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*Aleksandar Doderović[*1], Nikola Stanić[*2], Miljan Gomilanović[*3], Saša Stepanović[*4]*

SYSTEM FOR WATER COLLECTION THAT GRAVITIES INTO THE OLD BED OF THE RIVER ČEHOTINA[**]

Orcid: 1) https://orcid.org/0000-0003-3665-6784; 2) https://orcid.org/0000-0002-6620-8563; 3) https://orcid.org/0000-0002-1209-7423; 4) https://orcid.org/0000-0003-3485-201X

Abstract

Functioning of the drainage system has a great importance for the efficient and continuous exploitation at the open pits. Modern exploitation is realized at the open pits with increasing depth and surface, so it is of a crucial importance to accept as much water as possible before it enters the open pit contour. By this way, the loading of a drainage system inside the open pit is greatly reduced, but it also prevents the negative effects of water on the massif. This paper, using the example of the open pit Potrlica, presents how the already existing system, which fully solves all problems in a dynamic environment such as surface mining of lignite, can be improved. Timely improvement of the system can greatly relieve the existing drainage system and improve the exploitation system.

Keywords: *surface mine, drainage, river bed regulation, drainage factors, pumping station*

1 INTRODUCTION

Protection of the open pit from water is an important technological operation, and the exploitation of mineral raw materials at the open pits largely depends on its application. Therefore, the investments in the drainage system are necessary. The existence and functioning of the drainage system at the open pit directly generates costs, as well as the system of excavation, transport and disposal of overburden. A good drainage system generates costs that are fully in line with the system work. A bad system not only generates costs but can also cause a temporary suspension of works. In those situations, in addition to the costs, the suspension of work prevents the generation of profits for a long period of time.

Correct dimensioning and timely investment in order to form a drainage system for a longer period of time can reduce the drainage system costs. In addition to reduce the operating costs of the functioning of drainage system, it is possible to create such conditions in the deposit that will affect the increase in profits; some examples are given in the work of El Idrysy and Connelly [1]. In this paper, the drainage system at the Pljevlja surface mine is presented. A special

[*] *Mining and Metallurgy Institute Bor, Zeleni bulevar 35, Bor, e-mail: aleksandar.doderovic@irmbor.co.rs*

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review was made on the way the new technical solution functions after the relocation the main watercourse in the wider area of the open pit and improvement the system in the newly created situation.

2 DESCRIPTION OF THE CURRENT STATE

The open pit Potrlica is located in the territory of the municipality of Pljevlja in the northern part of Montenegro. The process of exploitation has been going on since the 80s of the 20th century, and the general direction of development the works is the northeast-southwest. The previous process of exploitation from the point of view of drainage had before it several key elements that affect its functioning, namely:

- Periodically increasing the depth of the open pit from the moment of opening.
- The position of the Ćehotina watercourse in the area where exploitation is planned.
- Large inflow of underground water from the Tvrdaš and Kutlovača streams.

Figure 1 (TK 1:25000) shows the position of the natural bed of the Ćehotina river (purple line), position of the Ćehotina river bed after relocation in 2004 (blue line) and position of the new projected route of the Ćehotina river (red line). Figure 1 also shows the position of the Tvrdaš outcrop, as well as the boundary of the Potrlica-Kalušići deposit.

