A CONCEPTUAL HYDROGEOLOGICAL MODEL FOR THE OPEN PIT MINE “POLJE E” (KOLUBARA COAL BASIN, SERBIA)

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Abstract

The Kolubara Coal Basin ranks among the largest coal basins in the Republic of Serbia. Numerous exploration-exploitation fields: “Polje A”, “Polje B”, “Polje C, “Polje D”, “Polje E”, “Polje F”, “Polje G”, “Veliki Crljeni”, “Šopić-Lazarevac”, “Tamnava – Zapadno polje”, “Tamnava – Istočno polje”, “Radaljevo”, “Zvizdar”, “Ruklade” and “Trlić” have been delineated administratively in the Basin. The “Polje E” of the Kolubara Coal Basin is the exploration area dealt with in this paper.

The analysis and drawing of specific conclusions on the hydrogeological function of present lithological members at the exploration area, as well as realizing of their spatial relations are extremely significant while forming the conceptual hydrogeological model of an area. The main purpose of a conceptual hydrogeological model is drawing conclusions on the distribution of present aquifer types in the area, their mutual relations, as well as conditions of groundwater movement. As such, later it represents a basis for the superstructure - the development of a groundwater regime hydrodynamic model.

Observed in a vertical profile, according to the hydrogeological function of rock masses, there have been separated overall seven layers in the open pit “Polje E”, among which four are confining strata, the fourth layer is a water-bearing one, and two are combined water-bearing-confining strata. Both the separation of these layers and their contouring were carried out on the basis of conducted analyses of numerous geological and hydrogeological explorations.

A conceptual hydrogeological model of the “Polje E” was developed on the basis of data with coordinates of borehole positions and separated layer elevations and with carried out schematization, where by software support, the separation and survey of some lithological members, as well as the survey of unlimited number of geological and hydrogegological profiles are enabled.

Keywords: a conceptual hydrogeological model, open pit mine, aquifer, coal basin

INTRODUCTION

The Kolubara Coal Basin covers an area of about 600 km^2. It is situated about 50 km south east of Belgrade (Figure 1). It spreads in the middle and lower flow of the River Kolubara and its tributaries: the Tamnava on the left, and the Peštan on the right sides.

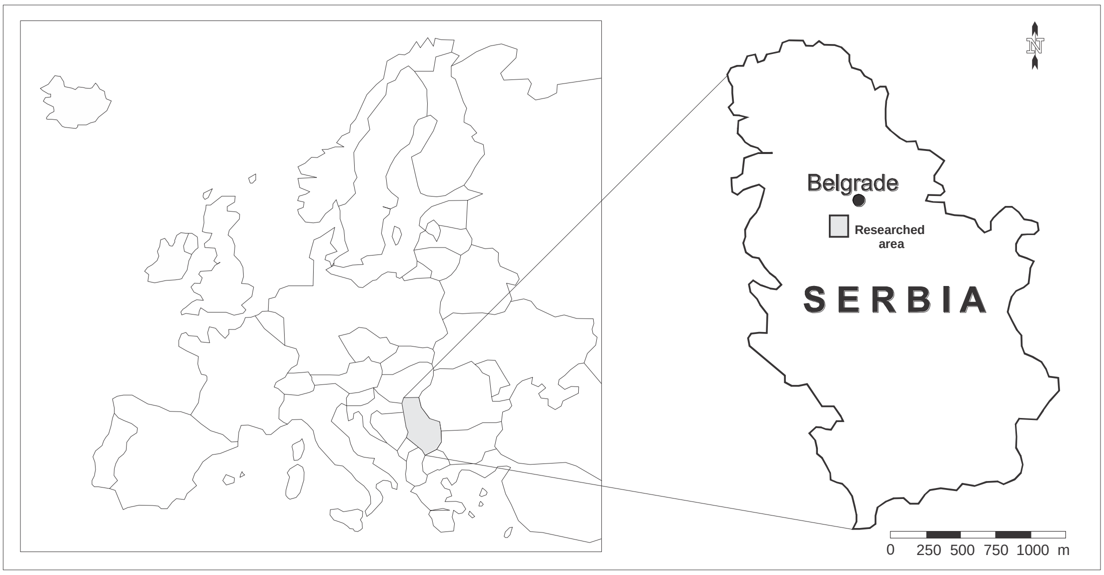
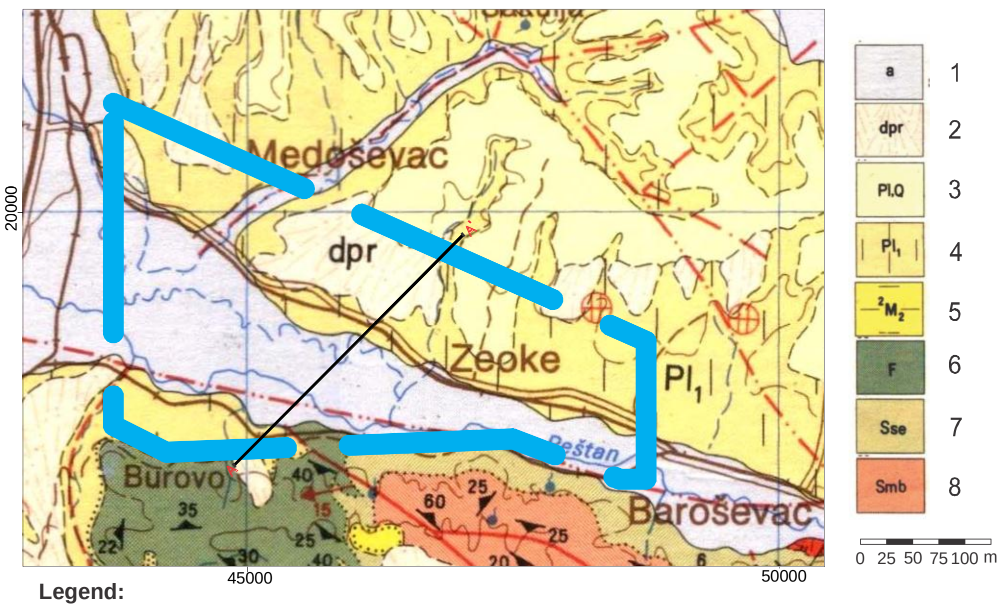


