FORMATION OF THE RISK MODEL AT THE INTERNAL LANDFILL OPEN MINE PIT "TAMNAVA-WEST FIELD"

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Abstract: *Insufficient exploration of landfill sites directly affects the accurate assessment of gaps or errors in mine design, which carry high risks and potential consequences from unwanted events. In order to develop a procedure for forming a risk model for mining systems at landfill sites, it is necessary to analize the examples of terrain destabilization and resulting consequences, such as damage to machinery, for instance. Accidental cases recorded during the period from 2014 to 2021 are encompassed by the analysis. Clear guidelines for reducing professional speculation, concealing employee injuries, or costs incurred during accidental events at landfill sites will be provided in the conclusion.*

Key words: RISK, LANDSLIDE, LANDFILL, RISK MODEL

INTRODUCTION

The formation of the internal landfill of the open-pit mine "Tamnava-West field" began in 2000.

The expansion took place and still takes place to the south, in parallel with the advance of the mine. The only break in the disposal was in 2014, after the systematic demolition of the Kladnica dam and the controlled submersion of the mine. By redirecting the flood wave to the working figure of the mine, the risk of damage to the thermal power plant "Nikola Tesla" in Obrenovac was removed. The measures taken created an artificial lake (area of 8.50 km^2) that surrounded the landfill for ten months. The new conditions allowed only the excavation and transport of tailings to the northwestern part of the internal landfill of open-pit mine

"Tamnava-West field". For the first time, we began to think about the nature and condition of the landfill and its floor. Until the flood, all estimates of the stability of the slopes at the landfill, 90 m high with a slope of the upper surface of 4 °, were reduced to speculation. In this particular case, landslides were expected with the direction of movement towards the artificial lake. There was a risk of destabilization of the submerged working slope in the process of lowering the water level.

On the other hand, it was not realistic to expect that the pumping out of the lake would cause the overturning of the submerged machinery or that the sandy, quartz-deciduous floor, 100 m thick, positioned under the body of the landfill, would collapse by filling the tailings at a height. To realize this scenario, the weight of the newly deposited masses would have to produce a pressure greater than the soil resistance within the massif of different types of deposited soil, with a total thickness of 90 m.

Also, it was unlikely that the eventual vertical pushing of the earth block would form a fracture figure with sliding surfaces up to 2 km long, up to the submerged working slope. The prediction of a number of experts that the elevation of the upper surface of the northwestern part of the landfill will collapse its floor has been refuted by the achievement of a height of + 142 m, which is 32 m above the projected maximum elevation.

PURPOSE OF THIS PAPER

The aim of this paper is to point out the importance of forming and using a risk model for the functioning of mining systems at the landfill, given that in practice the factors that affect the occurrence of terrain instability (landslides, erosion, subsidence, cracks...) were not recognized in a timely manner and eliminated in time. The topic deals with the sources of professional and scientific uncertainty, the significance of human omissions and errors, uncertainty in predicting the consequences of accidental situations, and explores ways to verify subjective beliefs with research [5, 6].

The focus of the analysis was on data collected after extreme rainfall in 2014 until 2021, when a fire occurred at the spreader engine. Doubts about the assessment of harmful consequences at the internal landfill during and after the pumping out of the controlled flooded mine were also stated. The paper contains an illustration of the division of activities and conditions at the landfill and a documentary photographs. In conclusion, a schematic risk model will be provided as a product of a combination of proposals for the observation of deformations in open-pit mines [2], for the selection of methods for risk assessment [3], for hazard identification, risk assessment and management of the industrial system with an emphasis on the safety of mining systems [4].

CONCEPT AND METHODOLOGY OF RISK DETERMINATION

Risk analysis and monitoring is an important part of asset management and usable quality. It is usually done by forming a risk matrix and determining the cumulative probability of risk, which is partly made up of: the probability of the occurrence of a risk situation, the probability of the occurrence of a consequence and the probability of preventing the cause in a timely manner.