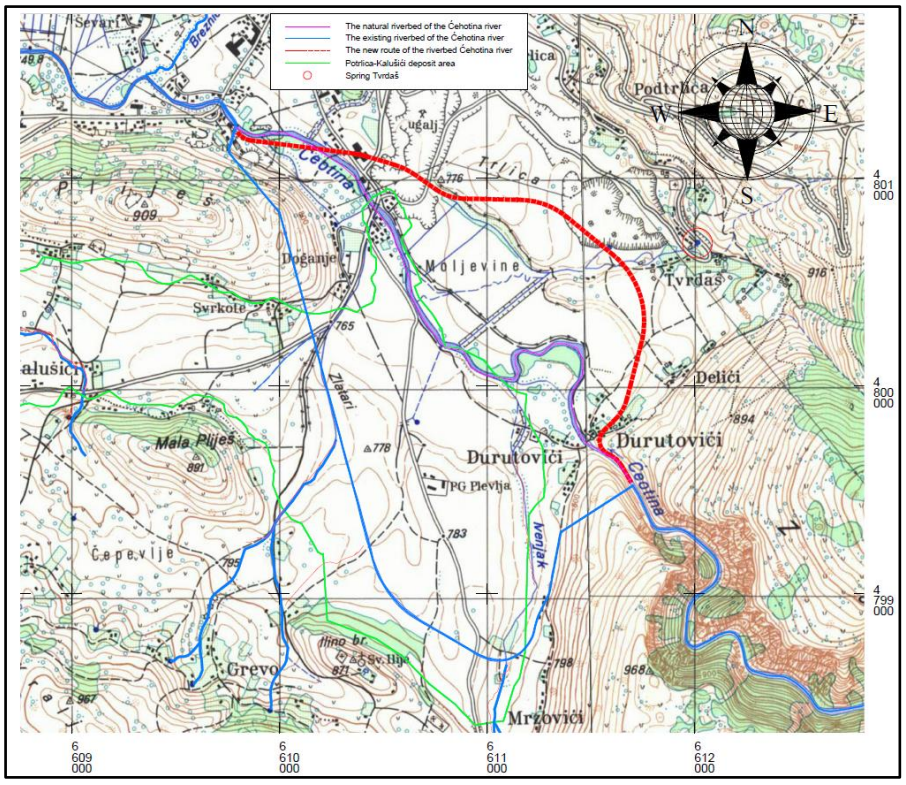

Figure 1 *Position of the bed of the Ćehotina river in different stages of exploitation at the open pit Potrlica-Kalušići*

The exploitation process as well as the drainage system successfully fit into the mentioned natural conditions, so that during the exploitation process there were no major problems from the point of view of drainage. In 2004, in order to ensure the continuation of exploitation, the first relocation of the Ćehotina river was carried out to the position where it is today. The increased inflow of water from the outcrops, which at one point was 400 l/s seconds from the Tvrdaš outcrop [2], as well as the problem of permanent increase the depth of the open pit, was solved by the correct dimensioning of water evacuation system from the open pit. The values of the amount of pumped water for the period from 1998 to 2018, shown in Table 1, were taken from the Supplementary Mining Design for the coal exploitation at the open pit Potrlica - Pljevlja for the period from 2020 to 2025 [3].

Table 1 *Quantities of water pumped from the central part of the open pit Potrlica in the period 1998-2018 [3]*

