Implementation of the Rehabilitation Operational Strategy for the flooded Opencast Mine Tamnava-West Field

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Abstract

Floods of opencast mines are relatively rare, but are more and more likely with changes in climatic conditions, when special and additional measures should be taken for the protection of mines against surface water. In the recent past, some of the coal opencast mines were flooded worldwide. It required, on average, about two years to reactivate these mines. In May 2014, catastrophic floods hit Serbia and the majority of the Kolubara coal basin. On that occasion, the largest opencast mine in this basin, Tamnava-West Field, was completely flooded with about 190 million m^3 of water, along with all continuous systems for production.

In order to repair the active opencast mine Tamnava-West Field completely, and to return it to the designed operations, early in June, just a fortnight after the floods, the authors have assembled an expert team who elaborated a plan for the rehabilitation of these opencast mines against consequences of the flooded waters. The expert team defined *Rehabilitation Strategy***,** i.e. a scheduled document covering a wide range of synchronized and manageable processes and activities on the project for implementation of rehabilitation on this opencast mine.

Strategic objectives were implemented while respecting the rules of the profession and the world's best practice in realization of similar projects, with maximum consideration of the opencast mine overall reliability, as well as measures to protect the environment and ecology in general. Established strategic objectives are mainly implemented on schedule, with minor variations in investments realization. This project on the opencast mine Tamnava-West Field reconstruction presents a good example on how to react in an emergency, like this flood. The rehabilitation project foresees all the necessary activities, its scope and implementation dynamics in function for the safe rehabilitation by dewatering of the flooded mine, and reliable continuation of mining.

Key words: dewatering, rehabilitation, reliability, ecology, risks

Introduction

The largest producer of coal in the Mining Basin Kolubara is the opencast mine Tamnava-West Field. From the total of 30.7 million tons of coal produced in 2013, this mine has produced a record of 14.6 million of tons, which is 47% of the total production of the Kolubara basin. Along with all the produced coal, 33 million m^3 of overburden was excavated as well. Achieved production was implemented by nine continuous systems, from which eight are with bucket wheel excavators and one with a bucket chain excavator. According to the provided coal production information, opencast mine Tamnava-West Field is essential for the power generation in thermal power plant Nikola Tesla and overall energy stability in the country.

In mid-May 2014, the main parts of central and western Serbia were affected by catastrophic floods. These floods especially affected the western part of the Kolubara basin, where the Tamnava-West Field opencast mine is located. The opencast mine (OCM) was completely flooded, along with all continuous systems for production (Fig. 1).

Figure 1 *Flooded opencast mine Tamnava-West Field, view from the north and the south.*

Previous preliminary analysis show the following approximate flooded situation in the opencast mine Tamnava-West Field:

- Elevation of water table: 76.5 m
- Elevation of the deepest part of created lake: 10.2 m
- Surface of water table: 7,445,428 m^2
- Area of the opencast mine flooded part: 7,513,006 m^2
- Volume of the opencast mine flooded part: 190,586,345 m^3

The established expert team has developed an operational strategy as a planning document for the rehabilitation of the flooded opencast mine Tamnava-West Field. General objective of this document was to provide reliable and real dynamics for the gradual achievement of the designed production capacity in the opencast mine Tamnava-West Field. Strategic objectives of the project were, based on the analysis, to define the following:

- Optimal rehabilitation plan for the opencast mine in the function of equipment operation reliability and stability of the opencast mine;
- Dewatering dynamic of flooded opencast mine in the function of operating and final slopes stability, internal dumps and equipment and environmental protection;
- Dynamics of the opencast mine protection against surface water (river flows, retention, etc.);
- Dynamic, technology and equipment for mining on the flooded opencast mine.