The assessment procedure is usually done expertly or on the basis of a timeline of the state (history) of accident situations [3]. In the case of the mining industry, it is often necessary to define a customized model of risk cause and effect analysis due to a number of specifics of the working environment. In this paper, the model is adapted according to the geotechnical characteristics of the landfill at the open-pit mine "Tamnava-West field". The concept and methodology of risk determination is based on the fact that there is no control system in landfills to determine the condition and changes in the behavior of the landfill soil or it's floor. Some consequences are reported to certain services only if nothing can be done on the spot, which has affected and continues to affect the lack of objectivity in the database, without which a realistic insight into the categories of danger can not be obtained.

The lack of a risk control model is reflected in the increased costs of maintaining the machinery (subsidence of the conveyor, breakage of the slippers on the excavator track, etc.), loss of profit due to the occurrence of an injury at work, occupational diseases or work-related illness [3], an unrealistically large number of overtime hours. Infrastructure and housing facilities are sometimes threatened, as well as the quality of life of the local community, for which landslides along the final slopes have potentially endangered or aggravated living conditions [6]. In the following, the steps (1) to (3) for risk research will be outlined, examples of good coordination of the flood monitoring team and the consequences of its resolution.

(1) HAZARD IDENTIFICATION PROCEDURE

For proper and impartial identification of danger, it is first necessary to form an expert team in which different professions are represented (geological, mining, mechanical, electrical, geodetic, ecological, urban, economic, legal...) [4].

(2) SETTING UP A RISK IDENTIFICATION TEAM

In practice, it has been seen that the lack of knowledge of key risk factors at the landfill is a consequence of the absence of geotechnical and hydrogeological research, as well as the absence of cooperation between different professions. There was none, and no exists, a hazard identification team. As an initial step for more serious research of risks in landfills, the situation with pumping water from an open-pit mine was when a team was formed in 2014, with the task of monitoring the impact of water pumping on the stability of the slopes of the open-pit mine.

However, after the successful remediation of the consequences of the flood in 2015 [6], the team was disbanded, and accidental situations were solved on the fly, subjectively, without considering the costs of repairing them.

(3) HAZARD IDENTIFICATION

During the monitoring of the consequences of the remediation of the flooded open-pit mine, the team members had the opportunity to study the nature and behavior of the landfill in all weather conditions. Today, this research can be roughly divided into two phases.

The first phase was during and the second after pumping water out of the open pit mine. It is certainly worth mentioning the preliminary phase, when, due to the lack of data on the physical and mechanical properties of the deposited soil, accidental situations were controlled with a sandy support object at the lowest elevations, in the foot of the slope of the landfill. The empirical method has proven to be exceptional in controlling the risk of landslides in the internal landfill during the pumping of water from the open-pit mine [1, 6].

RESULTS OF THE RISK ASSESSMENT

Risk assessment is the process of identifying risk situations and determining the degree of risk according to the elements of the risk matrix. In relation to the real situation at the internal repository of the open-pit mine "Tamnava-West field," the structure of risk in a three-dimensional coordinate system is presented (Figure 1) with five levels of risk, for which linguistic descriptions are defined: extreme, large, worrisome, acceptable and insignificant. Each of the degrees of risk has an appropriate combination of risk elements: the probability of an accident occurring, the severity of the consequence, and the possibility of detecting and preventing an accident.