Godina	Mesečne količine ispumpane vode (m^3)												Ukupno (m^3)
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1998.	809.178	776.208	665.994	657.516	986.274	673.530	621.720	543.534	637.734	618.894	1.120.980	1.058.808	9.170.370
1999.	876.060	878.886	1.042.794	866.640	786.570	711.210	669.762	559.548	390.930	332.526	585.924	1.080.474	8.78.1324
2000.	1.035.258	938.232	1321.626	1.309.380	1.010.766	684.834	519.984	438.972	383.394	433.320	410.712	474.768	8.961.246
2001.	803.526	727.224	1.000.404	821.424	1.026.780	788.454	690.486	682.950	668.820	972.144	862.872	913.740	9.958.824
2002.	761.136	895.842	888.306	1.079.532	990.042	743.238	720.630	848.742	820.482	1.379.088	987.216	873.234	10.987.488
2003.	1.344234	1.172.790	1.090.836	1.182.210	1.011.708	832.728	725.340	649.980	664.110	646212	815.772	907.146	11.043.066
2004.	1.139.173	1.146.398	1.370.380	1.131.145	1.199.383	1.147.201	1.074.146	1.098.198	830272	923303	1.061.575	1.400.566	13.521.740
2005.	1.196.024	1.037.362	1.584.716	1.526.094	1227.884	958.349	892.717	835.369	943.693	1.091.524	971.730	1.211.317	13.476.779
2006.	1.118286	923.940	1.542.661	1.520.996	1.438.160	1.114.463	1.096.940	864.043	797.137	820.076	873.601	943.056	13.053.359
2007.	1.117.012	1.093.435	1.220.875	1239.354	778.658	1.043.734	1.072.408	996.581	782.482	1.038.636	1.310.720	1.589.814	13283.709
2008.	1.408.849	1.176.271	1.446.444	1364.245	1348.952	1.055.203	1.296.065	1.171.811	851299	905.461	1.016.971	1.672.650	14.714.221
2009.	1.512.076	1.412.035	1.628.046	1.607.656	1359.148	1.193.476	1.329.836	1.117.012	973.642	1.122.746	1.452.818	1.468.746	16.177.237
2010.	1.487.016	1.373.472	1.712.052	1290.708	1350.216	1.274.292	1.149.804	1.186.740	1.038.312	1.042.632	1.162.944	1.582.200	15.650.388
2011.	1.394.712	1.215.936	1.373.112	1230.552	1376.064	1.264.896	1.222.200	1.218.240	1.010.376	1.022.904	1.037.880	1.100.664	14.467.536
2012.	1.069 200	1.177.200	2.123.280	1.969.200	1.804.320	1.535.040	1.386.000	1.173.600	1.102.320	1.125360	1.129.680	1.270.800	16.866.000
2013.	1.622.160	1.770.480	2.163.600	1.910.880	1.889424	1.562.400	1.364.400	1.231.200	1.033.200	1.069.920	1.021.680	1.044.000	17.645.040
2014.	1.251.360	1202.400	1.265.040	1.643.040	2.471.760	2.061.360	1.824.480	1.468.080	1.211.040	1.501200	1.398.240	1.928.880	19.226.880
2015.	1.699200	1.933.200	2.278.800	2236.320	2.008.080	1.548.000	1.528.740	1.433.664	1.026.684	1.177.848	1.280.448	1.192.896	19.343.880
2016.	1.205.892	1.440.504	2.283.876	2.057.472	1.828.332	1.772.928	1.746.936	1.601.244	1.303.020	1.359.792	1.673.748	1.501.380	19.775.124
2017.	1.254.456	1.495.908	1.699.740	1.571.832	1.936.404	1.692.216	1.396.044	1.417.932	1.212.048	790.305	817.650	1.296.260	16.580.795
2018.	1.282.435	1.159.596	1.370.730	1.786.464	1.461.816	1.435.140	1.545.948	1.410.444	1.174.140	964.458	844.938	1136970	15.573.079
Ukupno	**25.387.243**	**24.949.319**	**31.073.312**	**30.002.660**	**29.252.437**	**25.092.692**	**23.874.586**	**21.947.884**	**18.855.135**	**20.338.349**	**21.838.099**	**25.648.369**	**298.260.085**

Currently, the process of exploitation, that is, the position of the working levels of the open pit are in the immediate vicinity of the active bed of the Ćehotina river (at about 150 m), so it is necessary to relocate it as soon as possible. Figure 2 shows the position of excavation levels of the open pit and position of the existing Ćehotina river bed, as well as the new route of the river bed after relocation.