Fig.1. Geographic position of exploration area

Parts made of Palaeozoic and Mesozoic formations and vulcanite (south and south–east areas), as well as those made of Neogene sediments (north-east area) can be separated in the geological setting of the east Kolubara Basin (the "Polje E"). The geological map of the exploration area is presented in Figure 2, while the geological profile of the terrain is presented in Figure 3.



Legend:
(1) bed facies: gravel, sand and loam, (2) deluvial-proluvial sediments,
(3) river-lacustrine terrace, (4) marly and coal clay, diatomaceous earth and sand,
(5) clayand sand, (6) phyllite, metamorphosed alevrolite and metamorphosed sandstone,
(7) sericite-chlorite shale and metasandstone, (8) corneite, micaschist and gneiss

Fig. 2. Geological map of exploration area

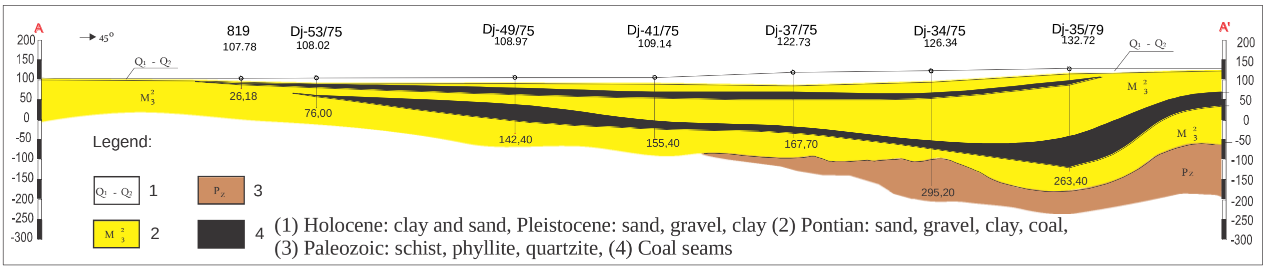


Fig. 3. Geological profil A-A'

The tectonic structure is clearly pronounced due to the impact of the Alpine-Hercynian orogeny. Palaeozoic formations were modified by movements of the Hercynian orogeny, and consequences of a volcanic activity and contact metamorphism are present as well.

Mesozoic formations were reshaped in younger phases of the Alpine orogeny. Complex breaking zones, particularly faults of E-W and NW-SE strike are distributed here, and in addition fault structures of WNW-ESE and NW-SE strike [1].

Miocene-Pliocene and Quaternary formations belong to the upper structural stage and are characterized by simple tectonic setting.

Neogene sediments are sub-horizontal in position, while these layers are bent even more steeply (to 25°) at some places as the consequence of post-Pontian tectonics when old faults were activated again [1].

The consequence of these movements, is that a coal series in east and south parts of the Basin has been disturbed, therefore coal lies in shallow synclines and anticlines of the WNW-ESE strike. The coal series was partly to completely eroded in limbs and apexes of anticlines during the Quaternary, while, in synclines, it has been completely preserved. Neogene sediments are covered by lacustrine - river alluvial deposits of Quaternary age on its complete surface [1]. The block diagram of the Neogene substratum, with the survey of the rupture texture, is presented in Figure 4, while the block diagram of the current relief, with the survey of the rupture texture, is presented in Figure 5.