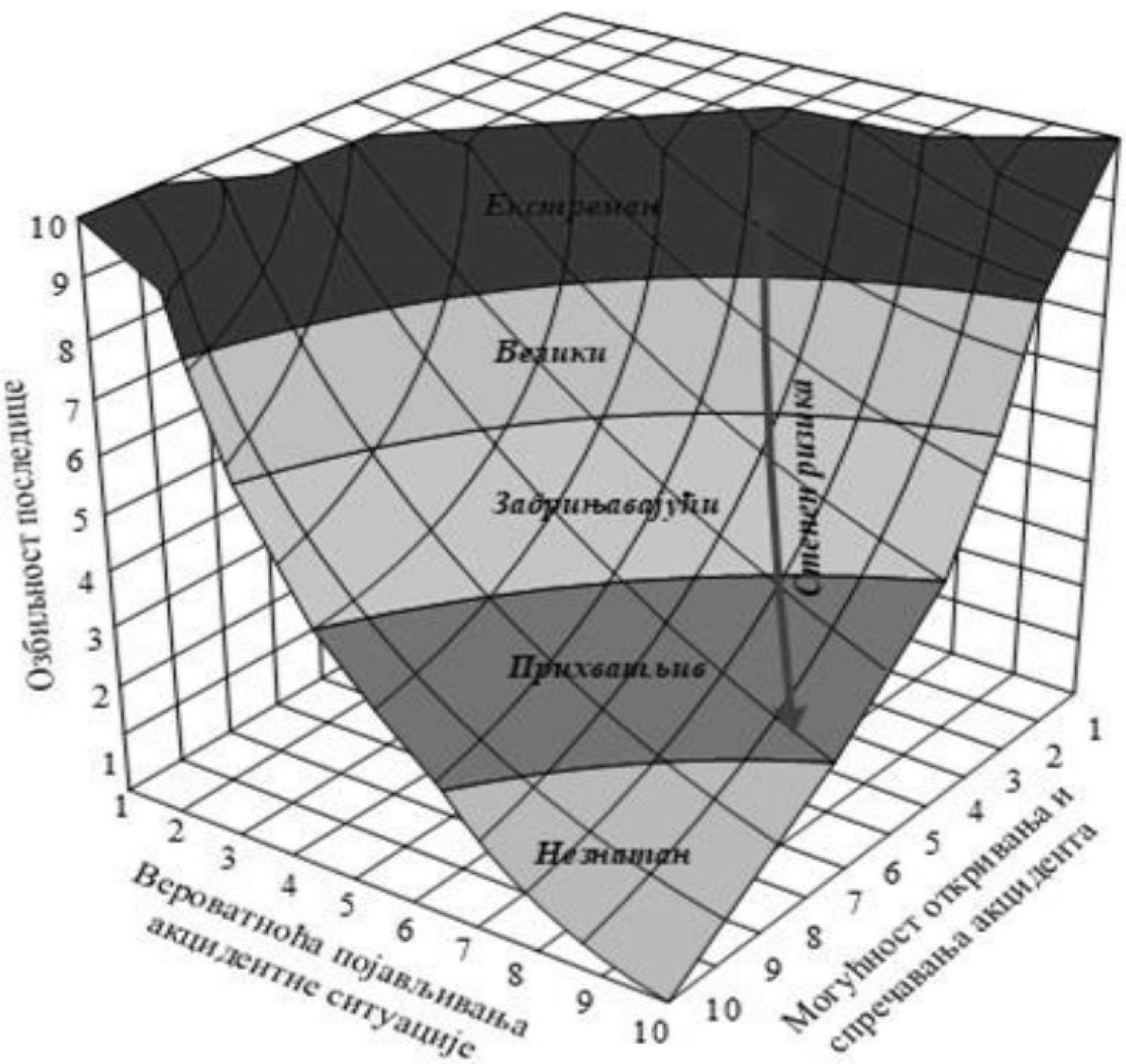

Figure 1, Structure of risk in relation to the degree of risk

According to these descriptions, Table 1 is formed, which provides an overview and analysis of accidental situations on the analyzed object. The table also shows the type of hazard and the method of remediation.

