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RaDMI 2011

PROCEEDINGS

Volume 2

Editor:
Predrag V. Dašić

2

15 - 18. September 2011.
Sokobanja, Serbia

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P R E F A C E

The First Conference ″Research and Development in Chemical and Mechanical Industry″ **- RaDMI 2001** was held upon the initiative of Predrag Dašić and prof. dr Miroslav Radovanović in Kruševac from October 22-24, 2001.
Until now, 9 conferences were realized. The conference accepted and published over 1.700 papers, from which 1.200 were from abroad from 40 various countries of the world. Total number of authors and coauthors is over 2.000. Papers of the 10th conferences were published in 18 proceedings in hard copy and 9 proceedings in electronic form (CD-ROM). Amount of printed material was approximately 12.000 pages. Some papers from the 8th International conference RaDMI 2008 will be printed in special issue of international journal from SCI-E paper ″Strojniški Vestnik – Journal of Mechanical Engineering″ Vol. 55, no. 2 (2009) (Web site: http://en.sv-jme.eu/).

Eleventh International Conference ″Research and Development in Mechanical Industry″ **RaDMI 2011** will be held on 15–18th September 2011 in Sokobanja, Serbia.

Topics of the Conference RaDMI 2011 are:

- **Plenary Session:** Invitation papers, with 12 papers;
- **Session A:** Research and development of manufacturing systems, tools and technologies, new materials and production design, with 39 papers;
- **Session B:** Transport systems and logistics, with 8 papers;
- **Session C:** Application of information technologies in mechanical engineering, with 29 papers;
- **Session D:** Quality management, ISO 9000, ISO 14000, TQM and management in mechanical engineering, with 65 papers;
- **Session E:** Application of mechanical engineering in other industrial fields, with 48 papers.

The aim of organizing the Conference is: animating scientists from the faculties and institutes and experts from the industry and their connecting and collaboration, and exchanging the experiences and knowledge of domestic and foreign scientists and experts.
On behalf of the organizers, we would like to extend our thanks to all organizations and institutions that have supported the initiative to have this anniversary gathering organized. We would also like to extend our thanks to all authors and participants from abroad and from the country for contribution to this conference.

Sokobanja, September 2011.

CHAIRMAN OF ORGANIZING COMMITTEE

Predrag Dašić, prof.

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"Research and Development in Mechanical Industry"
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A TRANSIENT THREE-DIMENSIONAL NUMERICAL MODEL OF WATER IMPERMEABLE SCREEN EFFECTS ON THE GROUNDWATER INFLOW REDUCTION INTO THE MINE (CASE STUDY: OPEN PIT MINE DRMNO, SERBIA)

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Summary: *In this paper are presented effects of water impermeable screen in dewatering system of the open pit mine. The Drmno open pit mine is the second largest active mine in Serbia where coal has been exploited for more than twenty years. The nearness of Danube and Mlava river being in intensive hydraulic connection with aquifers surrounding the mine have conditioned both the complexity of hydrogeological terrain and the mine protection system from groundwater. So far in the design solutions of the Drmno open pit mine pre-dewatering, the protection system from groundwater in front of the mine advancing contour has consisted exclusively of drainage wells. However, such a mine protection system has not yielded satisfactory results, thus significantly higher groundwater table than required for undisturbed work has been recorded. Therefore, the possibility of constructing water impermeable screen in front of face advancing has been considered whereby the water inflow from the rivers would be prevented. The selection of screen location has been determined on the basis of extensive exploratory work. The presented hydrodynamic analysis is the first quantified indicator of a water impermeable screen influence on the groundwater inflow reduction into the mine.*

Key words: *groundwater modeling, open pit mine, dewatering system, water impermeable screen.*

1. INTRODUCTION

The Drmno open pit mine is situated 100 km east of Belgrade, in the vicinity of the confluence of the Mlava River into the Danube. These rivers, as well as Dunavac channel, being intensive hydraulic connections with aquifers formed in alluvial sediments, Romanian gravel and Pontian sand which overlying two main coil soils. In this circumstances design of mine protection system from groundwater is very complex. In the past twenty years several numerical model was created to improve designing of the dewatering system. The previous multi-layer model of the Drmno open pit mine was completed in 1999 [1 Pusic et al., 1999]. In the meantime, significant changes of the size and shape of the open pit mine flow field have occurred, thus in order to conduct this hydrodynamic analysis of screen completing effect at the Drmno open pit mine, its new numerical model was required.

