Restoration and Revitilization of the Abandoned "Suvo Rudiste" Mine Site on Kopaonik, Incorporating Collection, Treatment and Multipurpose Use of the Mine Waters

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Abstract
The area of the abandoned underground – surface dig "Suvo Rudiste" on Kopaonik represents an ecological 'black' spot on the border of the protected zone of the National Park and it prevents its extension, presentation and evaluation of the natural assets. For this purpose the suggested Project of restoration and revitalization completely fulfils and satisfies all ecological principles of the development of Kopaonik, verified primarily through the Spatial Plan for the development of the National Park Kopaonik, and also with the General City plans of the development of the tourist resort Suvo Rudiste and other city plans of higher rank.

Key words: Kopaonik, restoration and revitalization, ground mining waters

Introduction

Kopaonik, a mountain in the central part of southwest Serbia (280 km from Belgrade) and the belonging protected area of the National Park (established in 1989, Official gazette RS 4/89) represent a unique natural whole. However, in spite of the fact that Kopaonik was given priority in regards to new development of mountainous area in Serbia and the fact that it deservedly carries the epithet of the 'first' mountain that has the necessary spatial capacity to enable the return of humans to nature, upon which we have returned en masse, it has in return received a powerful blow or clearly stated, has experienced grave consequences.

In almost two decades of active existence major changes occurred in the area of the National Park, and the mountain, a national treasure and property has been damaged. To be more precise, uncontrolled, unplanned building in the wider area of the tourist zone with multiple exceeding of the bordering capacity of the infrastructure, traffic chaos – active transit through the protected area, the unsolved issue of solid waste disposal in the winter period as well as the non-functioning of the sanitary system of the disposal-faecal waters that are directly disposed off into the first recipient with mining and mining waters…, speak as evidence of incomprehension of the seriousness of the damage of the disturbed eco-system in its entirety of the central part of the mountain Kopaonik, and bring the value of the area, i.e. the existence of the category of a National Park into question. Precisely one of the examples of this kind, of a permanent devastation of the area and a proposal for its restoration and return to its purpose is being presented through this paper.

Namely, on the roof of Kopaonik, more precisely below its highest peak, the peak of Pančić (2017masl) and in the immediate vicinity of the tourist resort, lies an abandoned surface and underground excavation site "Suvo Rudište" (1970 masl), upon which, after an extensive ore exploitation, all the activities have died down about twenty years ago. As the current situation stands, the previous mining activities in the greater area of the Suvo Rudište mine have devastated the immediate area of the extensive exploitation in its entirety, as well as the surrounding area that has been, due to its current state and appearance, excluded from the current borders of the NP Kopaonik. Due to all this, the National Park is sustaining immense consequences on account of the inability of widening the high-mountain protection zone around the abandoned mine thus representing a permanent danger to the visitors of the area.

At the height of 1740 masl, in the vicinity of the tourist resort, the mining waters are flowing out from the underground part of the pit of the Suvo Rudište mine, in the quantity of 10 – 30 l/s, polluted with iron, manganese, copper, zinc, nickel and cadmium. The mining stream in question, since the abandoning of the mine, has been completely 'dead', devoid of all living things, because the proscribed restoration and revitalization of the underground facilities and hallways has not been done, and a significant amount of mining equipment and tools was left behind. However, it is of import to