Operational strategy for the opencast mine Tamnava-West Field rehabilitation

Project implementation of the rehabilitation strategy refers to a plan for the opencast mine rehabilitation (Pavlovic 2014), based on the previously conducted analysis on:

- Geometry of the flooded opencast mine, the internal dump site and location of the equipment under water;
- Stability of the opencast mine and internal dump site in the function of the flooded opencast mine dewatering dynamics;
- Stability of the opencast mine and internal dump site in the function of the mining technology and dynamics;
- Condition of river flows, retention basins and water reservoirs in the affected area on the opencast mine;
- The risk of coal mining continuation in the function of the opencast mine geometry, stability, dewatering and quality of pumped water;
- Direct and indirect damages on the opencast mine.

Since the opencast mine was completely flooded, for more reliable *situational analysis* it was necessary to perform mine, dump site and equipment geodetic underwater survey, as well as geodetic survey of river flows, retention basins and water reservoirs in the impact zone on the opencast mine, followed by an analysis of the stability of the flooded opencast mine and inside dump as well as deposit hydrodynamic model, at the end (Drebenstedt 2014).

SWOT analysis included the following factors:

- *Threats from the external environment:* climatic conditions during rehabilitation, impact on the environment and ecology in general, and funds.

- *Strong points of the project:* continuation of safe, reliable, efficient and effective production in the opencast mine and defined and manageable system of the opencast mine rehabilitation.
- *Weak points of the project*: insufficient reliability of the existing database for project development.

Risk assessment of project for the opencast mine Tamnava-West Field rehabilitation

Considering the importance of the opencast mine reconstruction project for the overall energy stability of the country, the high level of investments required for rehabilitation and the degree of uncertainties related to the project, the expert team has conducted an *ad-hock* risk analysis of the project (Pavlovic 2014).

Risk analysis covered the following aspects:

- Personnel;
- Mine and equipment:
  - Pumping of water and the amount of mud in the mine
  - Degree of machinery damaged and caused by flood and funds for repair
  - Preparation for mines rehabilitation;
- Environment Protection.

The risk analysis is based on the parameters shown in Table 1.

Table 1 *Risk Assessment.*

Result	Consequences			Probability of an event - result				
	P	A	E	1	2	5	10	20
	Personnel	**Mine and equipment**	**Environment protection**	**Hardly possible** (< 1 in 1000)	**Unlikely** very unlikely (1 in 100 > 1 in 1000)	**Probably** unusual but possible (1 in 10 > 1 in 100)	**Very likely** (certain > 1 in 10 cases)	**Almost certainly**
1	Without injury	No damage	No effects	(5) Low	(10) Low	(20) Low	(25) Medium	(50) Medium
2	Easy injuries	Small damages (< 10.000.000 €)	Smooth effects	(10) Low	(20) Low	(40) Medium	(50) Medium	(100) High
5	Lower injuries	Medium damages (10-50.000.000 €)	Low effects	(25) Low	(50) Medium	(60) Medium	(75) High	(250) Extreme
10	Major injuries	Serious damaged (50-100,000,000 €)	Localized effect	(50) Medium	(100) Medium	(200) High	(250) Extreme	(500) Extreme
20	Permanent disability	Very serious damaged (80-200,000,000 €)	Main effect	(100) Medium	(200) High	(400) Extreme	(500) Extreme	(1000) Extreme
40	Multiple deaths	Catastrophic damage (> 200,000,000 €)	Massive effect	(200) High	(400) Extreme	(800) Extreme	(1000) Extreme	(2000) Extreme

The following important results and conclusions of the risk analysis are provided:

Personnel

Slope stability. In case of slopes sliding, there can be fatal injuries. *Probability of the event - unlikely 40/2*.