Table 1, Overview and Analysis of Accidental Situations with Risk Assessment

Type of danger, damage, conditions of occurrence	***Method of remediation***	***Probability of occurrence accidental situations***	***Ability to detect and prevent accidents***	***The severity of the consequences***	***Degree Risk***
Landslide on the south, working slope, 1700 m wide, 360 m long,a staircase deformity. It was created by lowering the water level in the lake by 20 m (2016).	Soil compaction. Construction of a supporting structure made of sand/soil with a higher volume weight and water permeability compared to the soil that is deformed.	Rarely recorded for the first time	Monitoring of precipitation and river levels, better planning of protection from the effects of surface flows, as well as better maintenance of existing hydrostructures.	The conveyor was damaged and the dragline was endangered, as well as the pumps for pumping out the lake. Risky movement of employees and overhaul of damaged and endangered machinery.	Extreme
Damage to the O2 transporter (2014.) (Figure 3)	Soil compaction, crack filling, terrain drainage and adjustment of belt movement speed and tailings loading, vibration control on conveyors.	Frequent occurrence	Compaction control. It is necessary to devise a method for the quick and uniform consolidation of deposited, fine-grained, non-vibration-resistant soil.	Costs of remediation of conveyors, delay in excavation of tailings (Figure 2).	Worrying
Waterlogging of the forefoot zone of the landfill after pumping out the floodplain lake	Sludge displacement in the east-west direction, towards the lowest elevations on the ground	Rarely recorded for the first time	Better planning protection from the effects of surface flows, more adequate dimensioning of protective embankments and hydroconstruction facilities, as well as better maintenance of existing ones.	The inability to excavate mil. tons of lignite. The problem of lignite exploitation at lower elevations and the safe expansion of landfills.	Acceptable

Type of danger, damage, conditions of occurrence	***Method of remediation***	***Probability of occurrence accidental situations***	***Ability to detect and prevent accidents***	***The severity of the consequences***	***Degree Risk***
Landslide on the second ETD system. Slope over 50 m high, built of pieces of alevre with a granulation of 300 to 1000 mm (2017.)	Production of lower slopes (up to 30 m), transport of alevrite in pieces up to 500 mm for easier homogenization and a more uniform consolidation of the soil	Frequent occurrence	Better cooperation of services in the field of technical and technological preparation, respect for the physical and mechanical properties of the soil that is excavated and disposed of.	Block with a length of 450 m and a width of up to 380 m in motion (Figure 1)	It is worrying. To Acceptable
A fire on disposal excavator. The case has not yet been clarified.	Multi-month overhaul of the disposal excavator.	Unique	Control of the passability of service roads, stronger supervision of excavator crews and mining, mechanical and electrical activities, as well as stronger control of equipment overhaul.	The disposal excavator was damaged, worth 20 million euros the disposal and excavation of soil was stopped, and the excavation of coal was prevented.	Extreme
Cracking of the terrain (change in soil consistency, vibrations from the operation of the transporter and/or impact of the soil on the terrain during its disposal).	Devise a method for the rapid and uniform consolidation of deposited, fine-grained soil, sensitive to changes in humidity and vibration.	Frequent occurrence	Regular мonitoring	Cracks tens of meters long, with a yawn of up to 30 cm. Forming a hundred non-stable blocks. Endangered transporter and spreader.	Slightly

For easier understanding and explanation of the problems in the field, Figure 2 gives the disposition of zones with different levels of risk, degree of mining activity and the size of deformations, which were registered during pumping water from the mine (landslide, sludge zone).

THE INTERNAL LANDFILL
OPEN MINE PIT „TAMNAVA-WEST FIELD" (2014-2021)