note, that during the time of the active mining operations, the same groundwaters were used, and their quality regularly inspected, for the fulfilment of needs for drinking water of the mine personnel and the two nearby hotels. This directly implies that the groundwater quality within the mining facility at the place of operation complied with the Act of water quality.
Due to the all aforementioned and the growing needs to bring the analyzed area back to its purpose a **Study of feasibility and the Project of restoration and revitalization of the abandoned mine Suvo Rudište** was done. The project stipulated the restoration of the surface dig and the part of the underground facilities, the intake of the mining waters from the underground area of the dig, their treatment until the desired quality was achieved, and then the pumping into the area of the surface dig Suvo Rudište, which would serve as a multi-purpose water collector, of volume **300.000 – 350.00 m^3.**
The aim of the Project is to give a feasible technical solution of the building of an entire system in the function of economic justification through a realistic period of exploitation, where, by the means of the suggested solution, a large number of existing infrastructural issues connected to the very roof of the mountain Kopaonik, would be eliminated (the non – existence of an organized anti-fire system of the high-mountain area, the non-existence of water accumulation of the gravitational character for the renewal of the skiing sites Kopaonik, the possibility of inclusion of the excess of the intake waters for the improvement of the overall state of water supply on Kopaonik, the development of systems with the aim of securing a certain amount of water for the provision of heat and technical needs of the users etc).

The design solution for the system of water intake structure and the watercollector
The ore deposit "Suvo Rudište" on Kopaonik during the phase of intensive exploitation was mined in two different ways, and consisted of the surface dig and the underground pit exploitation.
The surface dig "Suvo Rudište" is located at the height of 1878 – 1970 masl, is shaped like an amphitheatre, and as a result of the extensive exploitation a depression of an ellipsoid shape remained, with its larger diameter around 350 m, and the shorter one 200 m, which makes for about 7 ha of horizontal projection, with lateral widening of roughly 2,0 – 2,5 ha as an accompanying active surface.

The underground pit exploitation section
The underground part of the mine was opened with a main mine at the height of 1740 masl (simultaneously the lowest point), divided vertically into five basic horizons that are linked by a system of transport and transit haulway rooms, a network of roads on the horizon itself, a network of exploratory hallways, bars for the transport of mined materials, and a network of trimming hallways and other auxiliary rooms.
The main transport mine – horizon at 1740 masl, is simultaneously a main road, a room for drainage, a hallway of the main entry air current for ventilation, a room for fixtures, telecommunications etc, so it is naturally one of the main links to the surface – the main transport line.
Apart from this, the main mine, there were four other links – surface exits:¨

- One at the level of horizon at 1769 masl that exits into the river of Zdravačka;
- Second, at the level of horizon at 1867 masl, that exits at the same side as the previous one, only 100 m higher (the former hallway for the exiting ventilation current; this link is now severed as a result of works done at the terrain's surface);
- The third exit is also from this horizon via a special branch and rooms built due to the explosive devices warehouse that has a separate entry and exit onto the surface, from the same side as the previous two;
- The fourth exit is the present ventilation haulway that links the horizon at 1867 m with the horizon at 1914 m, and from the horizon at 1914 m on to the surface at the height of around 1930 m.

The general assessment, based on the conducted research, is that the underground facility is stable and secure and there are no significant cave-ins counting from the time of time of its construction despite the well-known earthquakes of 1980, 1983 and 1984, as well as the immediate tremors caused by the blasting on the surface dig.

At the end of the mine and the lateral hallways several exploratory wells were done in the effort to define and follow the body of the ore. The groundwaters under pressure and further free fall towards the exit are the ones that stand out from all the wells with a full profile. The entire length of the pit facilities at the level of mine at 1740 masl (the mine and the lateral hallways) is around 1820 m, of an average width of 2,2 m, respectively of the entire area of 4004 m^2 or volume 8808 m^3.

The presence of groundwaters in the underground hallway at 1740 masl

An important characteristic connected to the phenomena of the presence of groundwaters within the mine, is that the body of ore was grasped by the mine that is simultaneously the lowest point in the underground, so that the entire drainage is gravitational, without pumps and energy utilization. The present quantities of groundwaters that are flowing out from the underground hallway at the height of 1740 m, are originating from the water sources along the cut sediment zones as well as the eight research wells, created purposefully for the intent of defining the body of ore, and which with their full profile provide water.