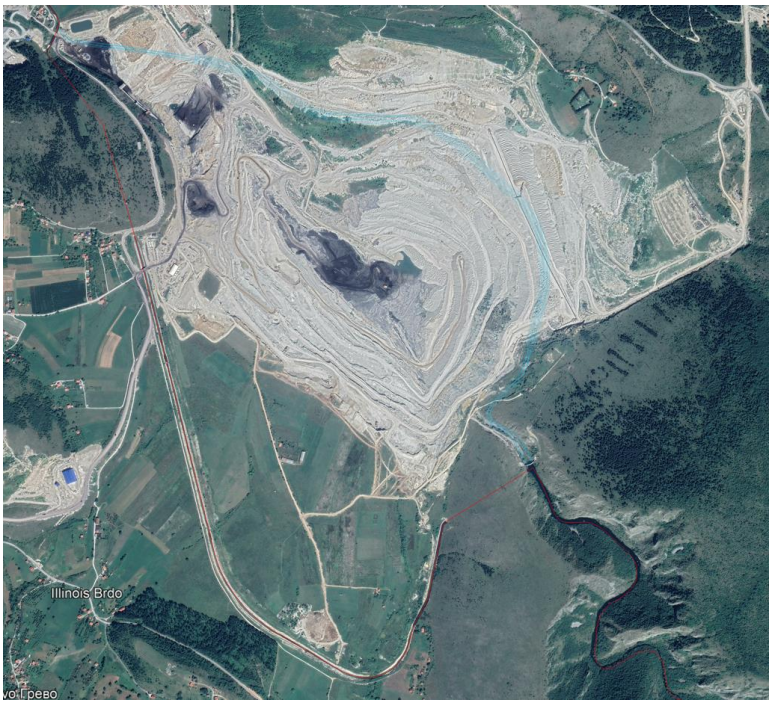

Figure 2 *State of works at the Potrlica open pit (Google Earth satellite image)*

3 DESCRIPTION OF THE PROBLEM

3.1 Introduction to the problem

The current situation requires the continuation of exploitation in the Coal Basin Pljevlja in the coming period with realization the significant investment steps such as the relocation of the Ćehotina river. The primary reason for realization of this investment is to ensure the safe continuation of exploitation at the Potrlica deposit, as well as the creation of conditions for expansion of the open pit in the area of Kalušić, and thus the extension of the mine life.

From the point of view of functioning the drainage system, the relocation of the Ćehotina river will bring significant changes, not so much to the way of its function, but to the change of water flow into the contour of the open pit. Position of the objects to be defended, but in the configuration of the surrounding terrain, the surface, cover, direction and fall that gravitate towards and from the objects, will also depend on the amount of water that comes into the contour of the surface mine [4]. Changing the flow direction of the main recipient completely changes the orientation of catchment areas that gravitate towards the open pit. Depending on the position of exploitation objects in space, size, slope and type of surface, an analysis of distribution the catchment areas and water inflow from them into contour of the open pit was carried out for the condition before and after relocation of the Ćehotina river.

As it can be seen in Figure 3, before relocation the Ćehotina River into the open pit

area, water flows from the catchment areas P2, P3 and P4, while water from the catchment area P1 flows directly into the Ćehotina River.

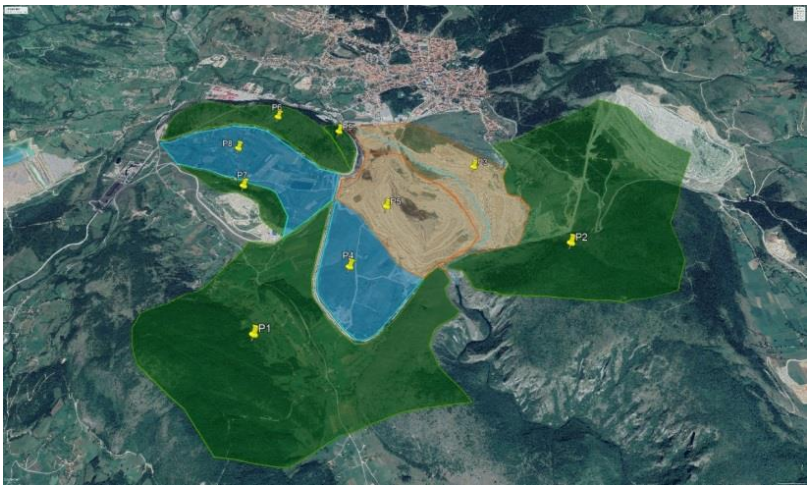

Figure 3 *Positions of catchment areas in the wider area of the open pits Potrlica-Kalušići after relocation of the Ćehotina river (Google Earth satellite image)*

After relocation of the Ćehotina river, the distribution of catchment areas is different; the new bed will collect water that gravitates from the catchment area P2 and P3, as well as a part of water from the catchment area P9. The old bed of the Ćehotina river will collect water from the catchment slope P1 and part of P4, P6 and P8. Figure 4 shows the layout of the catchment areas after relocation of the Ćehotina River.