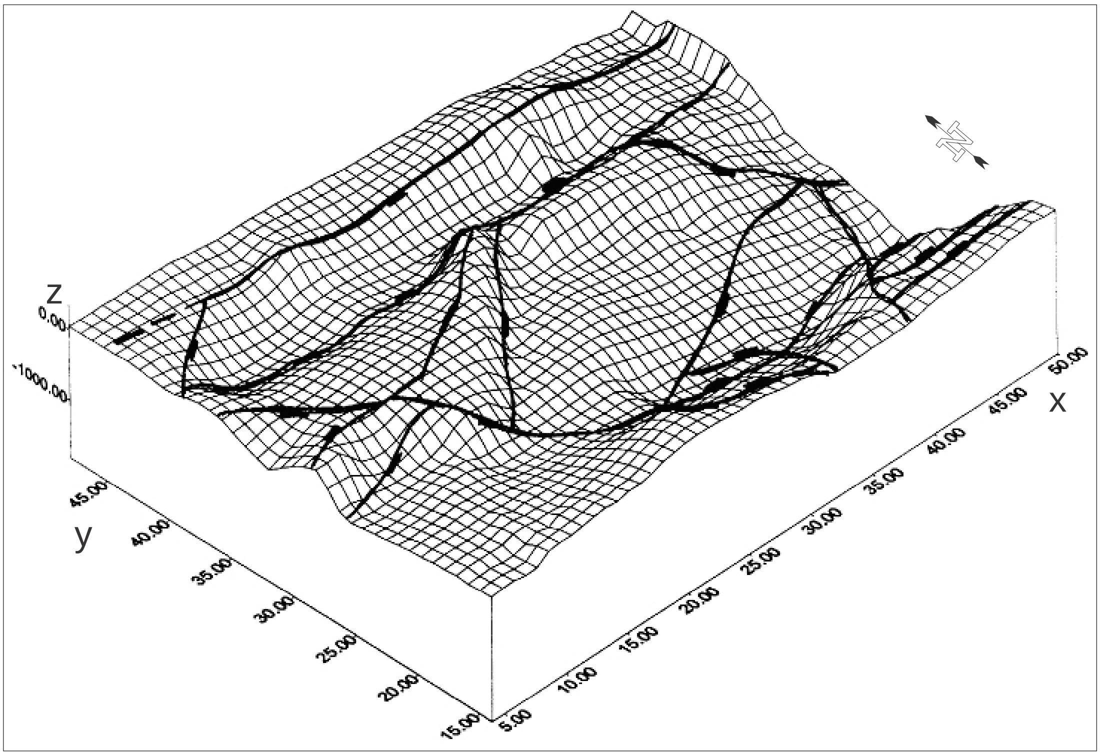


Fig. 4. Block diagram Neogen substratum with survey of rupture texture in exploration area