In the mine, at five points, there are appearances of permanent water sources of groundwaters, and three have been regulated and smaller reservoirs with the volume of around 3 m^3 have been built, from where the intake waters were transported by a set-up pipeline to the one-time consumers at the surface of the mine, the resort "Olga Dedijer" and the resort "Kragujevačko", and for the pit, more precisely the mining drilling and blasting, with the aim of reducing dust. The drinking water reservoirs at the level of the main mine were at: the first at 570 m from the entrance, the second at 930 m and the third at 1100 m.

The flow of groundwaters within the main mine varied within the limits from 300 l/min to 1500 l/min or from Q_{min} = 5 l/s to Q_{max} = 25 l/s (measured during the time of active operations of the mine) while the water quality for the water supply, was controlled and approved by the authorized health institutions.

From the aspect of hydrogeology in the wide area of the main mine and the surface dig "Suvo Rudište", conditions are such that there is no objective danger of any major water penetrations from the surface of the terrain that could endanger the stability of the underground facilities. To be more precise, above the facilities mentioned there are no active surface courses and the position and the height of the mine already enable the drainage of the groundwaters of the immediate perimeter in a natural way, and are gathered within the mine and flow out of the same due to gravity at 1740 masl.

The surface exploitation section

The surface dig was opened as the depth-type with tiers and spiral transport routes at the dig, respectively between the tiers. The dig due to operations reached at its deepest section the height of 1870 m and considering the existence of activities in the part of the underground horizon underneath the dig itself at the height of 1865 m, there was a violation of stability in the disturbed section and a minor cave-in of the ceiling above the underground hallway at 1865 m.

The contours of the dig in the northern part are not clearly emphasized while the southern contours are completely preserved and in good shape. The depth of the dig has reached approximately 100 m, the length of the longer axis is 350 m, and of the smaller 220 m, and the entire dig is of an ellipsoid – amphitheatre shape that with the tiers, in the general slant in the form of a mild funnel drops towards the deep.

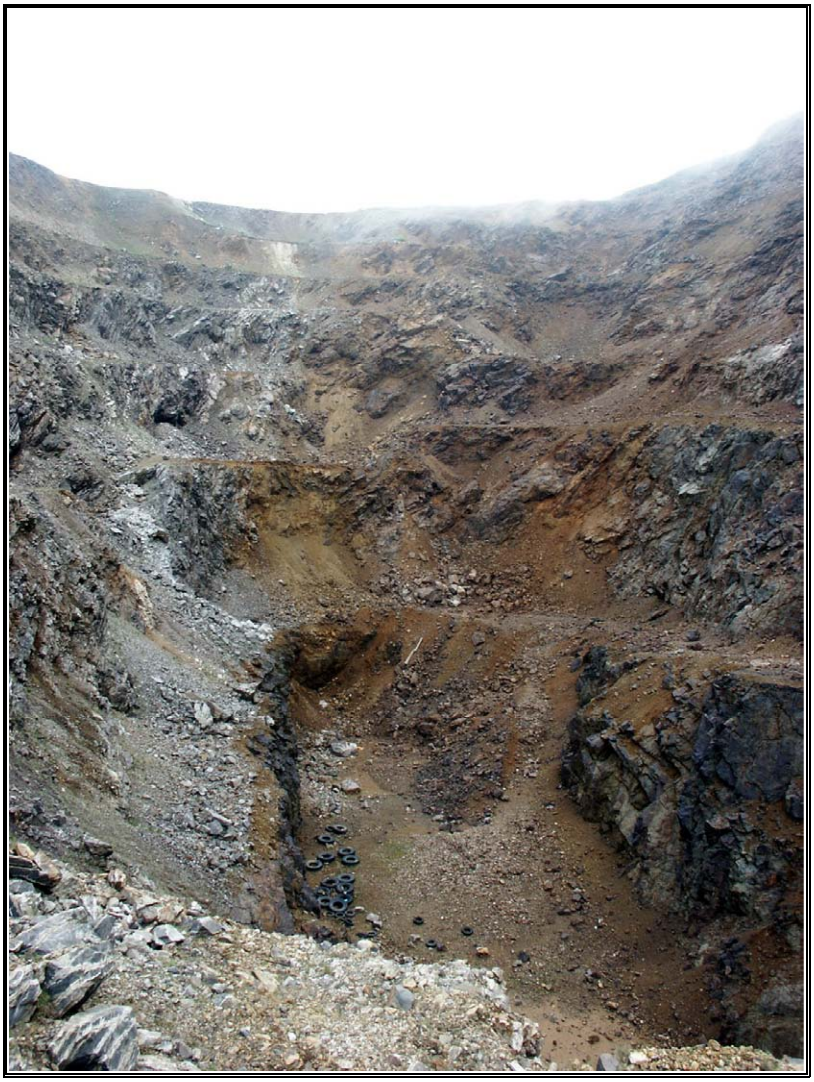
The present condition of the surface dig has the following, clearly defined characteristics:

- the condition of the rock mass within the dig is good, without any signs of subsidence and slides of larger proportions;
- the clearly emphasized rock mass, from a hard, compact rock, is manifested on the individual sections and counter – slant;
- the tier planes, the passages for communications, from the northern side of the dig have already began losing their original shape and the purpose of the traffic, while on the southern side they remain in good condition and could still be used for transport with minor improvements;
- the southern side of the dig has almost in its entirety kept its original shape, such as it was during the time of the end of the exploitation of the ore, with proper slopes and berms;

- the northern side of the dig, that is in the sun during the entire day, shows sign of levelling of the slopes with an almost even-keel slant;
- vegetation at the surface dig is practically non-existent, apart from the rare places where some low growth plants have developed.

Considering the present configuration of the dig and the previously shown condition of the rock mass, the dig is not endangered with any potential peril and that can be confirmed by the fact that from the day of its closure till today the terrain has been stable.

Figure 1 *The interior of the surface dig Suvo Rudište*



Groundwaters intake – measured at the weir

At the point of the flow out of mining waters from the main mine of " Suvo Rudište" mine, more precisely at about 50 m downstream where the flow is concentrated, the purposeful set-up of the Thompson's weir for the measurement of the flow of the water that flows out, was conducted (figures 2 and 3). The mining waters in question are gathered at the lowest point of flow-out at 1740 masl and are via the existing (active mine) main hallway evacuated to the surface of the terrain. The catchment area of the waters in question starts from the height of the peak of Pančić at 2017 m, up to the level of the main mine at 1740 m – the point of the mining waters flow-out, or at about 250 m of the height difference of the border area of the basin of about 3 km^2.

In the following table the representation of several year of observations of the mining waters flow-out regime from the main mine at 1740 mal, under Krst on Kopaonik.

Table 1 *The representation of the abundance of the mining waters from the main mine at 1740 masl (2004 – 2007)*

	"Water source of mining water", measurements during 2004											
month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
H (cm)	15.5	16.0	16.3	16.5	16.5	16.0	15.0	15.0	15.0	14.5	14.5	14.5
Q (l/s)	14.5	15.0	15.5	16.0	16.0	15.0	14.0	14.0	14.0	13.5	13.5	13.5
	"Water source of mining water", measurements during 2005											
month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
H (cm)	15.0	16.0	16.0	16.5	17.0	17.0	17.0	19.0	19.0	17.0	16.5	16.0
Q (l/s	14.0	15.0	15.0	16.0	18.0	18.0	18.0	22.0	22.0	18.0	16.0	15.0

	"Water source of mining water", measurements during 2006											
month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
H (cm)	15.0	14.0	15.0	15.0	15.0	16.0	17.0	16.0	17.0	17.5	16.0	15.0
Q (l/s)	14.0	13.0	14.0	14.0	14.0	15.0	18.0	15.0	18.0	19.0	15.0	14.0
	"Water source of mining water", measurements during 2007											
month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
H (cm)	14.0	13.0	14.0	15.0	16.0	17.0	17.5	18.0	18.5	17.5	16.5	16.0
Q (l/s)	13.0	12.0	13.0	14.0	15.0	18.0	19.0	20.0	21.0	19.0	16.0	15.0