Mine and equipment

Slope stability. If water pumping is not effective in accordance with the soil-mechanical characteristics of the material, it can lead to the collapse of slopes. In this case, three possible damages of equipment may occur:

- Complete dump site sliding with damage of the majority of equipment. The mine would be without production for minimum two years. Direct damage to the equipment and the indirect damage caused by the import of electricity are very high. *The risk is in the field 40/5, and the estimated damage is €800 million.*
- Partly dump site sliding (lowest benches - interburden). In this case, one spreader, one dragline and conveyor line (3 km) with two drive stations may be destroyed. *The risk is in the field 5/10, and the estimated additional damage is €75 million.*
- Partially sliding of excavated bench. In this case, bucket wheel excavator SchRs 1600 and part of the conveyor route with one drive station may be damaged. The damage is due to a complete refurbishment of the excavator, with longer downtime of excavation at overburden, as well as indirect damage by electricity imports. *The risk is in the field 10/10, and the estimated damage is €250 million.*

The amount of mud in the mine. If there is a lot of mud in the mine, and if it cannot be removed by pumping water, the following risks could happen:

- Complete line of coal is under the mud;
- Bottom line of coal is under the mud;
- Excavated area is under the mud.

Water pumping. If the water pumping is very slow it may cause the following risks:

- The equipment will be exposed to corrosion for a long time.

Degree of machinery damage caused by the flood. If the flood was very strong, it could cause damage on a part of the machinery. If this happens, it could cause the following risks:

- Complete two main coal conveyor lines are destroyed;
- Undermined area on which the bucket wheel is;
- Parts of frames are destroyed;
- All the equipment of Kolubara Metal Company is destroyed.

Funds for repair. If the amount of funds for the repair is small, a complete refurbishment of flooded machinery is not to be performed, which in the future will result in less availability and higher maintenance costs:

- Funds for repair are insufficient (less than €30 million), complete replacement of the electric is not performed;
- Funds for repair are insufficient (less than €50 million), complete replacement of the electric is performed, but without mechanical parts;
- Funds for repairs are €60 million, complete replacement of the electrical is performed, and mechanical parts.

Preparation for mines rehabilitation. If the time for recovery preparation is very long, i.e. if project documentation and equipment specification for the procurement is not done on time, if the tender procedures are being done too slowly, opencast mine may be out of operation for a longer period of time:

- Project documentation is not ready, i.e. takes a long time to prepare it, consequences of the inability to compile precise specifications for procurement, possible errors in the procurement and others. *The risk is in the field 10/5 unusual but possible, and the estimated direct and indirect damage is €200 million.*
- Tender procedure has been slow, consequences are that equipment was out of operation for a long time. *Risk is in the field 10/5 unusual but possible, and the estimated direct and indirect damage amounted to €200 million.*

Environment protection

Leaking of transformer oil, hydraulic oil and gear unit oil. If there is a leakage, direct pouring of water in the river Kolubara will be prohibited, and in this case, water must be cleaned. *Probability of the event is very likely, the risk in the field 1/10 with additional damage of €10 million*.

Detailed Project for rehabilitation of the opencast Tamnava-West Field implementation plan

Rehabilitation of the opencast Tamnava-West Field implementation plan is presented in Figure 2.