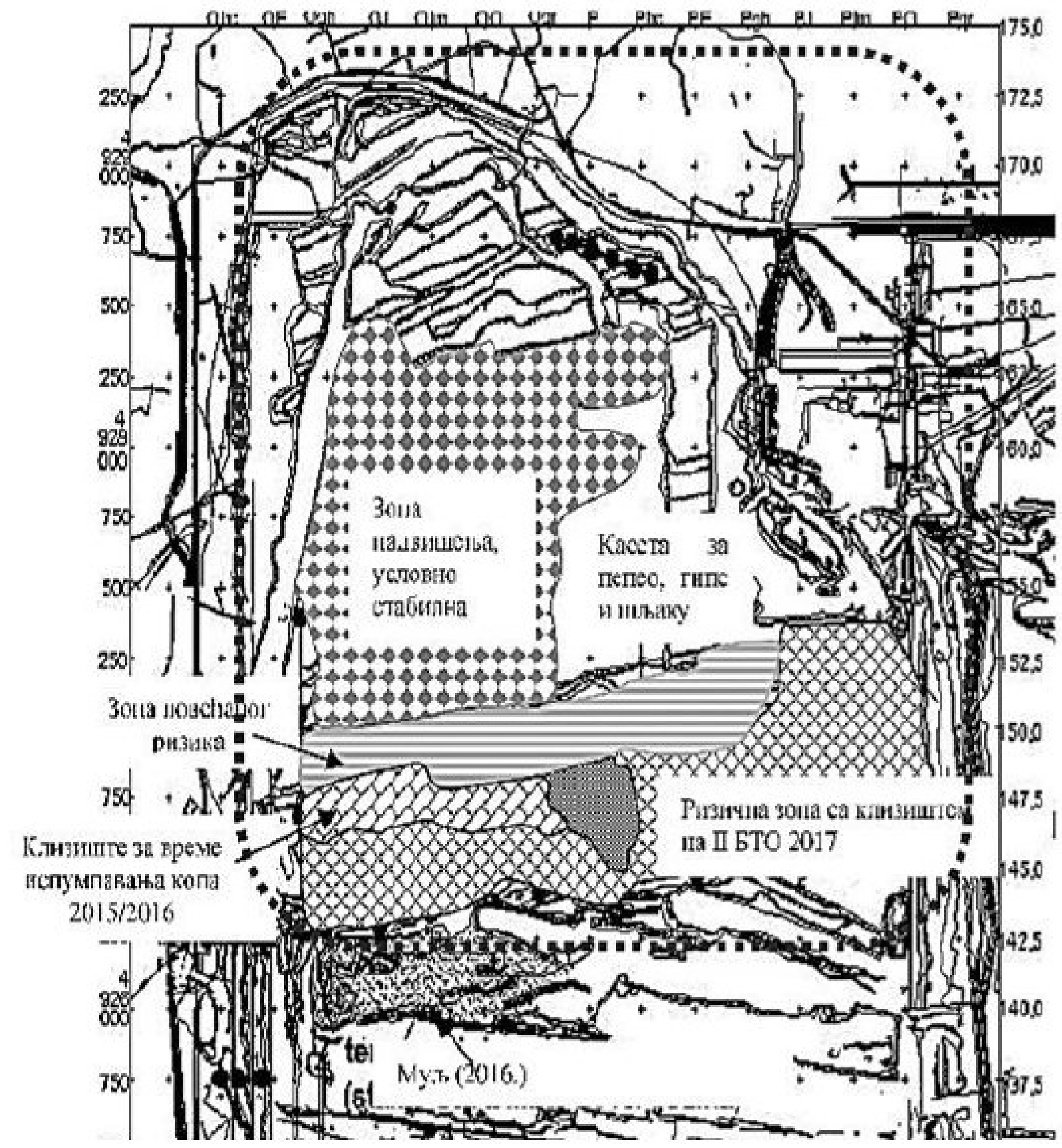

Figure 2, Disposition of zones with different levels of risk

On the basis of the above-mentioned zones, a risk assessment should be provided for the following situations:

(1) Elevation of the landfill above the projected maximum elevations + 110m in the zone of the northwestern part with the provision of continuous pumping of water from the mine with the possibility of saving submerged machinery,
(2) Remediation of the front-of-the-leg waterlogged and sludge-covered part of the landfill in order to continue safe disposal,
(3) Ensuring the stability of the planum along the future corridor for the transfer of machinery to the future open-pit mine "Radljevo", and
(4) Adaptation of disposal technology to increase the production of lignite for 2 000 000 t/year.

Four realistically feasible technical solutions for further prevention of risk consequences for the considered landfill case are presented in more detail below.

(1) POSSIBILITY OF OVERHANGING THE LANDFILL ABOVE THE MAXIMUM ELEVATIONS

In the conditions of pumping water out of the open-pit mine, the excavation of tailings continued. For the installation of conveyors with a belt, a route along the western final slope was determined. The disposal could only be carried out within the inactive part of the internal repository, more precisely, between 172.5 and 155.0 of the internal line, where the O1 disposal excavator was installed.

This section was narrower by one kilometer than the flooded southern front (Figure 2) and two kilometers from the floodplain lake.