Figure 2 *The point of mining waters flow-out right underneath the main mine*

Figure 3 *The representation of the measuring of the abundance of mining waters at the Thompson's weir*

The analysis of the mining waters and commentary

The results gathered of the chemistry of the mining waters from the main mine at 1750 masl indicate an increased concentration of certain elements - Fe (2.25-3.36 mg/l), Mn (0.82-1.23 mg/l), Cu (0.094 mg/l), Ni (0,041 mg/l) and Zn (2.0 mg/l) while the microbiological indicators are within accepted limits.

Table 2.*The results of the chemistry and microbiology of the mining waters testing*

Anions		**Cations**		**Metalloids**		**Metals**		**Ni**	0.042
HCO_3	24.4	**Ca**	23.2-30.2	**NH_4**	<0.05	**Fe**	2.25-3.36	**Li**	0.003
SO_4	50.0	**Mg**	4.4-5.4	**P**	<0.010	**Mn**	0.82-1.23	**Rb**	<0.01
Cl	3.3	**Na**	2.2-3.3	**SiO_2**	12.2	**Cr**	0.005	**Zn**	2.0
NO_3	1.54	**K**	0.7	**B**	<0.1	**Al**	0.09	**Cu**	0.094
NO_2	<0.01					**Sr**	0.04	**Pb**	<0.001
						Ba	0.02	**Cd**	<0.001

T (^oC)	**pH**	**Ep** (µS/cm)	**M** (mg/l)	**S.O**. (mg/l)	**^{o}dH**	**$KMnO_4$**
6.0	6.25-7.5	120-190	120-155	150	4.2-5.5	1.0-1.3

The design solution for the system of water intake structure and the watercollector