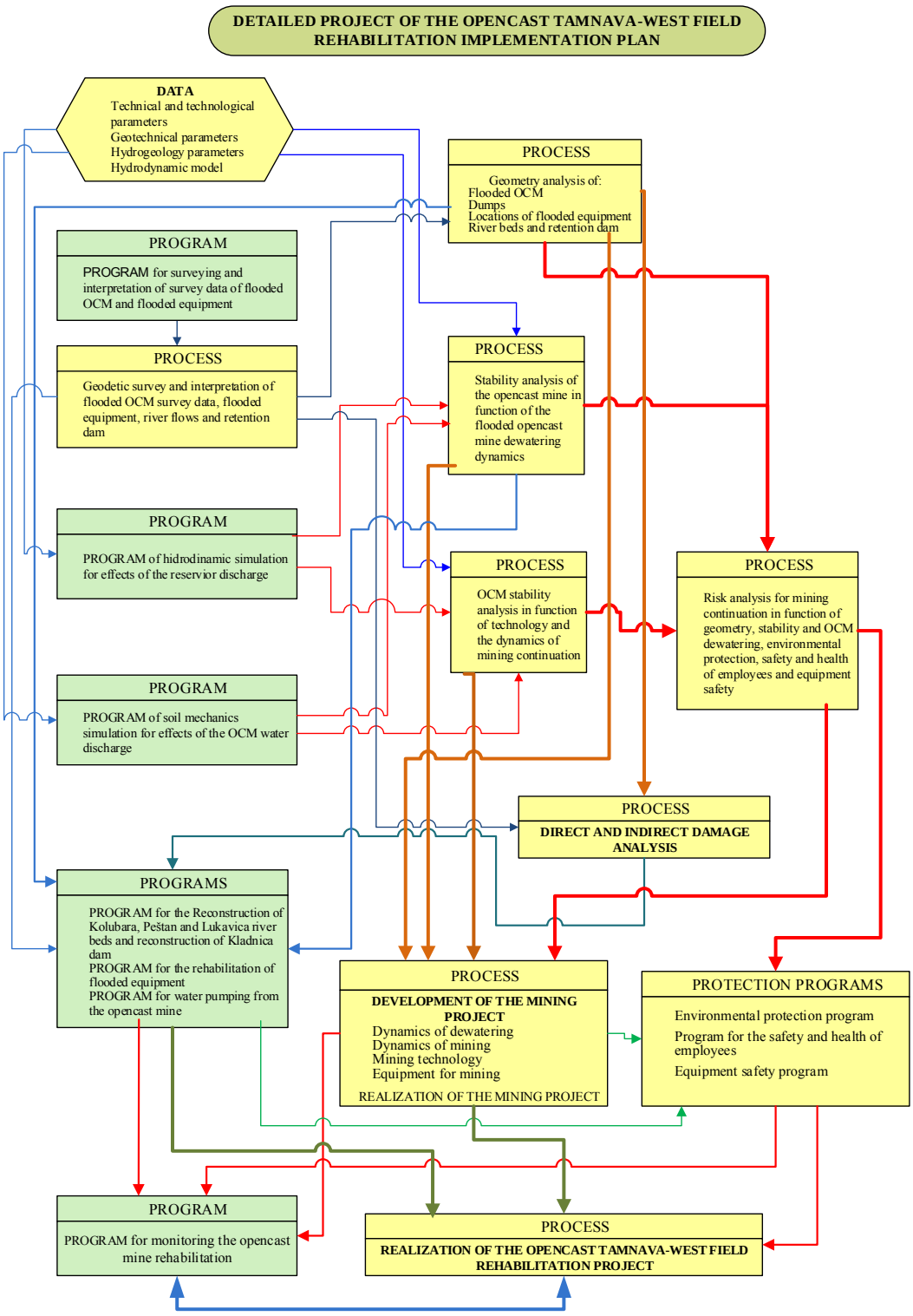
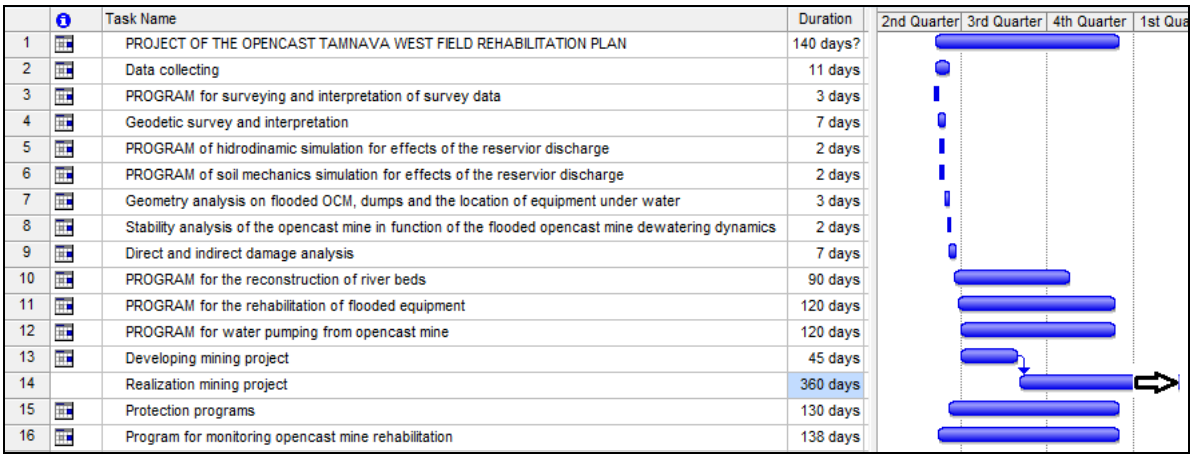