2. MATERIAL AND METHODOLOGY

The geology conditions around the Drmno open pit is very comlexity. The result of sedimentation conditions is periodic appearance sedimentary series, which consist alluvial deposits and loess, Romanian gravel (Pl_1), the second coal soil, Pontian sand ($^2Pl^3_2$), dusty sand and the third coal soil (from top to bottom) (figure 1). Identified layers from the surface of the terrain are given in table 1.

The overlying bed of the Fifth or the Sixth layer (unevenly) is comprised of the Third coal layer, which is, by its hydrogeological and hydraulic mechanism an aquifuge. As an illustration of the stated schematization, in Figure 1, there are shown schematized lithological profiles of the Drmno open pit striking south-north and west-east.

The drainage wells are located in the from of line barrages along the boundaries of the open pit mine and in front of the face line in ten barrages (figure 2). The distance between well barrages is from 450-650 m. Each well barrage consists of two well lines (one for tapping aquifer in Romanian gravel, one for aquifer in Pontian sand) being at the distance of 50 m, except the SLA barrage being with one well line (tapping only aquifer in gravel). Wells in line are from 75 to 150 m far away one from another. All the wells are worked as fully penetrated, with the depth of 26.5 - 143 m.

Table 1: Identified layers of the Drmno open pit

First water-bearing layer	Overlying alluvial and loess sediments
Second water-bearing layer	Predominantly gravel water-bearing layer
Third water-bearing layer	Sandy and clayey layer in the overlying bed of the Second coal soil which drifts into the overlying sandy layer of the Third coal soil;
Fourth combined aquifuge - water bearing layer	The Second coal layer (aquifuge) drifting into overlying sandy layer of the Third coal layer;
Fifth water-bearing layer	Sandy layer overlying the Third coal layer. In western part of the terrain it overlies the Sixth (model) water-bearing layer;
Sixth combined aquifuge – water-bearing layer	The silt-sandy layer overlying the Third coal layer. In part of the terrain where it is absent, sands, whose main representative in the model is the Fifth water-bearing layer, constitute the overlying bed of the Third coal layer.

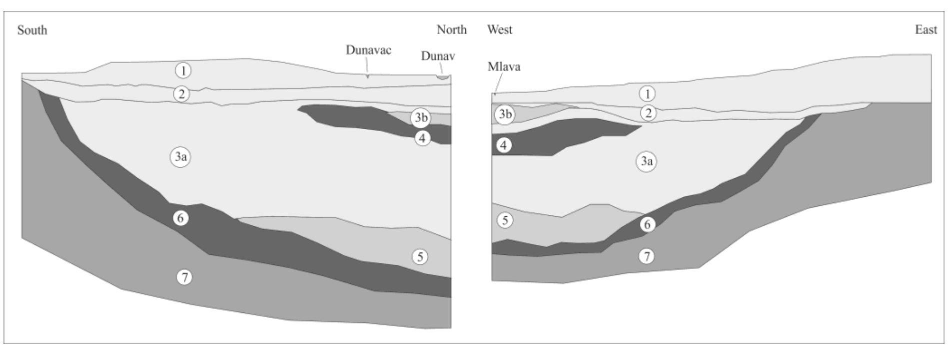

Figure 1: Schematic cross-section of the Open Pit Drmno [2 Pusic and Polomcic, 1999]
Legend: 1.Alluvial and loess sediments; 2. Romanian Gravel (Pl_1); 3a. Upper Pontian Sand ($^2Pl^3_2$); 3b. Upper Pontian Clay ($^2Pl^3_2$); 4. The Second coal soil ($^2Pl^3_2$); 5. Upper Pontian Dusty sand ($^2Pl^3_2$); 6. The Third coal soil ($^2Pl^3_2$); 7. The lower Pontian aquifuge sediments ($^1Pl^3_2$)