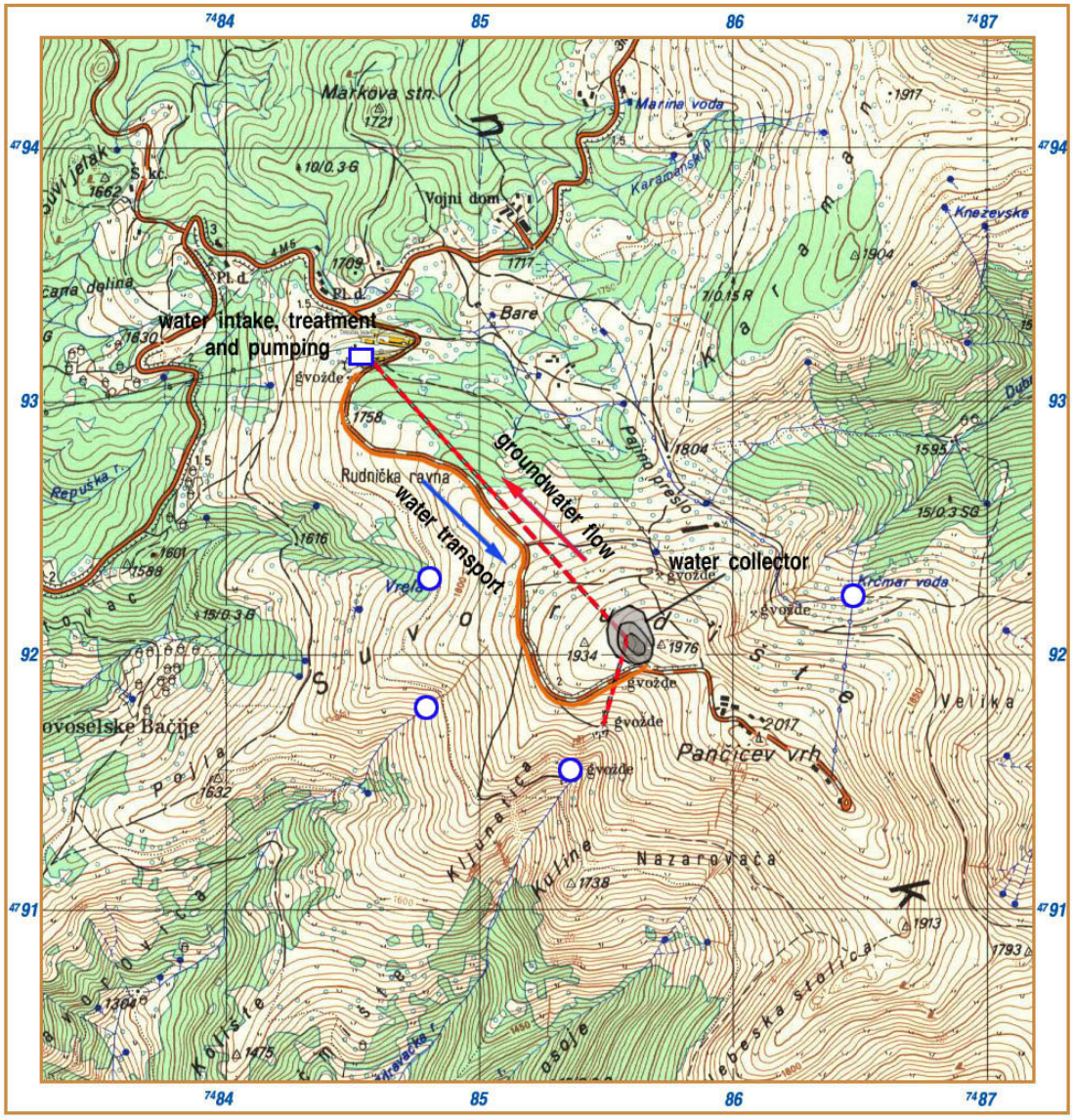
In accordance to all the discoveries and the existing infrastructural facilities on the location of the abandoned mine Suvo Rudište, the following conceptual solution for the provision of large enough quantities of accumulated water for different purposes is given as inevitable. The complete hydro-technical system "Suvo Rudište" on Kopaonik would consist of the following parts (figures 4 and 5):

1. The groundwater source – water intake structure
2. The facility for groundwaters treatment
3. Pumping stations 1 at the height of 1740 masl and a high pressure transport pipeline up to the water collector
4. The water collector within the area of the surface dig "Suvo Rudište"
5. Pumping station 2 within the future water collector

