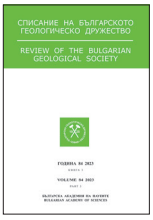
СПИСАНИЕ НА БЪЛГАРСКОТО ГЕОЛОГИЧЕСКО ДРУЖЕСТВО,
год. 84, кн. 3, 2023, с. 307–310

REVIEW OF THE BULGARIAN GEOLOGICAL SOCIETY,
vol. 84, part 3, 2023, p. 307–310



Национална конференция с международно участие „ГЕОНАУКИ 2023“
National Conference with International Participation “GEOSCIENCES 2023”

History of the development of the hydrodynamic model of the open pit mine “Drmno”, Serbia

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История на развитие на хидродинамичния модел на открит рудник “Дрмно”

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Abstract. With the creation of a hydrodynamic model, the need for it usually ceases until some next moment when the model needs to be updated and used for the set task for the necessary project documentation or dedicated studies. It is relatively rare that almost every year the model is improved and used for forecast calculations. The paper presents the basic characteristics and development of the hydrodynamic model of the open pit mine “Drmno” for 25 years. This open pit mine is the second-largest mine in Serbia. At the time the model was made (1998), it was the largest and most complex model that was made in the former Yugoslavia. Also, advanced model calibration techniques were used for the first time in Serbia.

Keywords: hydrodynamic model, open pit mine, model recalibration, drainage system.

Introduction

Coal mining at the open pit mine “Drmno” (Serbia) has been successful for more than 35 years. In the past period, a mathematical simulation of the drainage of the coal deposits was made, based on which the mine protection projects from underground water were created.

Creation and development of the hydrodynamic model by P.K. “Drmno”, period 1998–2007

Pronounced lithological layering in the vertical profile, and uneven horizontal distribution of lithological units in the wider area of the open pit mine, result in pronounced spatial movement of groundwater. These few mentioned facts influenced the decision to approach the creation of a multi-layered model with a total of six model layers that corresponded to a certain real layer. At the time this model was made (1998), it was the most complex and largest model in Yugoslavia. The main coal layer that is exploited sinks to the north to a depth of more than 200 m in relation to the surface of the terrain, which conditions the considerable wateriness of gravelly and sandy sediments up to 100 m thick that are located above the main coal seam. The basic dimensions of the matrix, which covers the studied terrain, are 6725 m × 5550 m. The discretization of the current field in the plan was performed with a basic initial cell size of 100 m × 100 m, which was later densified in the area of greater interest with cells of dimensions 25 m × 25 m. After appropriate interventions, the model ended up with 158 rows and 177 columns, in 6 layers with a total of 80 851 active fields.

https://doi.org/10.52215/rev.bgs.2023.84.3.307

In the hydrodynamic model of the open pit mine "Drmno", the following boundary conditions were applied: *Constant Head BC* (rivers Danube, Mlava, and Dunavac), Boundary with defined flux which includes (peripheral flow along the eastern boundary of the model in layers 1 and 2 and operation of drainage wells) and model contours with no flow, Mixed BC (Drainage BC in the Modflow code), and effective infiltration (Fig. 1a).

The first numerical model was calibrated only for stationary flow conditions (1998), which is a consequence of the pool of input data on the underground water regime and the operation of the mine drainage system (Pušić, Polomcić, 1999). A total of 191 l/s was captured by the drainage wells, and 22 l/s reached the pit.

Over time, the original multi-layer model from 1998 has been revised several times, and its initial features have been changed. The recalibration of the model in this period was done based on the results of new geological and hydrogeological research, the development of the monitoring network and by setting the current state of progress of open pit mining and the development of the accompanying drainage system, and by the needs of the preparation of technical documentation (2005, 2006 and 2007). Recalibrations of the model were done in transient flow conditions, unlike the original model.

Development of the hydrodynamic model of the open cast mine "Drmno", period 2008–2013

Due to the progress of the mine, the inclusion and exclusion of a large number of wells from the operation, the reconfiguration of the monitoring network, and the need to review the development of the mine within the appropriate technical documentation, certain original characteristics have changed. In the period 2008–2013, the model was recalibrated every year.