In addition to the location, a good element about the same terrain was the knowledge that there had been deposited siltstone there for 15 years. During this period, it was considered that the deposited soil consolidated and that over time it acquired similar physical and mechanical properties of the undisturbed sediment in the deposit. On the basis of all the above, it can be seen that in emergency conditions there was not much time for geotechnical and hydrogeological research. Preliminary prognosis are given on the basis of the analysis of geodetic bases and data collected in the field. After a small number of field and laboratory tests, calculations of slope stability were performed according to the Spencer method, and the data from Tables 2 and 3 [1 and 6] were used for the calculation parameters.

Table 2, Engineering geological properties of the terrain for the zone – 1 poorly consolidated soil

Geotechnical soil	Bulk density γ	Dry density γ_d	Cohezion c_u	Angle of friction φ_u	Oedometar modulus $Ms_{\sigma\ (100\text{-}200)}$
	kN/m³	**kN/m³**	**kN/m²**	**(⁰)**	**kN/m²**
Deposited alevre 1	18,90	14,80	50	0	1550-7600

Note: *The presented shear strength parameters were obtained for samples under undrained conditions, taken from the backfill of a submerged slope, and were adopted for a horizon with a depth ranging from 8.00 m (depth determined by seismic testing) to 10.00 m.*

Table 3, Engineering geological properties of the terrain for the zone - 2 well-consolidated soils

Geotechnical soil	Bulk density, γ	Bulk density, γ_d	Cohezion c_u	Angle of friction φ_u	Oedometar modulus $Ms_{\sigma\ (100\text{-}200)}$
	kN/m³	**kN/m³**	**kN/m²**	**(⁰)**	**kN/m²**
Deposited alevre 2	20,80	17,78	32	39,40	1450-6100
Deposited alevre 3	With an increase in depth (over 15.00 m) it is possible to improves the structure and physico-mechanical properties of dumping soil and that from the point of view of soil mechanics it can be seen as an undisturbed sediment in the deposit				

Note: *The presented strength parameters applied to samples from a horizon at a depth of 10.00 to 15.00 m, which were assumed to have been drained due to the weight of the overburden and are now compacted.*

The elevation of the landfill above the projected maximum elevations was regularly monitored by visual observations, and observations on soil behavior were compared with instrumental geodetic surveys of the area through a network of 43 rappers. The analyses excluded the effects of the highest on the lowest, saturated parts or the possibility of forming a sliding body in the length of 2.00 km, which was the distance to the artificial lake, formed by evacuated water from the retention area of the damaged Kladnica dam. Due to the possibility of overlooking some factor of instability, it was proposed to fill the tailings in increments of 10.00 m in height, but in wide fronts. By applying the described technologies, a more uniform consolidation of loose material was expected in all weather conditions.

The risk assessment at this part of the landfill also included an analysis of the northern final slope in the length of 2.00 km, i.e. the impact of the landfill elevation above critical elevations on its stability. The observations of the expert team have collected enough data to stop speculation about the destabilization of the landfill when disposed of above the projected maximum elevations. It was determined that the cause of the collapse of the northern, final slope was the negative impact of water, accumulated for years in the depressions between the embankment prisms made of poorly permeable siltstone.

This case of instability has shown that dense, rectilinear deposition and leveling of deposited masses with a well-designed surface drainage can ensure overhang [6] and avoid the consequences of fracture of the overhanging surface. The first successful elevation was achieved in February 2015 at an elevation of + 120 m, which is 10 m higher than the projected values. The importance of the disposals performed, under unknown circumstances, can now be seen as a successful experiment in a 1:1 ratio, which confirmed that after 15 years, due to the action of its own weight, the deposed soil was completely consolidated.

It turned out that the assumed risk was justified, given that there were no occurrences of slope instability, nor was the impact of increased stresses felt or recorded in lower, forefoot and watered slopes during geodetic monitoring of seven cycles at 43 points (measurements lasted from September to March 2017) [6]. The analyzed case has supplemented the knowledge about the behavior of the landfill body and its floor, which can be applied for the purpose of optimizing the future open-pit mine Radljevo-North, as well as other coal mines of similar geological structure.