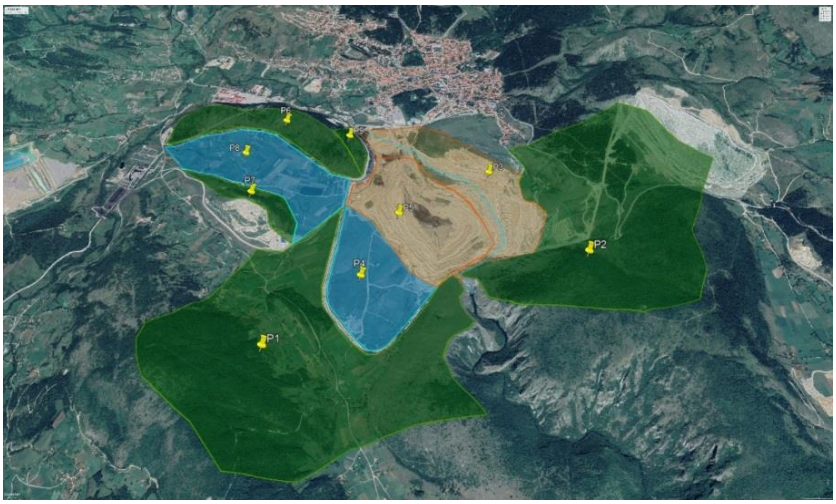

Figure 4 *Positions of catchment areas in the wider area of the open pits Potrlica-Kalušići after relocation of the Ćehotina river (Google Earth satellite image)*

3.2 Elaboration of the problem

The old river bed, through which the river flowed before relocation, retains its hydrological function even after relocation, until it is completely cut by the exploitation works and its connection with the tunnel under the Velika Pliješ hill is cut off. In accordance with the dynamics of development in order to continue the exploitation, the existing bed will be cut by the mining works. From this moment, all water from the eastern catchment area (P1), as well as several streams that flow into the bed, will be directed towards the contour of the open pit. During the forecast calculation of the flow of water into the intersected bed, a shortened version of the catchment area P1, position is shown in Figure 4, was considered. For the purposes of the analysis, a catchment area of 2.5 km^2 was adopted, as well as a runoff coefficient of 0.6. Since the expected groundwater inflow is not known, it is estimated at 50 l/s. The expected inflow of water into the cut bed for rainfall with a return period of 50 years and rainfall intensity lasting 8 hours is 4.47 m^3/s.

This amount is not negligible, but it is certainly about precipitation that can be expected rarely, once in 50 years. Certainly, the climate change has affected the changes related to the precipitation. So, in a situation where the bed is left open towards the open pit contour and working floors, all water that falls on the aforementioned catchment area would directly flow into the open pit. On that occasion, there would not be a successive inflow of water into the open pit contour, but water would flow into the open pit contour via the working floors in the form of watercourse of a temporary nature. The inflow of water into the open pit contour in this way and in such amount would certainly adversely affect the exploitation process. This would result in the reduced mobility of equipment in the inflow zone, but also deterioration of the geomechanical characteristics of the environment in the wider inflow zone. Also, all water that reaches the open pit in this way, which is about $2x10^6$ m^3/year, would have to be evacuated from the main reservoir to the recipient. In this way, in addition to the amounts shown in Table 1 (in the continuation of exploitation, a slightly smaller amount of water for pumping is expected), it would be necessary to pump an additional 2 x 10^6 m^3 of water/year with a pumping height of 100 m.

4 ALTERNATIVE SOLUTIONS

The possibility of free flow of collected water to the existing watercourse after the mining works cut the old river bed of the Ćehotina River is no longer possible, and as an alternative to evacuating the collected water there are two ways (variants). Controlled discharge of water into the open pit contour and subsequent pumping of water from the bottom of the opent pit to the recipient (V1) or by direct pumping of water from the old river bed of the Ćehotina river to the recipient (V2). In order to avoid the additional pumping of significant amounts of water from the bottom of the open pit, as well as the additional installation of pumping units and pipelines, but also the generation of significant costs, the variant V2 was taken into consideration, which is the direct pumping of water from the old bed of the Ćehotina river.