Figure 2 *The opencast Tamnava-West Field rehabilitation implementation plan.*

Dynamics of the project implementation

Dynamics of the project implementation includes development time and time for implementation, as presented in Figure 3.



	Task Name	Duration
1	PROJECT OF THE OPENCAST TAMNAVA WEST FIELD REHABILITATION PLAN	140 days?
2	Data collecting	11 days
3	PROGRAM for surveying and interpretation of survey data	3 days
4	Geodetic survey and interpretation	7 days
5	PROGRAM of hidrodinamic simulation for effects of the reservior discharge	2 days
6	PROGRAM of soil mechanics simulation for effects of the reservior discharge	2 days
7	Geometry analysis on flooded OCM, dumps and the location of equipment under water	3 days
8	Stability analysis of the opencast mine in function of the flooded opencast mine dewatering dynamics	2 days
9	Direct and indirect damage analysis	7 days
10	PROGRAM for the reconstruction of river beds	90 days
11	PROGRAM for the rehabilitation of flooded equipment	120 days
12	PROGRAM for water pumping from opencast mine	120 days
13	Developing mining project	45 days
14	Realization mining project	360 days
15	Protection programs	130 days
16	Program for monitoring opencast mine rehabilitation	138 days

Figure 3 *The opencast Tamnava-West Field dynamics of the project implementation.*

Measures and programs for the implementation of strategic objectives

To achieve the established strategic objectives, a series of hierarchically separated emergency measures were defined, with Implementation of the following programs:

Program of surveying and development of geodetic basis for all potential projects and rehabilitation works on the opencast mine Tamnava-West Field that are carried out in details, reliable and with high quality geodetic surveys, as well as the condition of the river flow, retention dam and water reservoirs in the impact zone of the opencast mine.

Program of hydrodynamic simulations for effects of the reservoir discharge for every 10 m of the water level being lowered in the opencast mine. This program includes innovation of a hydrodynamic model for the Tamnava-West Field deposit, with the purpose of simulation.

Program of soil-mechanics simulation for effects of the reservoir discharge from the accumulated amount of surface water in the condition of the opencast mine, soil-mechanics stability and internal dumps were analyzed each 10 m of lowering the water level in the opencast mine.

Program for the reconstruction of Kolubara, Peštan and Lukavica river beds and reconstruction of Kladnica dam includes all necessary activities on reconstruction, based on hydrologic and hydraulic analysis in accordance with new hydrological conditions, which are a result of flooding.

Program for water pumping from the opencast mine provided the reliability of pumping floodwaters by implementing the following activities:

- An analysis for determining possible dynamics of water pumping from the mine was carried out, taking into account the real technical possibilities, slope stability and the surrounding terrain and other factors of importance, while making sure pumping water in the shortest period is the primary objective.
- The conceptual design of a system for monitoring the elevation of groundwater modification in the area of the opencast mine is defined, depending on the dynamics of abstraction, the stability of the opencast mine and dump site and the quality of the water that is pumped into the recipients.