The average annual groundwater quantity pumped by the drainage well system amounts about $12.78*10^6$ m^3. To prevent the inflow of groundwater from alluvial layers of the Mlava River to the layout of the mine, a water impermeable screen (figure 2) with the length of 2200 m and the depth of 12-30 m was built in along the southern and south-eastern border of the mine field during the year 1984.

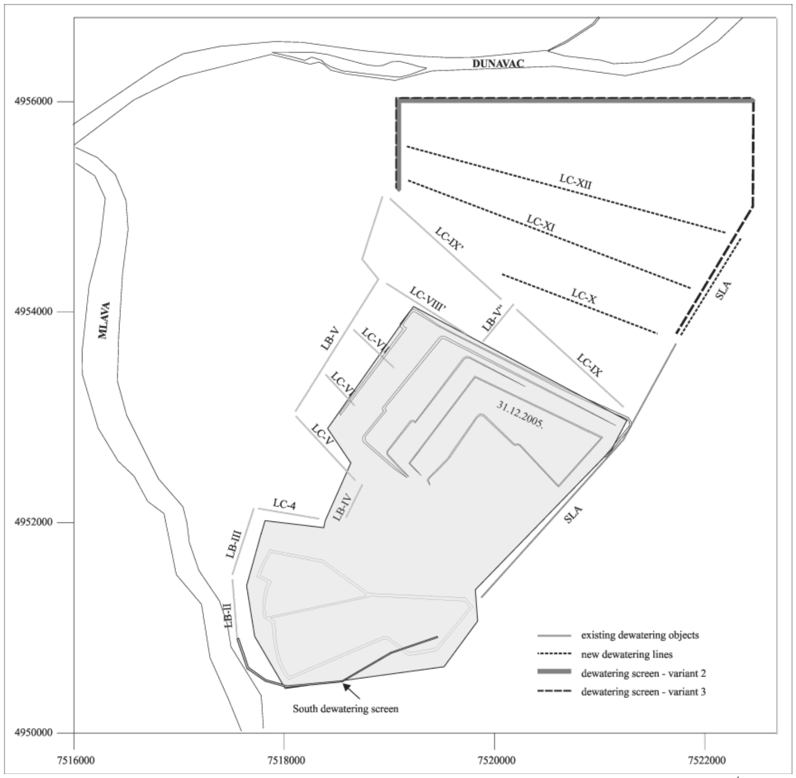

Figure 2: Location of existing buildings for protection from groundwater (1st January 2006), as well as of designed buildings (till 31st December 2011)

2.1. Concept of mine protection from groundwater inflow till end of 2011

Till 31st December 2011 the designed drainage wells are distributed in front of the face of mining work in three barrages (LC-X, LC-XI and LC-XII), and along eastern and western sides of the designed open pit mine shape in two barrages (SLA and LB-V) (Figure 2). Wells are fully penetrated and tap water from either alluvial gravels or alluvial gravels and sands in the overlying bed of the third coal layer. The distance between wells in the line tapping only the gravel aquifer is 100 m, while the distance between wells tapping both the gravel and sand aquifers is 75 m. The distance between barrages of wells is about 320 m in western part, and about 500 m in eastern part. The depth of wells is the shallowest in eastern part of the deposit (10 m), and the highest in north-west part of the deposit, and it amounts 144 m.

The hydrodynamic analysis of the work effects of the Drmno open pit mine protection system is carried out to the end of the year 2011 inclusive taking into account the layouts of the mine advancing [3 Polomcic and Subaranovic, 2006] for this period have been made yearly.