In this variant, the entire system was considered as a drainage system inside the open pit, so during the calculation, the system was dimensioned in accordance with the way of dimensioning the water reservoirs and pumping stations inside the open pit. [5] In accordance with the calculation for reception of this water, it is necessary to provide a reception area of 100,000 m^3 and it is necessary to install on it a pumping station with a capacity of 290 l/s, with an additional reserve in the capacity of 90 l/s, and the expected evacuation time of collected water is 290 h.

In accordance with the conditions on the ground, the expected dynamics of development the mining works and request for the necessary accommodation capacity in order to prevent the inflow of collected water into the contour of the mine, it is necessary to block the bed with an embankment and carry out its additional arrangement. Evacuation of the collected water to the recipient is carried out by a pump-pipeline system.

By dividing the bed with an embankment and installing a pumping station, it can be said that a water reservoir is formed on the terrain surface. This kind of phenomenon may not be common for the open pit exploitation, but it is certainly possible to come across such cases. The open pit Gacko drainage system has one object of this type in its system [6].

4.1 Additional arrangement of the old bed of the river Ćehotina

In order to ensure the formation of a reception area in the old bed of the Ćehotina river, it is necessary to carry out the following works:

- Construction of the Embankment-1 in order to close the bed and possibility of forming a temporary reservoir.
- Construction of the Embankment-2 in the area of the "Ivenjak" stream in order to ensure favorable conditions for pumping out water.
- Revision the bottom of the riverbed from Embankment-2 to the concrete part of the riverbed.
- Elevation of the embankment in order to secure the floodplain up to the level of 779 m above sea level.

Figure 5 *Position of the Embankment-1, Embankment-2 and embankment overhangs of the Ćehotina river bed*

4.2 Construction of the Embankment-1 and Embankment-2

The barrier Embankment-1 ensures the closure of the old bed of the Ćehotina river and enables the formation of water accumulation. Position of the Embankment-1 was chosen in accordance with the developed dynamics of works until the 10th year, but also with the requirements of the reservoir volume.

According to the shown calculation, the required capacity of the water reservoir is 100,000 m^3, and the reservoir volume from the intended position of the embankment to the Durutovići tunnel for the water mirror level up to the elevation of 779 m above sea level is about 127,000 m^3. This volume re-

fers to the space without priorarrangement of the bottom and construction of the Embankment-2.

The barrier Embankment-1 will be built up to the level of the flooded area (elevation 779) in two sub-levels on the side towards the open pit and one level towards the water accumulation. In order to ensure the water tightness, the embankment will be made of clay and protective film. For the purposes of forming the Embankment-1, it is necessary to install 3235 m^3 of clay and 1900 m^2 of protective film. Figure 2 shows the cross-section of the Embankment-1 barrier.

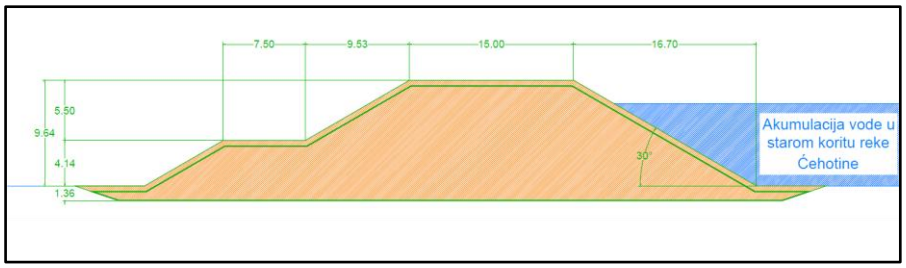

Figure 6 *Layout of the Embankment-1 barrier*

Due to the construction of the Embankment-1, the deepest part of the bed is located next to the embankment itself, and thus the position for installation the pumping station is predetermined. The long distance from the recipients would require large investments to form a pumping station, but also frequent displacement of pipelines due to the progress of exploitation works.