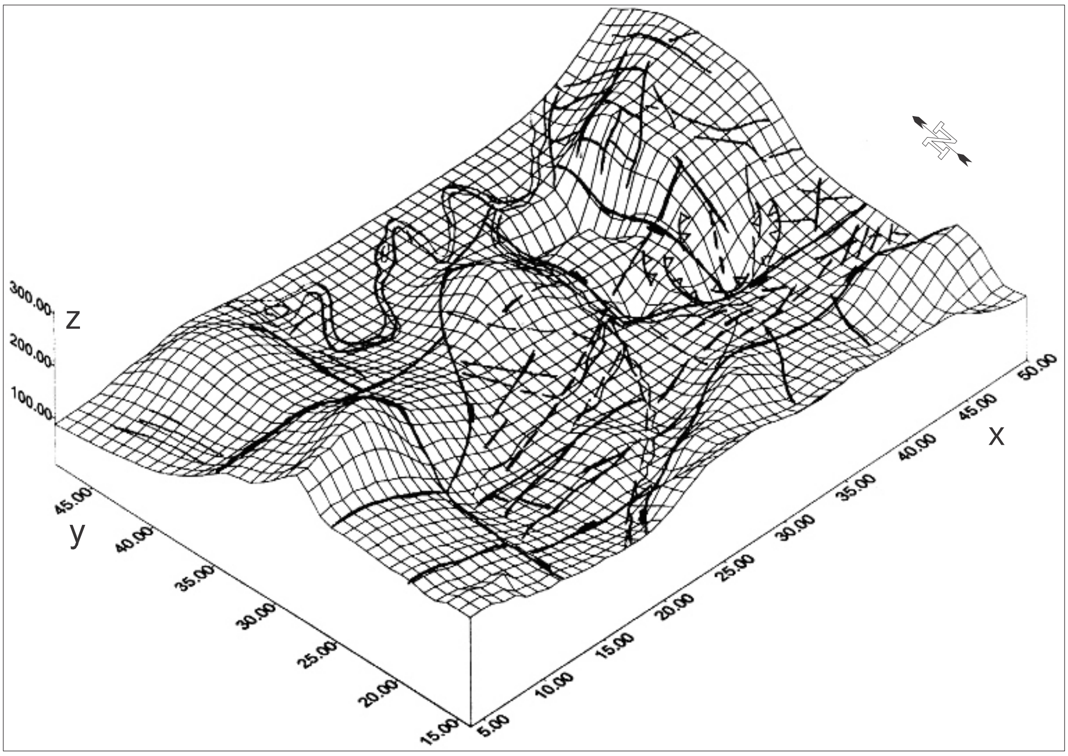


Fig. 5. Block diagram of current relief with survey of rupture texture in exploration area

HYDROGEOLOGICAL CHARACTERISTICS OF OPEN PIT MINE "POLJE E"

In the wider area of the Kolubara Coal Basin, there have been formed three aquifers: overlying, interlayered, and substratum ones.

The overlying aquifer was formed in alluvial and Upper Pontian sand and gravel in the roof of the upper coal seam. In east part of the open pit mine "Polje E", as well as in the neighbouring open pit mine "Polje C", whose normal extension is the "Polje E", there is also immediate contact of alluvial and interlayered aquifers. Taking into consideration the erosion of the main coal seam also occurred in the open pit "Polje C", there is no possibility of water overflow from the overlying aquifer of the main coal seam into the alluvial aquifer [2]. The overlying aquifer is cut off in the north by mine works of the open pit mine "Polje D", and in the south and east is related to the alluvion of the Peštan River. The aquifer is recharged by infiltration of precipitation and river water of the Peštan, while drainage is diffusive on bottom sides of gullies and brooks.

The interlayered aquifer is formed between two coal seams in so called interlayered sands. By its distribution, location, and thickness it is the most significant aquifer within the Kolubara Coal Basin. Within the open pit mine "Polje C" this aquifer represents an extension of the overlaying aquifer from the south part of the open pit mine "Polje D", where the main coal seam represents a substratum aquifuge. The interlayered aquifer is recharged in the area of the unconfined aquifer where water is infiltrated by precipitation and in some zones of the "Polje C", where the upper coal seam is eroded, thus in these parts the alluvion is in immediate contact with interlayered sands [2]. The drainage is carried out naturally via the alluvion of the Kolubara River, where hydraulic connection between the interlayered aquifer and the aquifer in the alluvion of the Kolubara River is realized, and artificially via water tapping facilities (wells).

The substratum aquifer was formed in Lower Pontian sands underneath the main coal seam. It is situated below the level of the erosion basis and the water level of the Turija and Peštan rivers. As the main coal seam lies as deep as the – 200 m elevation, this aquifer is under pressure as the main coal seam makes the roof of the substratum aquifer [3]. The aquifer is recharged in terrains beyond the "Polje E" by infiltration of precipitation in the area of eroded coal and uncovered substratum sand, in addition via water infiltration of the Turija river. The substratum aquifer is drainaged in the area of the Kolubara river alluvion, and the secondary drainage occurs through the substratum part of coal, through holes that remained after drilling in the area of the Junkovac shaft [3].

On the basis of terrain exploratory work and the conducted analysis of distributed lithological members and their hydrogeological function there have been separated oveall seven layers in he vertical profile on the open pit mine “Polje E”. Observed from the surface of the terrain, from the hydrogeological aspect, corresponding terrain layers are [4]:

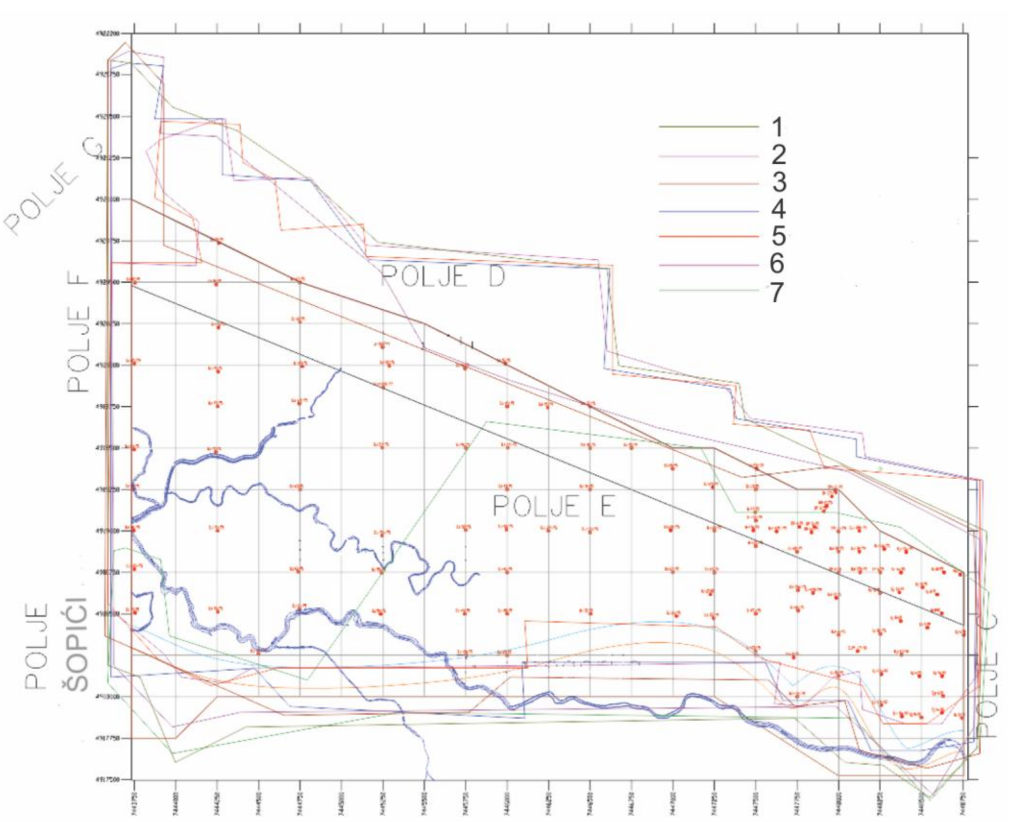
first confining stratum	overlying clayey sediments of Quaternary age
second combined water – bearing -	alluvial gravel and sand in which overlying aquifer was formed
confining stratum	clayey sediments in south pat of terrain
third mainly confining stratum	upper coal seam changing into sandy sediments in south part of terrain
fourth water- bearing stratum	Pliocene sandy sediments of interlayered aquifer
fifth mostly confining stratum	main coal seam wedging out in south part where sand of substratum aquifer and decayed shale appear
sixth combined water-bearing -	sandy sediments in north part of terrain where substratum aquifer was formed changing into
confining stratum	clayey sediments
seventh mainly confining stratum	shale with isolated parties of sandy layers in north part of terrain

The contour determination of separated layers was carried out on the basis of data of numerous test holes (about 220) distributed on the whole exploration area. The location of boreholes within the coal deposit “Polje E” used for defining spatial characteristics of separated layers is presented in Figure 6.

On the basis of data processing from grain size analyses of core samples from boreholes, as well as the data obtained by data processing of well test pumping, values of hydrogelogical parameters of the porous environment (porosity, filtration coefficient, and specific storage) are given in Table 1 [4].

Table 1: Values of hydrogeological parameters

Lithostratigraphic unit	**Hydraulic conductivity (m/s)**	**Specific storage (1/m)**	**Porosity (-)**
Quaternary clay	1×10^{-7}	1×10^{-3}	0.44
Alluvial sand and gravel	1×10^{-4}	2.2×10^{-5}	0.25
Upper coal seam	1×10^{-8}	6×10^{-5}	0.1
Pl sand of interlayered aquifer	$7 \times 10^{-6} – 5.6 \times 10^{-4}$	1.9×10^{-4}	0.34
Main (lower) coal seam	1×10^{-8}	6×10^{-5}	0.08
Substratum fine-grained sand	8.7×10^{-7}	1×10^{-5}	0.36
Substratum clay	1×10^{-7}	1×10^{-3}	0.42
Decayed shale	2.5×10^{-6}	6.1×10^{-5}	0.1



Legend:

(1) boundary of Quaternary clay distribution, (2) boundary of gravel distribution,
(3) boundary of upper doal distribution, (4) boundary of intelayered sand distribution,
(5) boundary of lower coaldistributin, (6) boundary of lower coal sand,
(7)boundary of shale distribution

Fig. 6. Map of borehole location and contoures of all lithological members of “Polje E” coal deposit

METHODOLOGY OF DESIGNING THE 3D CONCEPTUAL HYDROGEOLOGICAL MODEL

A hydrogeological system is defined by specific incoming elements, environmental characteristics, processes in the monitored environment and outgoing elements, whereby incoming and outgoing elements are interdependent. Characteristics of a hydrogeological system are its geometry, namely the spatial distribution of a water-bearing environment and its seepage characteristics [5]. Basic processes occurring here are the filtration of groundwater in a porous environment, and the matter and heat transfer by aquifer flow. Owing to the impact of these processes, there also occur changes in the system itself, reflecting in the fluctuation of piezometric level of aquifers, the alteration of qualitative properties of aquifer water and soil deformation of filtration.