3. THEORY AND CALCULATION

The code selected to develop the numerical model was MODFLOW-2000; a modular, three-dimensional finite difference groundwater flow model developed by US Geological Survey [4 Harbaugh et al, 2000]. The program used in this work is Groundwater Vistas 5.33b (Environmental Simulations International, Ltd.).

The hydrodynamic model of the Drmno open pit mine was drafted and completed like a multi-layer model with overall six layers, observed in a vertical profile. Each of these layers corresponds to a specific real layer, separated on the basis of the knowledge of the terrain and the results of conducted analyses of large–scale field exploratory work. The real geometry of schematized layers is represented (simulated) in the model in compliance with the actual spreading of these layers, both in plan and cross-section view. The model is comprised of six schematised layers with 716772 cells in all, among which there are 439713 active ones. The discretization of the stream region is with fields ranging from 50x50 m to 12.5x12.5 m in plain. Groundwater flow is calculated in the model as real flow, confined or unconfined in each field of the discretization separately, whereby the conditions of flow in the model have been changed during time in accordance with real conditions.

As entering data for the recalibration of the existing model, there were used the data of well capacities of the drainage system and measured groundwater levels in the observing wells, recorded in the field during January 2005 till January 2006, the mean month water table of the Mlava and the Dunavac and sums of precipitation per months [2 Polomcic and Subaranovic 2006]; [5 Polomcic et al., 2006]. In Figure 3, there is shown the distribution of groundwater levels, obtained by the simulation of groundwater regime with the state on 10th January 2006.

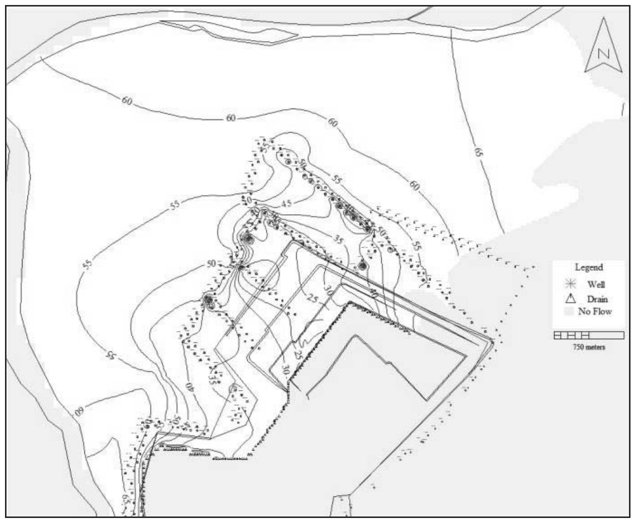

Figure 3: Distribution of groundwater levels in the fifth model layer obtained by simulation of groundwater regime with state on 10th January 2006

3.1. Predict calculations-assumption and dewatering variants

Predict hydrodynamic calculations have been realized in the transient flow regime taking into account and assigning all dominant parameters of the open pit groundwater regime. The basic calculating step was one month which at lower level of iterations was divided into 10 parts of unequal duration (factor 1.2).

Predict calculations embraced three dewatering scenarios (variants), all of them for the period from 1st January, 2006 till 31st December 2011:

a. Variant 1 – dewatering only by drainage wells beginning on 1st January 2006
b. Variant 2 – dewatering by drainage wells beginning on 1st January 2006 (in the same locations as in Variant 1), as well as activating a water impermeable screen in the location shown in Figure 4, beginning on 1st January 2008.
c. Variant 3 – dewatering by drainage wells beginning on 1st January 2006 (in the same locations as in Variant 1 excepting new wells in SLA barrage) as well as activating a water impermeable screen in Variant 2, extending the screen in eastern part of the field beginning on 1st January 2008.

Boundary conditions of the model in predict calculations were assigned taking into account both their real impact on groundwater regime and their real values.