(2) POSSIBILITY OF REMEDIATION OF THE SWAMPED, FRONT-FOOTED PART OF THE LANDFILL

During the remediation of the consequences of the floods, a solution was sought to increase the load-bearing capacity within the swamped part, in order to continue with the expansion of the landfill.

In the foreground part of the working slopes of the landfill, after pumping water from the open-pit mine through coal and sand, on an area of about 22 hectare, was formed an aquiferous terrain with the characteristics of a swamp. The described geodynamic phenomenon represented the basis of low bearing capacity for the needs of stable backfilling of tailings dump. The possible influence of unstable terrain on the stability of higher landfill systems and the probability of their interaction on the safety of coal systems was discussed.

The apparent low bearing capacity of the terrain limited safe access to the drilling rig, the drilling rig for static and dynamic penetration tests or any application of field geotechnical research.

A potential solution to this problem was, until then, an unapplied method of remediation of waterlogged terrain based on sludge straining with sand.

(3) ASSESSMENT OF PLANUM STABILITY ALONG THE FUTURE CORRIDOR "RADLJEVO"

In November 2014, with the water level dropping by 20 m, the deposited, unconsolidated allurites in the "coastal" slopes became unstable. The moving masses endangered the planum along which the construction of the "Radljevo" corridor is planned. A new landslide was then formed in 2017 on the II ETD system (Figure 2). This time, the cause of the instability was the disposal technology.

Rapidly deposited pieces of alevrite (granulation of 300-1000 mm), from a height of over 50 m, were not homogenized and uniformly consolidated.

With their disposal, a terrain of an unstable structure is formed, prone to slipping and deformation. The catastrophic consequences of the impact of the activated landslide were stopped by a sandy, deformed and water-saturated object designed to protect the machinery at the lowest elevations from damage in the period and before the flood.

(4) ADAPTATIONS OF DISPOSAL TECHNOLOGY IN ORDER TO INCREASE THE PRODUCTION OF LIGNITE

The solution of the last task is a function of the success of the previously described.

DESIGNING ACTIVITIES TO ACHIEVE SYSTEM FUNCTIONALITY AT THE LANDFILL

It is not unknown that in practice all forms of hazards on the mine are not reported and that many of them are tried to be solved on the fly. Due to the described manners, it is not possible to obtain a database and objectively look at the costs of repairing damage to machinery, injuries to workers, occupational diseases and the like. Table 3 lists some of the accidental situations from which it is possible to see a real need for the formation of a risk model at a landfill. The situations with the most pronounced consequences that occurred throughout the lifetime of the landfill are presented, with an analysis of the conditions of occurrence and the manner of remediation of the consequence and the assessment of the degree of risk. Figure 3 shows an example of damage to the conveyor on the II ETD system, and Figure 4 shows the condition of the submerged slopes and the protective rampart, as well as the submerged dumper.

Figure 3, Damage to the O2 transporter and the route of the future Radljevo corridor

Figure 4, Submerged working slopes, dumper and spilled sand rampart in the foreground part of the internal landfill of OP "Tamnava-West field" during pumping out (13/01/2015)

A schematic example of the organization of activities to be undertaken at the landfill in order to achieve the safe functionality of the system is given in Figure 5. The scheme can be used to monitor the steps of collecting data on the condition of the landfill and its floor, engaged machinery and the activities of employees within the mining, electrical and mechanical services. Analysis and planning of works with observation of topography by unmanned aerial vehicles with a cross-section of data obtained by terrestrial methods. Based on the amount of water evacuated by wells or pumps from the water collector and diverted by pipelines to the surrounding recipients, it is possible to make a dependence on the influence of precipitation or groundwater (for example, wandering or capillary water) and notice a possible problem. By visiting the landfill, it is possible to notice changes in the physical and mechanical properties of the deposited soil or to guess the condition of the landfill floor. Over time, the presented scheme can be modified and improved in terms of speed of data collection and quality.