In order to avoid this unfavorable situation, and also to avoid a large retention of water in the event that the pumping station is moved to the location upstream, it is necessary to construct the barrier Embankment-2 in the area of the Ivenjak stream and arrange the riverbed from the Embankment-2 to the concrete part of the riverbed. The works on the arrangement of the riverbed involve changing the longitudinal slope of the riverbed towards the Durutovići tunnel. In order to ensure the connection of a bed part between the Embankment-1 and Embankment-2 with a bed part in which the pumping plant is located, the barrier Embankment-2 will be built up to the level of 778 m above sea level. The remaining water from the first part of river bed, after lowering the water level below the elevation 778, will be pumped into the river bed part where the pumping station is installed.

By changing the longitudinal dip of the bed, a local depression is formed, suitable for positioning the pumping station for water evacuation to the new bed of the Ćehotina river. The depth of bed in this part after the reconstruction is 5.9 m. The barrier Embankment-2 will be constructed in the same way as the barrier Embankment-1, which requires 2500 m^3 of clay and 1800 m^2 of protective film.

Unlike the barrier embankments, the excavated material in the open pit from the higher floors will be used to arrange the bottom of the river bed. The surface layer (about 50 cm) of material, used to arrange the riverbed, will be made of clay in the same way as in the case of creating the barrier embankments. In order to realize these works, it is necessary to provide 15,000 m^3 of material.

Analyzing the configuration of the embankment around the bed of the Ćehotina river and predicted flood area up to the level of 779 m above sea level, it was observed that in the part of bend near the "Ivenjak" stream, the embankment is significantly lower compared to the predicted flood area. In order to prevent water from flowing out, it is necessary to build the embankment in

this part. The total length of the embankment that needs to be raised is 150 m, and the maximum height of overhang is 3 m. For realization of these works, it is necessary to install 5000 m^3 from the excavation from the open pit. During installation, the material should be spread in layers of up to 0.25 m and passed with a flat roller 6 times over the full surface of the poured material.

5 COMPARISON OF ALTERNATIVES

Table 2 shows a comparison of the electricity amount consumed for water evacuation that reaches the open pit contour (V1) from the catchment area P1, that is, the old bed of the Ćehotina River (V2).

Table 2 *Comparison of the evacuation methods from the catchment area P1*

	V1	V2
Pumping station capacity, m^3/h	2304	1044
Amount to pump out, m^3/year	2,000,000	2,000,000
Number of discharge hours h	868	1,916
Installed power of pumping station, kW	2,440	165
Total electricity consumption, kWh	2,118,056	316,092

As it can be seen from Table 2, the Variant V2 is significantly more favorable. The main reason for this is that with the application of this variant, the pumping units of lower power are engaged.

In comparison the two mentioned variants, the designed capacities and pumping stations without the required legal capacity reserve were taken into account. Also, in comparison the variants, the necessary investments were not considered, which are significant in order to arrange the bed of the old bed of the Ćehotina river and make an embankment, as well as for formation a new pumping station. As the pumping out analysis did not include the entire drainage system, but only the water from the catchment area P1, the comparison did not take into consideration the investments for expansion the pumping station inside the open pit in the Variant V1.

If the necessary investments were included in the comparison process, the difference between the variants would certainly be smaller, but even in that case the Variant V2 would be more favorable than the Variant V1.

6 CONCLUSION

The water evacuation system at the open pit Potrlica surface mine can be characterized as a good one. In addition to all mentioned aggravating factors, the large inflow of groundwater, its replenishment due to the great proximity of watercourses, as well as the permanent deepening of the pit and increase in the pumping height, it fully met all the requirements that were put before it.

This paper provides an example of how such system can be improved and become even better. By accepting the water that gravitates towards the bottom of the open pit before it enters the contour of the open pit (or the higher levels of the mine), it significantly reduces the cost of water evacuation, but also facilitates the entire process of exploitation. One of the negative things that follows this way of working is the wide spread of drainage facilities, not all of them

are centralized, which certainly requires the additional costs.

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