- The water table of the Mlava was assigned as the mean value of several years, at the elevation of
  71.07 m.
- The water table of the Dunavac channel was assigned by the maintained elevation of water table at the pump station at the elevation of 65.0 m;
- The average vertical infiltration amounts 6.6×10^{-9} m/s;

- In the eastern boundary of the model, the recorded groundwater inflow along the layout of the third coal seam wedging, which exists in the nature through loess and gravely sediments, is assigned in the model as the inflow of 10 l/s per km of this layout length.

In addition to these boundary conditions, in predict calculations, there were also assigned boundary conditions which simulate the development of the open pit mine and the mine protection system from groundwater, first of all: the mine layout, drainage wells and the water impermeable screen.

The dynamics of connecting and disconnecting, first of all drainage wells, assigned in predict calculations, is given in table 2.

Table 2: Dynamics of assigning of drainage wells in predict calculations

Date of assignment	Barrage mark	Number of wells in barrage	Kind of assignment
1st January 2007	LC X	31	Well activating
	SLA	12	Well activating
	LC VI	9	*Stopping work*
	LC VII	11	*Stopping work*
1st January 2008	LC XI	40	Well activating
	SLA	5	Well activating
	LB V	2	Well activating
	LC-VIII'	19	Well activating
	LB-V''	2	*Stopping work*
	LC-IX	1	*Stopping work*
1st January 2009	LB-V''	6	*Stopping work*
	LC-IX	21	*Stopping work*
1st January 2010	SLA	7	Well activating
	LB V	4	Well activating
	LB-V''	1	Well activating
	LC-IX	1	*Stopping work*
	LC-IX'	12	*Stopping work*
	LC-X	3	*Stopping work*
1st January 2011	LC-X	27	*Stopping work*
	LC-IX'	12	*Stopping work*
	LC XII	43	Well activating

Scopes of initial well capacities assigned in predict calculations are shown in table 3.

Table 3: Scopes of initial well capacities

Barrage mark	Well capacities in aquifer in gravel (the second model layer) (l/s)	Well capacities in aquifer in sand (the fifth model layer) (l/s)
LC X	4 - 8	1.5-7.3
LC XI	4 - 13	1.0-10.0
LC XII	4 - 15	1.5-10.4
LB V	17.5	4.0-12.0
SLA	1 – 3.7	/

A water impermeable screen is placed around the future border of the open pit mine to protect from groundwater inflow from north, west and east into the working space of the mine. The position of the screen is determined depending on the location of the designed layout of the open pit mine and the location of groundwater recharge source [8 Ilic S. et. al., 2006], [9 Subaranovic and Polomcic, 2006]. In relation to the gravel layer, the screen is a fully penetrated, whereby water bearing gravel layer would be cut off [10 Ilic S. et al., 2006]. According to Variant 2, the screen of total length of 4412 m protects the open pit mine from west and north from groundwater inflow (Figure 2). In this Variant, wells of SLA barrage serve for protection from inflow from the eastern side. In Variant 3, the

proposed screen is with the total length of 6999 m and protects the open pit mine from western, northern and eastern sides from groundwater inflow (Figure 2). Western and northern layouts are identical in Variants 2 and 3.
It was included in the defense system from groundwater on 1st January 2008. The thickness of the screen amounts 1.0 m, and the hydraulic conductivity of the screen filling is $K = 1x10^{-8}$ m/s [11 Subaranovic et al., 2006], [12 Milosevic et al., 2007].

3.2. Results of predict calculations

The results of the Drmno Open Pit Mine dewatering simulation for all three variants of mine protection from groundwater inflow were interpreted and shown in time cross sections at the end of 2008, 2009, 2010 and 2011 years. Maps of piezometric level distribution in the sandy water bearing layer which overlying the third coal soil at the end of each year of the prediction period for the variant 2 are shown in figure 4.