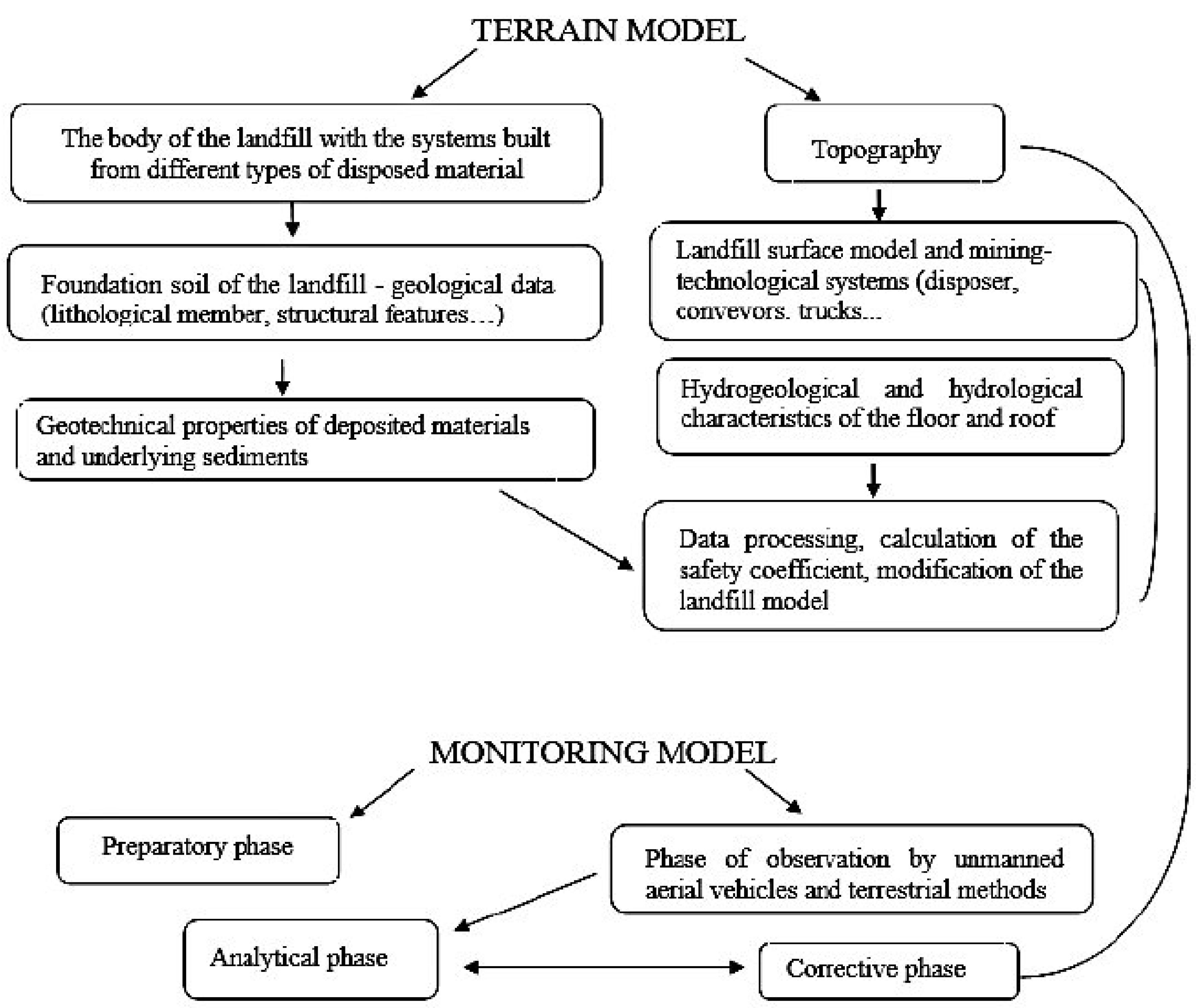

Figure 5, Schematic model of the risk of operation in the internal landfill

CONCLUSION

The observed accidents at the landfill drew the attention of the researchers to start adjusting the number of variable data and try to realistically assess the conditions at the mentioned mining object, which is a dynamic-static system.

These objectives are achievable with the application of the risk model of landfill operation (Figure 5), designed taking into account existing models of observations at mines [2] and risk level assessments (Table 3, Figure 1).

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