Except for the change in the contour of the mine and the number and location of drainage wells, the biggest change compared to the original model from 1998 refers to the increase of the area around the coal deposit covered by the model, to the south and north to the Danube (from the model dimensions of 6720 × 5550 m from 1998 to 6720 × 10320 m in 2008) (Fig. 1), and then a more detailed discretization of the current area was performed, which resulted in an increase in the number of model cells (from 80 851 in 1998 to 726 520 active cells, starting in 2008) (Fig. 1b). Model recalibrations were performed for transient flow conditions. In the version of the model from 2008, 910 l/s was captured by the drainage wells and 18 l/s reached the pit.

Development of the hydrodynamic model of the open cast mine "Drmno", period 2014–2018

During this period of evolution of the hydrodynamic model of the open cast mine "Drmno", the dimensions of the matrix included in the model were retained, but the following changes and improvements were made to the model's characteristics:

- part of the boundary conditions were converted into more complex ones (mixed types – Cauchy type), and some were entered into the model for the first time: in the 2014 version of the model, the hydraulic role of surface flows was simulated by River boundary conditions (in the Modflow code), while in 2016 version subsurface inflows/flows simulated by General Head BC (in Modflow code) (Fig. 1c);
- starting with the 2016 model version, drainage wells are assigned via grid-independent BC;
- in the recalibration of the model, starting from 2014, the PEST program was used with the parameter regularization option, which implies the assignment of Pilot Points that are used in the model calibration process. This was the first time that this method of automatic model calibration was used in a commercial model in Serbia;
- in the models in the period 2014–2018, the dimensions of the model cells were reduced compared to the first versions of the model and ranged from 10–80 m, whereby the smaller dimensions of the cells are in the zones of greater interest, i.e. in the locations of the wells and the zone of advancement of the surface mine according to the Danube;
- by the dynamics of the mining progress towards the Danube and the accompanying activities in the field, starting with the 2018 version of the model, the river bed of the Dunavac was moved and the hydraulic role of the Mlava River was corrected in the first two model layers;
- also, starting in 2018, the distribution and layer elevations of all three coal seams were corrected based on the results of new geological research.

In the version of the model from 2018, 1092 l/s was captured by the drainage wells, while 46 l/s was released into the pit.

The latest upgrade of the hydrodynamic model of the open cast mine "Drmno" in 2022

Very large structural changes were made in the 2022 version of the model. Based on the latest interpretation of the results of geological research, the represented lithological units were schematized in a completely new way, and the model was expanded in depth by adding layers with clayey sediments and sands in the bottom of the III coal layer:

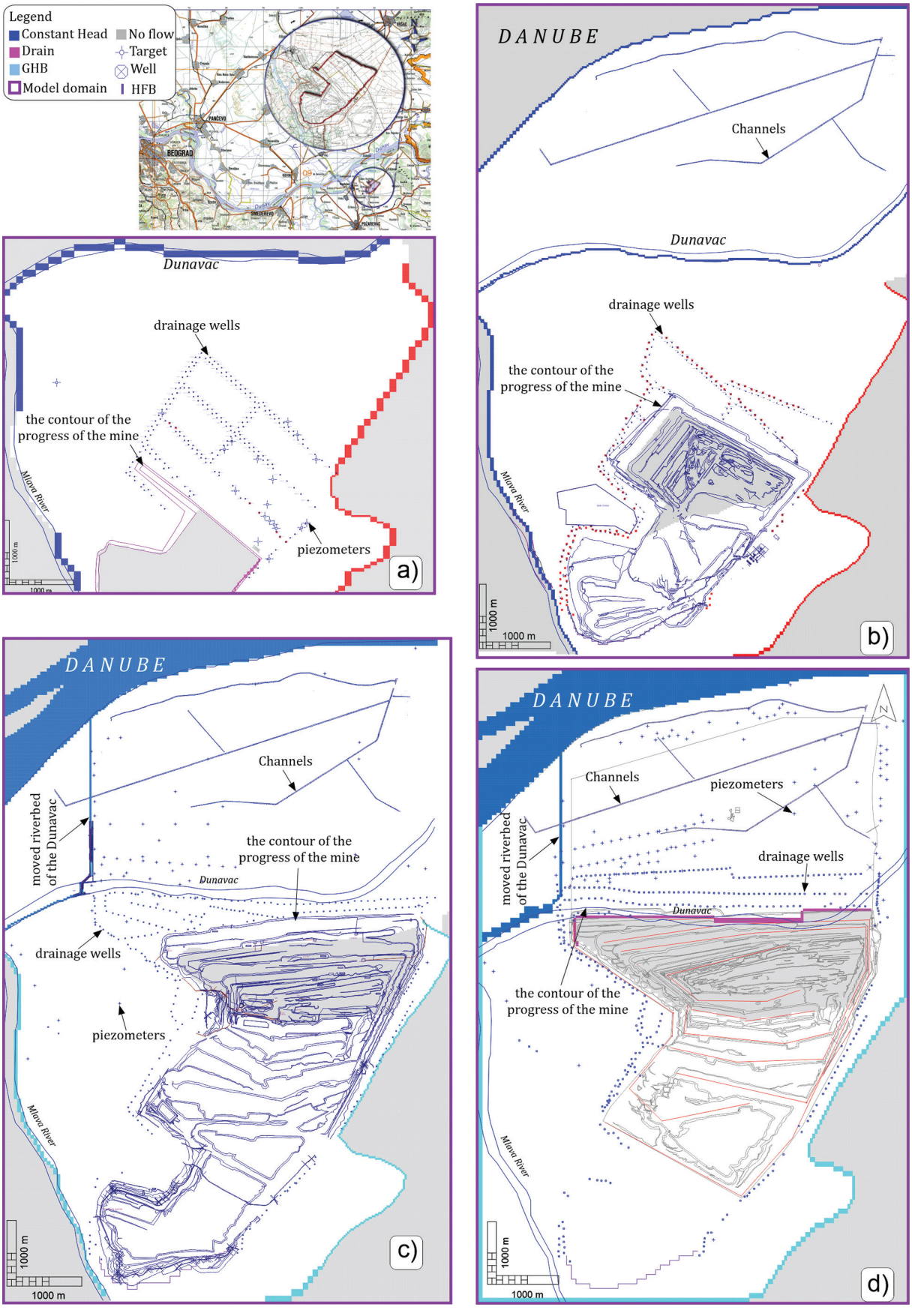

Fig. 1. Presentation of the model domain, the types of boundary conditions, the progress of surface mining, and the state of the drainage system for selected time sections: *a*, 1998; *b*, 2008; *c*, 2018; *d*, 2022

instead of the previous six layers, the latest version of the model has 10 layers. The three coal layers are specified through the appropriate values of the hydraulic parameters, compared to previous versions of the model where they were specified as model cells without groundwater movement ("no flow"). In addition to the above, the changes implemented in the 2022 model are:

• Discretization of the current area was performed with a basic grid with model cell dimensions of 75 × 75 m. In the area of greater interest, measuring 5475 × 3750 m north of the mine progress contour, the discretization grid was additionally thickened by setting an unstructured grid ("nested grid"). The densification of the basic discretization grid for this area was performed by a factor of 3 so that the dimensions of the modified model cell in this area are 25 × 25 m. Viewed in profile, this thickening is set in model layers 1–7. The model consists of 10 schematized layers, with a total of 307 568 active cells.

• Boundary conditions are set in the same way as in the previous model (version 2018) but with appropriate numerical values that are the result of the monitoring of the groundwater regime and the operation of the surface mine protection system against groundwater and include: effective infiltration, River BC, General Head BC, Drain BC, Grid independent BC, No flow cells (q = 0), Horizontal flow barrier (HFB in Modflow code) (Fig. 1d).

• The MODFLOW-NWT program version from the previous version of the model has been replaced by the MODFLOW-USG version (Polomčić et al., 2023).

In the last version of the model, the drainage wells absorbed 1048 l/s, while the inflow into the pit was 68 l/s.

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