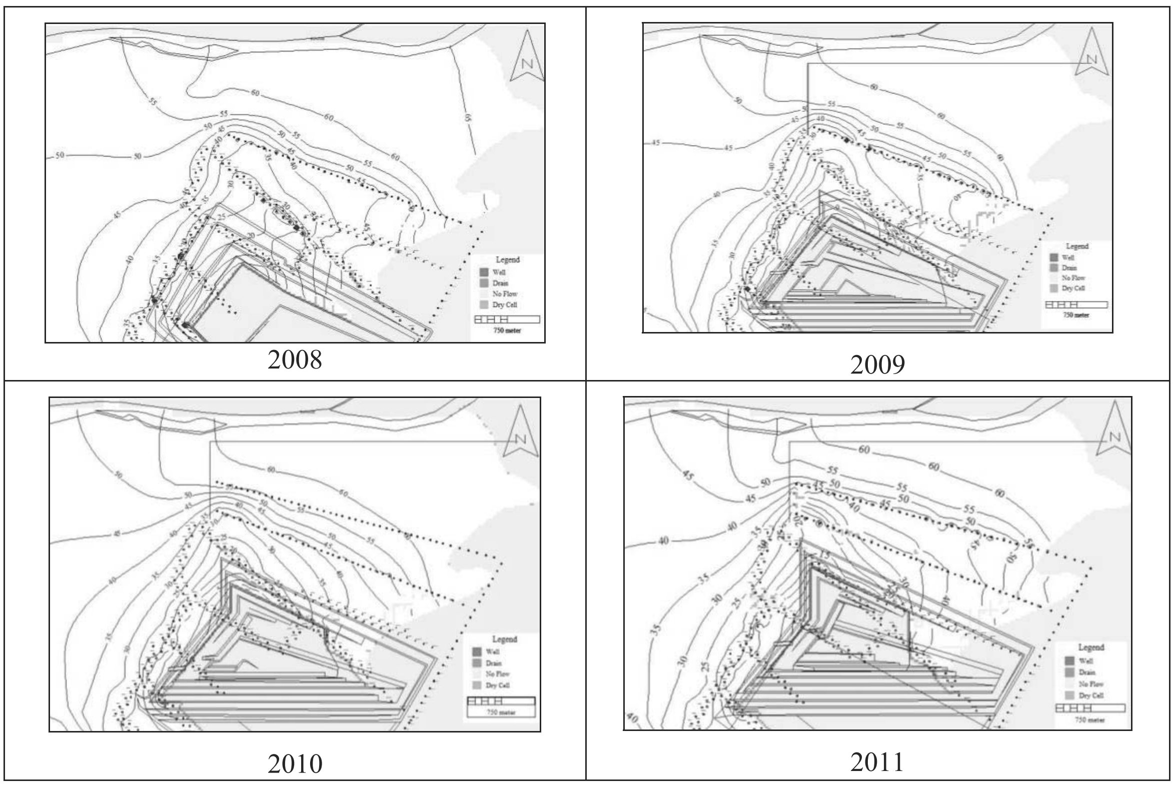

Figure 4: Map of contours of water table in the sand above the third coal seam (Variant 2)

Groundwater levels in model cells with the assigned well capacities which have been calculated, are the representative levels in these cells. Each well has been placed in a special discretization field, and the maximal error in the supposition of its location (by coordinates) is to ± ~6 m.
According to the shown maps, it can be concluded that in the overlying sand of the third coal layer the significant work effect of drainage wells is noticed, already at the end of the first year of the calculated period. The difference between the flow state of groundwater within bordering lines of the drainage system and the area beyond this line is obvious. By building the water impermeable screen (Variants 2 and 3) the direct impact of water infiltration from the Dunavac channel is stopped, except that, through deeper sandy sediments.
The general impact of the water impermeable screen in the dewatering system, which from the moment of its constructing affects the decreasing of overall well capacity in barrages, can be seen in the diagram in figure 5. At the end of the first year of the water impermeable screen existing (31st December 2008) the impact of the screen on the decrease of barrage capacity amounts 42.32 l/s

(Variant 2), namely 77.16 l/s (Variant 3). At the end of the forecast period (31[st] December 2011) the impact of the screen can be seen in the decreasing of 111.0 l/s (Variant 2), namely125.2 l/s (Variant 3). Calculated in relation to Variant 1, it means that according to Variant 2, it is required to pump 3.5×10^9 m^3 less groundwater yearly, namely 3.94×10^9 m^3 according to Variant 3.