The water intake – of groundwaters, will be conducted in the existing input-output, main mine at the height of 1740 masl, in the regime of gravitational outflow. The total measured capacity at the placed Thompson's weir (during a several year time period is Q_{min}=12 l/s and Q_{max}=25 l/s) so that the water intake itself is designed as a combination of a vertical entry shaft (of a large diameter) and an underground water gate – water intake structure (laterally anchored within the main rock) for the stopping and accumulation of groundwaters, with pumping aggregates for further transport of the waters towards the treatment facility installed within it.
The mine groundwater (analyzed) is, considering its origine, the composition of the main rocks and the ores, burdened with increased concentrations of iron, manganese and several oligo-elements and toxic heavy metals as: zinc, cadmium, nickel and copper. This is low mineralized water with a slightly lowered pH when compared to the drinking water, and is micro-biologically safe.
Beneath the area of the water intake structure, the groundwater, mining water is further transported to the system for quality improvement – **station treatment**. Within the station treatment, and on the basis of a previosly conducted, and the newest, analysis of the water, it is designed that the process of deferrization and demanganization (with a minimal reduction of the copper, zinc, nickel and cadmium content) is conducted. Equalization of this water resourse to the neccesary values, requires deferrization and demanganization with the simultanious cooprecipitation of heavy metal ions on an isoelectric pH, that is created in the process of deferrization and demanganization and has an acceptabale value. The essence of the process of deferrization and demanganization with a simultanious cooprecipitation of heavy metal ions is in oxidation and hydrolysis, i.e. the hydratation of iron (II) – ions and manganese (II) – ions, that result in exceedingly unsoluble, voluminous, of great and active surface and especially good filtrational properties, iron (III) hydroxide – $Fe(OH)_3$ and hydrated manganese (IV) oxide - $MnO_2 \cdot nH_2O$. In this way, the resulting water has the levels of iron, manganese and heavy metal ions concentration below the allowed – prescribed values, like the MAC (maximum allowed concentrations).
These physical, physicochemical and chemical processes are known, efficient, are wide-spread, can be automated and are cheap - investment, exploitation and service-vise. For comparesment, the removal and equalization of numbered components from this groundwater is a satisfyingly efficient procedure that can be realized. **It should be especially pointed out, that during this treatment no external substances – chemicals are used outside of the facility, meaning, a true 'green technilogy & green engineering" is in question.**
The water that was collected and prepared would be, via an installed **pumping station**, further transported along the existing bypass route towards the peak of Pančić (the entire length of 2300 m) and would be enclosed within the existing ambience of the surrounding area without disturbing the said area. The transport itself of the groundwaters would be done by pump aggregates and via a high-pressure **pipeline** in the conditions present on Kopaonik.
During this same period, paralleled to the previous operations, the process of **cleaning, preparing, concreting (Torkret method) and lining via a geo-membrane of the surface dig Suvo Rudište (preparing of the water collector)** would be conducted, during which the accumulation of the in-taken waters and the treatment of groundwaters is planned. At the mentioned location of the abandoned mine Suvo Rudište, the cleaning of the same from the remaining materials and their disposal at the pre-defined location would be done first, then the preparing of the bases – the construction of a drainage system with the aim of the elimination of the negative hydro-static pressure on the Torkret – concrete that is the bed for the geo-membrane. The placing of the Torkret – concrete and the stabilization of the slopes follows, and then the placing of the geo-membrane to provide impermeability for the accumulation bed. The geo-membrane is produced from a synthetic india rubber and its thickness is 2 mm, with the function of providing, in all climate conditions of the terrain on which it is used, permanent physicomechanical characteristics during the regular exploitation

without stretching and solidification. It is stable during the temperature, chemical and UV changes without additional protection and it possesses significant dilation properties due to possible quakes and other accidental situations.
We emphasise that an accumulation area thusly prepared is completely inert to the conditions of water – membrane contact, i.e. the worsening of the quality of the accumulated waters through time cannot happen.

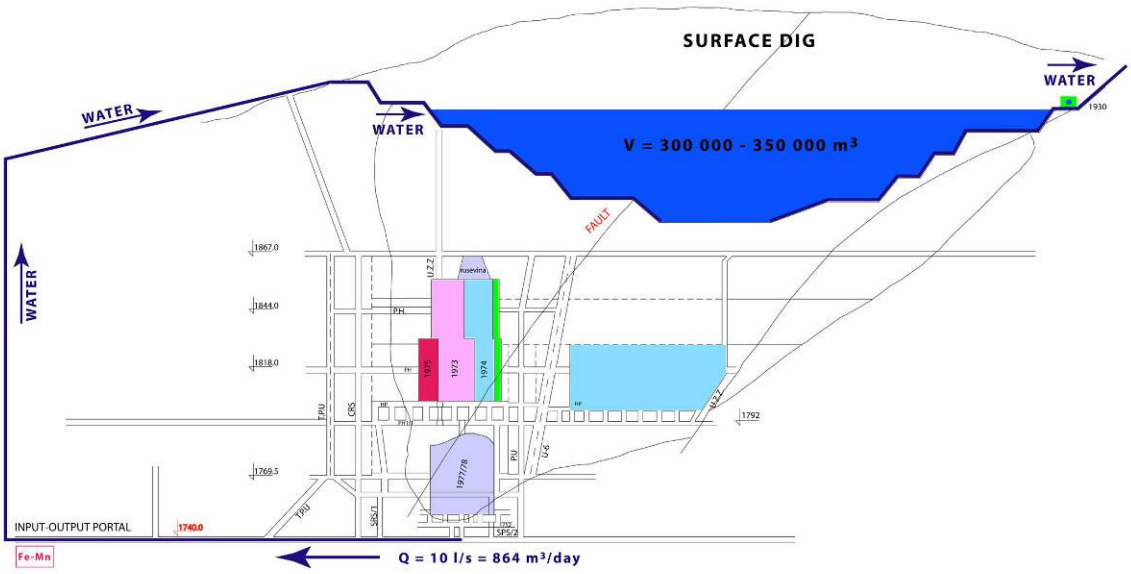
Figure 4 *Objects disposition in the "Suvo rudiste" surroundings*