On the basis of above mentioned it can be concluded that each hydrogeological system is characterized by the complexity of involved processes which cannot be interpreted directly mathematically. Therefore some simplification of the system is required, a form convenient for mathematical description of processes occurring in it - so called schematization of a hydrogeological system. Such simplification results in the development of a hydrogeological model. Thus a calculating scheme is formed which will serve as a basis for the development of a hydrodynamic (mathematical) model of the studied aquifer regime.

In the process of hydrogeological model development, the following pieces of schematization of the hydrogeological system are used [6]:

1.The schematization of the flow area (aquifer geometry) by which the changes of thickness of the water-bearing environment reach average values, or the aquifer flow is divided into parts of the same thickness;

2. The schematization of seepage characteristics of the porous environment and the hydrodynamic state of the aquifer flow caried out owing to the heterogeneity of seepage characteristics of the environment, and by it, zones of the same seepage characteristics of the porous environment are separated, then in case that a hydrogeological system is characterised by a complex character of aquifer water, the aquifer flow is divided into parts with the same flow conditions (parts of the aquifer under pressure and parts of the aquifer with unconfined level). This schematization also embraces an analysis of conditions of groundwater movement, whereby the unsteady state of groundwater flow is reduced to the quasy-steady one, and spatial (three dimensional) groundwater movement is also reduced to more simple plane flow types.

3. The schematization of the aquifer regime on the basis of which specific regularities of both the occurrence and the distribution of factors affecting the groundwater regime are determined;

4. The schematization of groundwater balance elements, where the number of incoming and outgoing balance elements is reduced by determining of specific relations among those elements, by their uniting or knowingly neglecting some of balance elements supposed to be less significant;

5. The schematization of boundary conditions of the hydrogeological system which, generally speaking, represent water inflow and outflow to the model and

6. The schematization of initial conditions, wich represent values of piezometric levels in some initial time.

The code selected to develop the conceptual hydrogeological model was MODFLOW-2000; a modular, three-dimensional finite difference groundwater flow model developed by US Geological Survey [7]. The program used in this work is Groundwater Vistas 5.33b (Environmental Simulations International, Ltd.).

3D CONCEPTUAL HYDROGEOLOGICAL MODEL OF COAL DEPOSIT "POLJE E"

As stated earlier, there have been separated seven layers being of heterogeneous composition. Carried out schematizations enabled the development of the conceptual hydrogeological "Polje E" model. The developed conceptual hydrogeological model with the software support enables the separation and survey of some lithological members and the survey of unlimited number of geological or hydrogeological profiles. Hydrogeological profiles of the open pit mine "Polje E" with the strike south-north and west-east are presented in Figures 7 and 8, as an illustration.