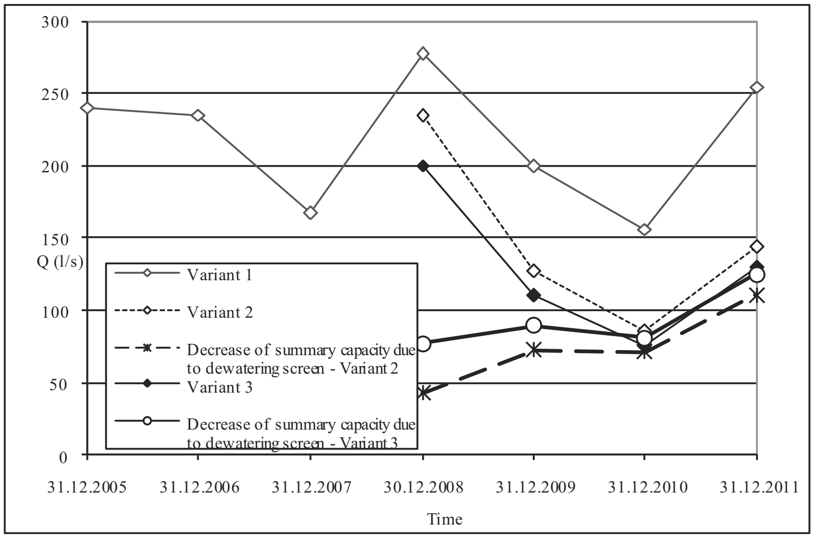

Figure 5: Diagram of overall annual capacities of all barrages in front of mine northern layout according to dewatering variants of Drmno open pit mine

3.3. Discussion of variant calculation results

In Variant 2 of the open pit mine dewatering with the constructed water impermeable screen in the north, together with the existence and work of designed wells, the inflow of groundwater is decreased as expected because of the infiltration of the water from Dunavac channel in relation to Variant 1. In this calculation Variant the aquifer in gravel is drained even faster, which results in larger number of drained wells which are being disengaged. In Variant 3, which in relation to Variant 2 has the prolongation of the water impermeable screen along the eastern pit layout, the stated situation is even more pronounced. Generally, for open pit dewatering Variants 2 and 3, it stands that the effect of water impermeable screen is pronounced more clearly after the second year of its existence.

On the basis of the obtained calculation results, the conclusion is reached that, dynamically observed, the time is the most significant factor in the process of the Drmno open pit mine dewatering. The increase of both capacity and the number of wells does not yield satisfactory effects. On the other side, the existence of the water impermeable screen plays a significant role in the lowering of groundwater level in front of the face advancing layout.

The results of the simulation of the mine protection from groundwater have shown that the water inflow from the aquifer in gravel, from the direction of the Dunavac amounts 0.140 l/s/m, and from the Mlava 0.478 l/s/m, while with the water impermeable screen the inflow from the Dunavac direction is reduced to 0.000453 l/s/m, namely from the Mlava to 0.00563 l/s/m. It means that by building in a water impermeable screen from the Dunavac direction groundwater inflow from the gravel will decrease by 99.67%, namely from the Mlava direction by 98.82%.

4. CONCLUSION

The existing system for the Drmno open pit mine protection from groundwater inflow does not yield satisfactory effects which can be seen in general increase of groundwater level and insufficient rate of groundwater lowering, especially in front of mining work face advancing. By earlier design solutions the mine protection system was exclusively anticipated by drainage wells. The effects of the mine protection system consisting of drainage wells and the water impermeable screen north, west and east of the face advancing layout are analysed in this paper. The carried out calculations together with the techno-economic analysis have pointed out significantly higher effects in the lowering of groundwater level and the decreasing of inflow in the mine with the participation of the waterproof screen, with lower costs of completion and maintenance.

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