Program for the rehabilitation of flooded equipment provides defining of the investment in flooded equipment on the opencast mine with implementation time schedule. The following main and auxiliary equipment and machinery was flooded on the opencast mine: 3 overburden systems, 3 coal systems, an interburden system and 4 draglines.

Programs for the environmental protection, safety and health of employees and equipment safety are programs based on which analysis of impacts and risks are made, and that define protection measures and monitoring parameters for the following environment conditions, safety and health at work and protection of flooded equipment during the implementation of the flooded opencast mine rehabilitation.

Program for monitoring opencast mine rehabilitation is a program of continuous monitoring of the rehabilitation plan implementation for the flooded opencast mine. Monitoring program for implementation dynamic of individual activities is based on the designed approach, while monitoring of the environment, safety and health at work and protection of flooded equipment is based on the monitoring of key performance indicators (key indicators) by defined protection programs. As a part of the rehabilitation of the flooded opencast mine, it is planned to draft the mining design, which includes mining reclamation works and bringing the opencast mine geometry in designed condition.

Investment evaluation for the opencast mine rehabilitation

Defining the investment in flooded equipment in opencasts mines of the Kolubara mining basin is an extremely complex task, especially since the expert public had no previous experience in assessing the damage after such failures. According to the plan for the rehabilitation of the opencast mine Tamnava-West Field with dewatering, it was necessary to install 3 pump stations PS-1, PS-2 and PS-3, for the realization of the mentioned rehabilitation dewatering (Pavlovic 2014). Figure 4 shows the starting location of pumping stations. Capacity of the pump stations at the beginning of the operation is 23 m^3/s. Further water pumping is followed by increasing of lifting height and the length of the pressure pipeline, therefore the pump station capacity decreases.

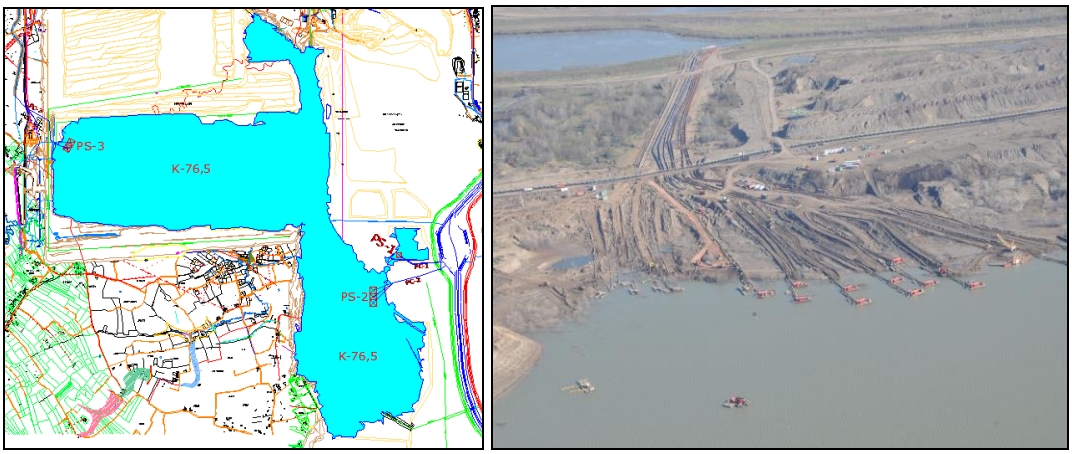


Figure 4 *Initial location of Pump Stations 2 on the flooded opencast mine.*

Investments include required equipment (procurement, transport, installation and commissioning of pumps, production of pontoons and procurement and installation of pipelines), materials and electricity for water pumping from the opencast mine Tamnava-West Field. Required investments amounted to €14.4 million. The value of the flooded equipment, if it would be procured as new, would amount to approx. €250 millions.