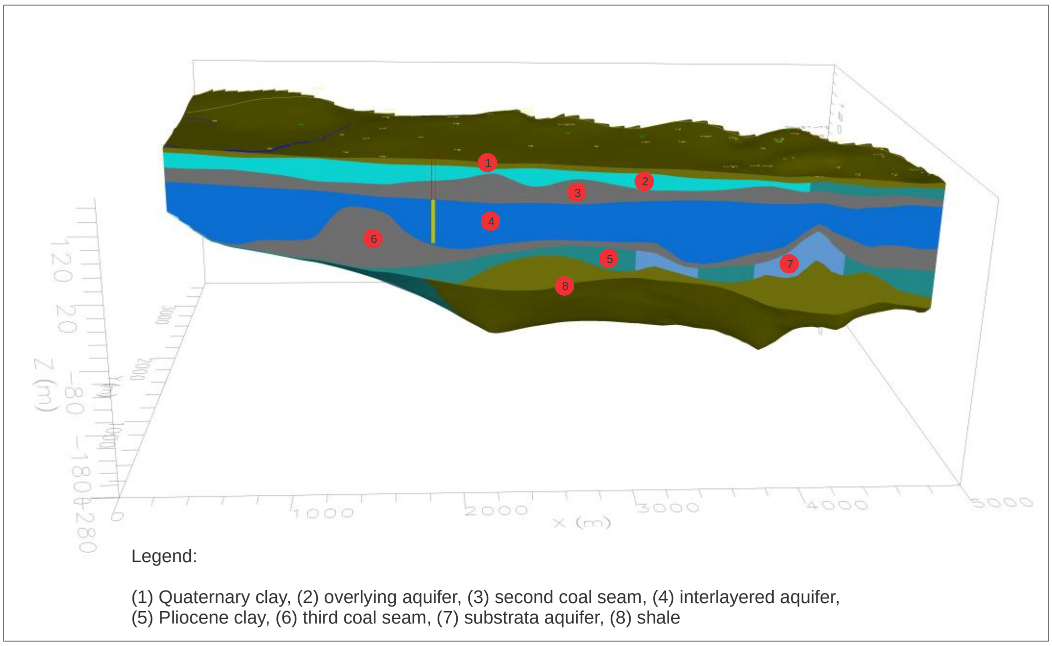
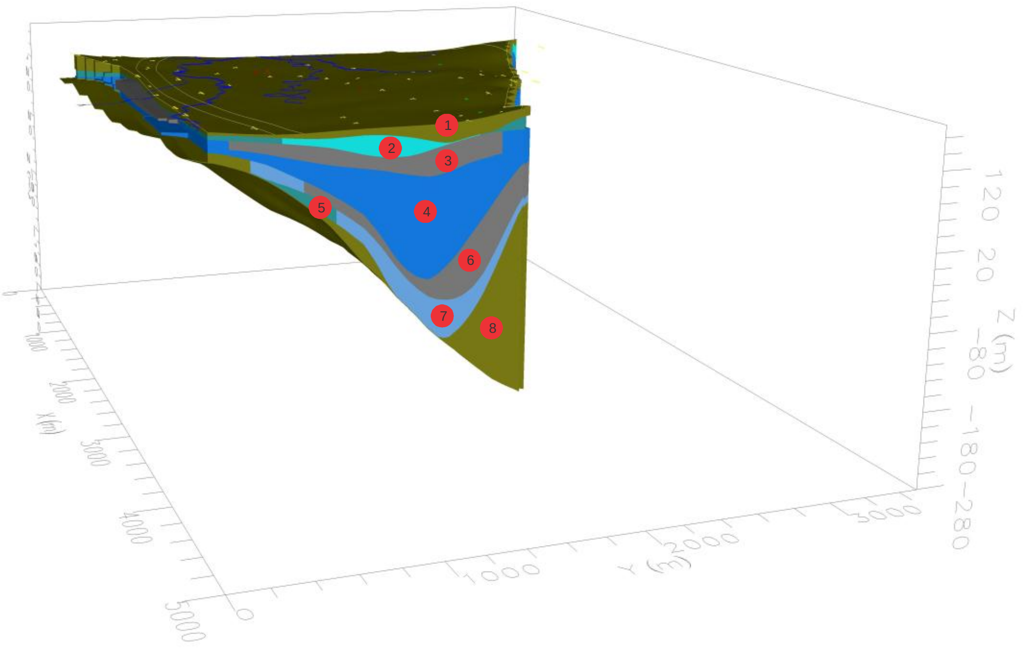


Fig. 7. Hydrogeological profile of strike south-north



Legend:

(1) Quaternary clay, (2) overlying aquifer, (3) second coal seam, (4) interlayered aquifer, (5) Pliocene clay, (6) third coal seam, (7) substrata aquifer, (8) shale

Fig. 8. Hydrogeological profile of strike west-east

The distribution of all seven layers can be stated in presented profiles whereby it is characteristic of the distribution of most layers (with the exception of the first and the fourth ones, observed from the surface of the terrain) that two and even three lithological members participate within one layer. Within the sixth combined water-bearing-confining stratum, there was formed a substratum aquifer in the north part of the terrain within sandy sediments that wedge out towards south. This layer occurs even further, whereby, laterally (towards south), it changes into clayey sediments spreading to the left bank of the Peštan where they wedge out and afterwards (in the furthest south) change into decayed shale located in the seventh layer. Thus, the sandy layer is represented as it exists in nature, namely in the form of lenses. Similarly, the upper coal seam exists within the third layer which in the north and the south of the terrain changes into sandy sediments. The main (third) coal seam occurs as the prevailing lithological member within the fifth layer. It wedges out in the south as well as, where the sand of substratum aquifer and decayed shale occur. Decayed shale also occurs within the seventh layer in the south and central part of the terrain (the open pit mine) with isolated parties of sandy layers in the north part of the open pit mine.

It has already been emphasised that three aquifers have been formed at the wider area of the Kolubara Basin: overlying, interlayered and substratum ones. Spatial positions of interlayered and stratum aquifers in the open pit mine “Polje E” are shown in Figures 9 and 10, as an illustration of the stated schematization.