Aspects of bringing the facility and the environment into accord

A high assessment of the area eligibility is reached through the proposed solution of the land restructuring and the use of resources, due to the opening and return to its purpose of this part of Suvo Rudište for the programs of presentation and resource utilization, recreational – skiing – hiking, educational and other facilities. With this solution, the access to the zone of hinterland of Suvo Rudište is opened, with the closing of the roundabout of the following locations: Krst - Suvo Rudište - Nebeska stolica - Crkvište-right Belo Brdo - left Krčmar – Duboka – Jaram. The possibilities of expansion of the borders of the protected area to the southern parts of Kopaonik are opened, in the direction of Leposavić municipality, i.e. the percentage of the entire protected area in Serbia is increased (that being one of the relevant conditions for the joining of Serbia to the European Union).

Figure 5 *The design solution of water intake structure and watercollector*



Ecological aspects of bringing the facility into accord

The influences upon the environment or the factors of the environment are perceived thought the current state of the quality of the following factors: water, air, soil, biological diversity etc.

Air

By building the object in question and restoring the locale, a large section of terrain from which the fine fractions of the sandy dust rise and are transported, is closed, and conditions for significant reduction of this form of air pollution are formed.

Water

With planned construction of the water intake structure and with the treatment of the mining waters, the negative physicochemical contents of the groundwaters (Fe, Mn, Zn, Ni and Cu) will be removed, which will create the conditions for the renewal of the eco-system in the mentioned watercourses that is now significantly in peril.

Soil

It can be stated that this area has the elements of a "rock desert". By building the suggested system, the restoration of the soil via biotechnical measures will be done – mass covering of the eroded areas, stabilization of loose slopes of the abandoned mine and prevention of further degradation; more precisely the improvement of the entire area and its increased closeness to other humane contents.

Biological diversity – vegetation

The biological diversity in the closer and wider area of "Suvo Rudište" – one of the highest zones of Kopaonik was destroyed by exploitation and opening of the mine surface and the slag deposit. The conditions for gradual revitalization of the biological diversity and the return of autochthonous sorts as well as the enrichment of the landscape are created by the construction of the facility and the implementation of the biotechnical measures.

Visual pollutions

The restructuring of this area and its function of preservation and protection of the total inheritance of the Republic of Serbia, i.e. the National Park Kopaonik, is being done with the construction of this system, and a high visual quality of the area is reached.

The safety of the facility and the environment

At the foremost, the visitors of the park, skiers and hikers are in jeopardy, due to the unsecured entry at the borders of the mine. The degree of the anti-fire safety in the forest area and the tourist resort is increased by the construction of the system.

Conclusion

Considering that on the territory of Kopaonik two significant elements of the development of Serbia can be found, and are interconnected (one protected – the National Park Kopaonik and the second, tourist – developmental, mountain resort of Kopaonik), it is of a national importance for the Republic of Serbia that the two segments mentioned mutually correspond and participate in the presentation and promotion of Serbia and its assets, with the adequate protection and securing of the area. The suggested Project is an adequate example where the mutual functions can be aimed towards the fulfilment of the national domain interests for Kopaonik and the Republic of Serbia.

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