Discussions were focused on three levels of the repair works and revitalization of mining equipment according to the following criteria (Table 2):

- The minimum investment and minimum time for bringing mining machinery to operating condition; these imply activities such as dismantling only basic flooded equipment, washing and cleaning, the necessary replacement of critical parts, service for all parts of mining machinery, assembly of tested and cleaned equipment, as well as functional trials (Option 1);
- Investments that will eliminate all the negative effects of the flooded main and auxiliary mining machinery; these imply activities such as complete refurbishment/replacement of flooded segments, service for other machines parts, assembly of repaired and new equipment, as well as functional trials (Option 2);
- Investments that include complete refurbishment and modernization of the mining machinery; these imply activities in the overall revitalization and modernization of mining equipment, with functional trials after the assembly (Option 3).

For all the equipment, all three versions were considered. In all cases, investments in the electric part are the same. Table 2 provides comparative prices of investment for all three options. For the opencast mine Tamnava-West Field, repairs are carried out according to Option 2. Assessment of the

investment or estimated direct damage caused by the opencast mine flooding was carried out on the basis of defined rehabilitation programs, presented in Table 2.

Table 2 *Assessment of investment for the rehabilitation of the opencast mine*

Description	**Amount €**
Program of geodetic surveying and geodetic database surveying	80,000
Hydrodynamic simulations program of the reservoir discharge effects	50,000
Soil-mechanical simulation program of the reservoir discharge effects	25,000
Program for pumping water from the opencast mine	14,400,000
Program for the reconstruction of Kolubara, Peštan and Lukavica river bed and reconstruction of Kladnica retension dam	5,600,000
Program for the rehabilitation of flooded equipment:	
- Option 1	32,360,000
- Option 2	45,698,000
- Option 3	46,858,000
- Kolubara Metal and Processing Plant	2,500,000

Total estimated investments required for the rehabilitation of the opencast mine Tamnava West Field, depending on the program selection for the rehabilitation of flooded equipment, range from €55 million to €69.5 million.

Conclusion

Flooding of the opencast mine Tamnava-West Field is a disaster caused by unprecedented floods and as such actualizes a number of issues related to emergency response in opencast mines and mining in general. On the example of the opencast Tamnava-West Field, the reconstruction project presents a good example on how to react in an emergency situation as it this flood was. Rehabilitation project foresees all the necessary activities, its scope and implementation dynamics in the function of safe rehabilitation by dewatering of the flooded mine and reliable continuation of mining.

Electric Power Industry of Serbia, and especially employees of the Mining Basin Kolubara, put in serious efforts so that the process of flood rehabilitation is done in a coordinated and more efficient manner, on the basis of the presented and accepted Operational Strategy Plan for dewatering and rehabilitation of the opencast mine. Dewatering and the reconstruction of rivers beds and retention dam were realized according to the Plan with costs that amounted to €20 million.

The plan anticipated that the complete electrical equipment is to be replaced by new one, which has been done. Estimated value of damaged electric equipment was €28.57 million, and the actual costs amounted to €28.43 million. Similar ratio of estimated and actual occurred damage at the mechanical equipment amounted to €17.5 million. When mechanical equipment is in question, Option 2 was applied. Established strategic objectives are mainly implemented on schedule, with minor variations in the realization of investments and mud extraction, with respecting the rules of the profession and the world's best practice in the implementation of similar projects and maximum consideration of overall operating reliability of opencast mines as well as measures to protect the environment and ecology in general.

References

Drebenstedt, C., Kuyumcu M. (2014) Braunkohlesanierung, Balkema, pp. 57-62

Pavlovic V., Ignjatovic D., Subaranovic T. (2014) Opencast Mine Tamnava-West Field Project of Sanation, University of Belgrade, pp. 31-37

Pavlovic V., Subaranovic T., Polomcic D. (2014) Opencast Mines Dewatering Systems, University of Belgrade, pp. 22-26