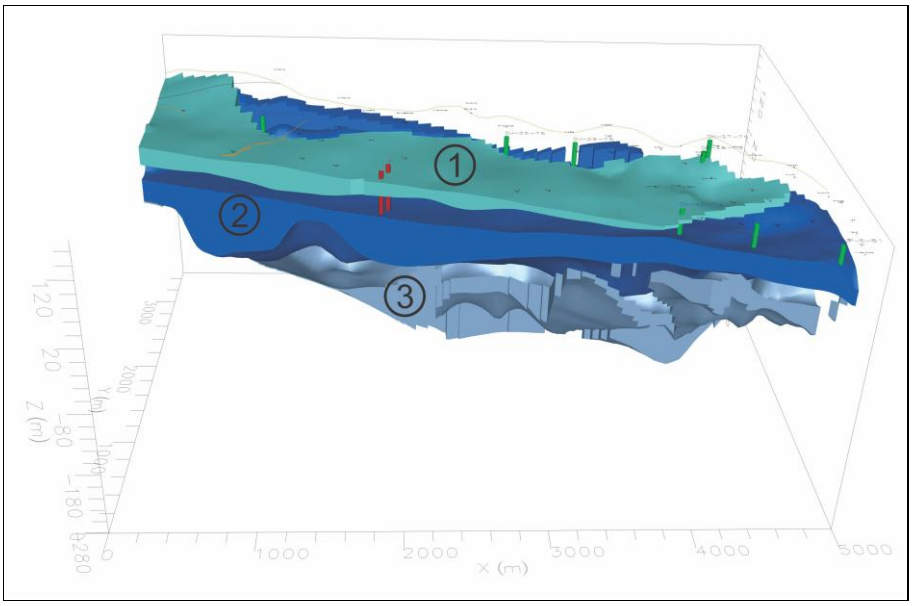


Fig. 9. Survey of distributed types of aquifers (cross-section west-east) - from surface of terrain: overlying (1), interleyered (2) and substrata ones (3)

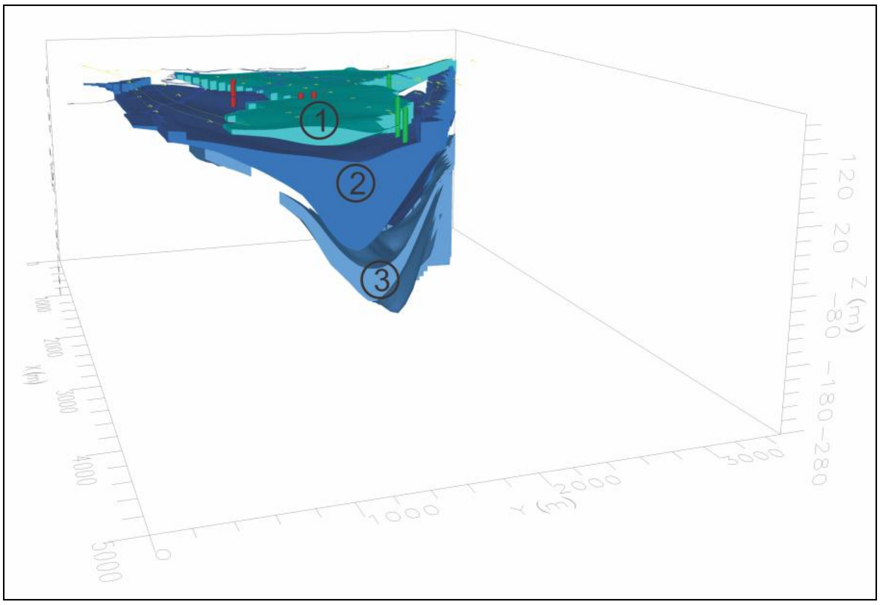


Fig. 10. Survey of represented types of aquifers (cross-section south-north) - from surface of terrain: overlying (1), interlayered (2) and substata ones (3)

CONCLUSION

Natural, geological conditions of the formation of lithological members in the study area have conditioned the geological setting and the texture of sediments as well as hydrogeological relations of lithological members.

The spatial (3D) flow of groundwater is pronounced in contact zones of sandy-gravely sediments with the sand of the interlayed aquifer, and lower, the sand of the stratum aquifer, where lithological stratification in a vertical profile and uneven horizontal distribution of lithological members are observed. This has impacted the selection of basic model characteristics, thus a multilayer hydrogeological model with seven layers in a vertical profile has been developed.

The completed conceptual hydrogeological model represents a direct basis for the development of groundwater regime hydrodynamic model that should enable carrying out of the hydrodynamic analysis of the “Polje E” protection conditions from groundwater with the selection of optimal system of drainage facilities.

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