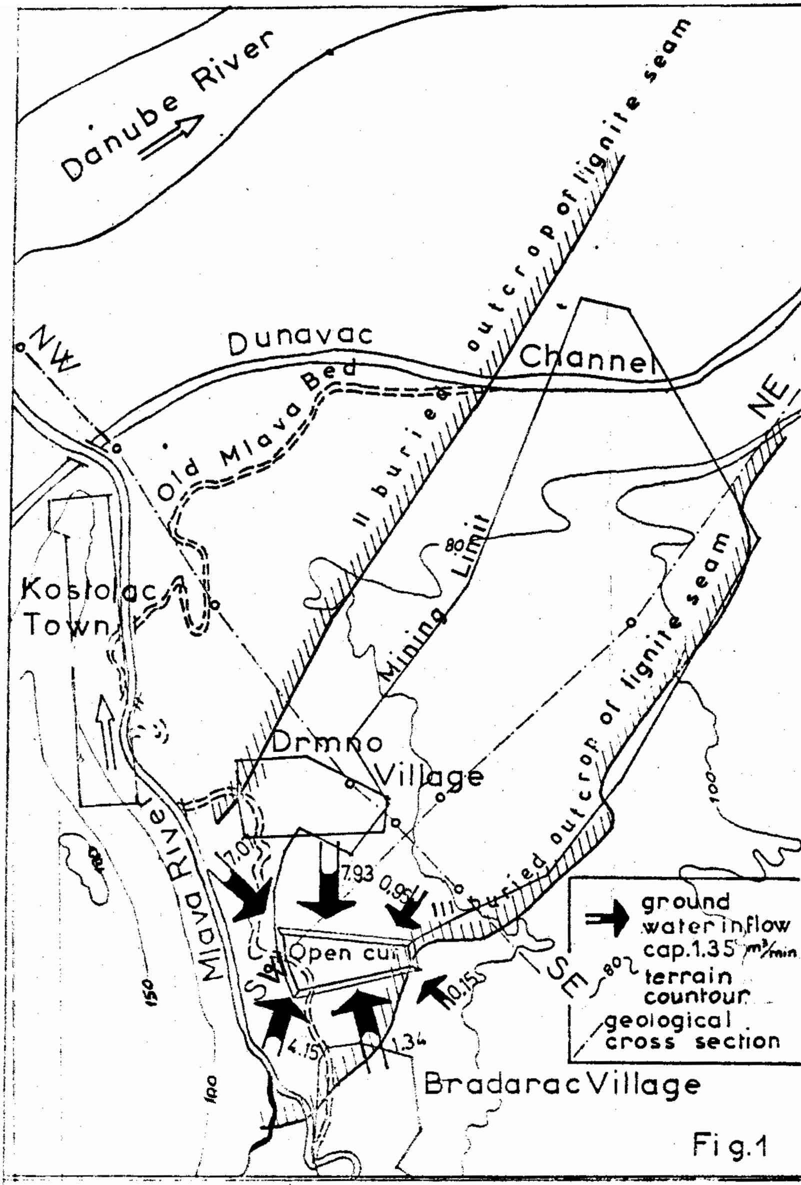

Map of Lignite Field Drmno

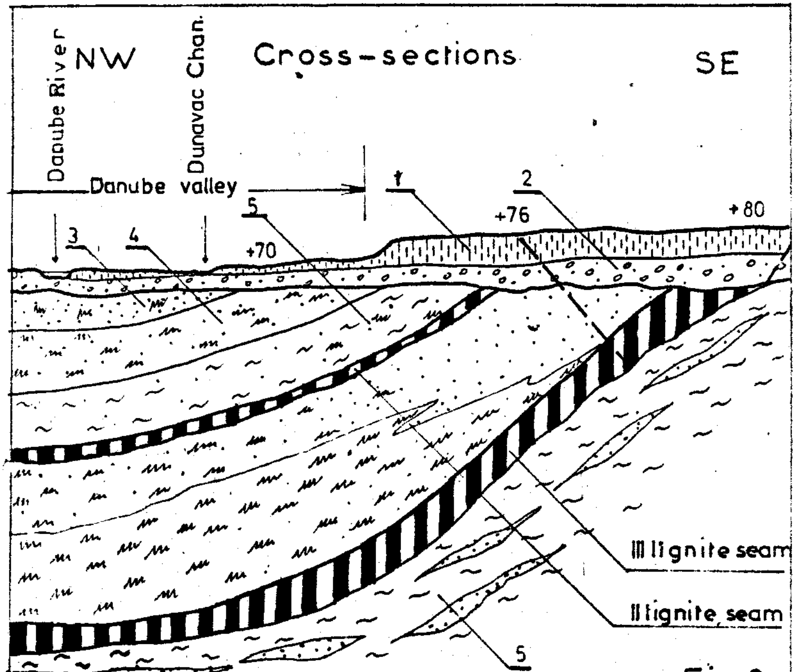
Danube River
NW
Dunavac Chan.
Cross-sections
SE
Danube valley
1
2
5
+76
+80
3
4
+70
III lignite seam
II lignite seam
5

Fig.2

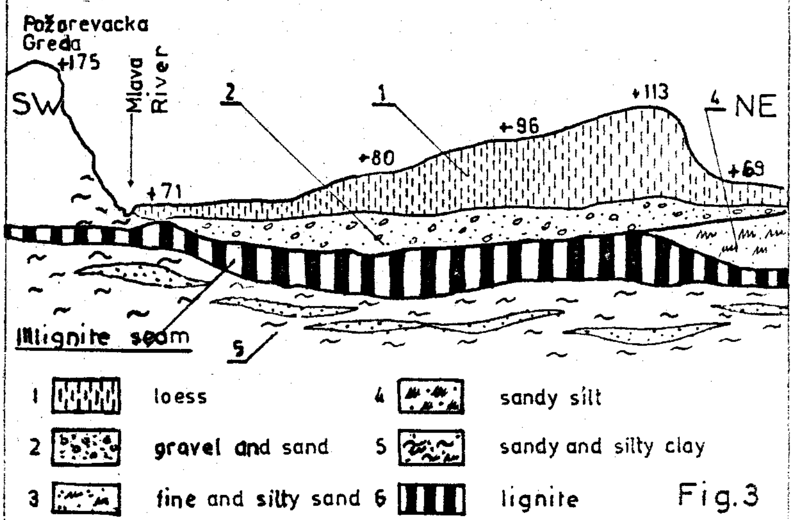
Požarevacka Greda
+175
SW
Mlava River
2
1
+113
4
NE
+96
+80
+69
+71
III lignite seam
5
1 loess
2 gravel and sand
3 fine and silty sand
4 sandy silt
5 sandy and silty clay
6 lignite

Fig.3