ARTIFICIAL LAKES IN FORMER LIGNITE OPEN-PITS AND THEIR UTILITY IN AGRICULTURE AND ECONOMY

Izabela-Maria, APOSTU[1], A. FLOREA[1]

[1]University of Petrosani, Faculty of Mining
E-mail: izabelamaria.nyari@yahoo.com

Abstract. *Remanent voids of former open-pits can be re-used in different directions with major benefits, irrespective of their future use, due to the fact that they involve the rehabilitation and the re-entry into the economic or ecological circuit of large areas of degraded mining land. An increasingly common method, applied worldwide, is the flooding of remanent voids and the formation of artificial lakes that can take up many functions. Artificial lakes formed in former open-pits are also known as "open-pit lakes." These occur after the cessation of exploitation as a result of naturally or artificially flooding of the remanent voids. In Romania, this method is less known, but it must be taken into account that the functions that an open-pit lake can take and their major benefits, will play an important role in the sustainable development of a former mining regions. In the case of deep open-pits, as in the case of lignite open-pits, with a high probability of intercepting deep aquifers with high water inflows, the formation of artificial lakes is the optimal choice as natural floods are favored, and the costs are minimal. The present paper presents the case of the North Pesteana lignite open-pit, for which, at the moment of the cessation of the exploitation activity, the flooding of the remanent void is pursued. The remanent void of the North Pesteana open-pit will be of impressive dimensions. It presents a high flooding opportunity, primarily due to the very favorable hydrogeological conditions in the region. The lake formed in the remanent void of the North Pesteana open-pit will bring a number of benefits to local communities and beyond, these being detailed in this paper. The general aim of the paper is to increase, at national and regional level (at the level of Rovinari Mining Basin), the degree of knowledge regarding the possibilities of flooding of the remanent voids and the use of artificial lakes formed in former lignite open-pits, but also the benefits that they can have, on a medium and long term, on human communities, from a socio-economic and environmental point of view.*

Key words: *lignite, open-pit, remanent void, artificial lake, flooding, benefits, agriculture, economy*

INTRODUCTION

Romania is known for the exploitation of coal, especially lignite and hard coal, important areas of the country flourishing at a time due to existing mining activities. Unfortunately, the coal industry in Romania is declining, coal mines are closed one at a time, mining perimeters are abandoned, and the health and safety of the environment and communities are endangered. In these circumstances, it is essential to adopt rational practices regarding the recovery of degraded mining lands and their use for new activities for the sustainable development of the region.

Localization of the North Pesteana mining perimeter

The North Pesteana mining perimeter is part of Rovinari Mining Basin (Figure 1). From an administrative point of view, it belongs to the Gorj County, being located within the Urdari and Bâlteni communes.

From the geomorphological point of view in the region are known subcarpathian units and the Getic Plateau to the neighborhood of the high piedmont plains situated in front of the moesica platform.

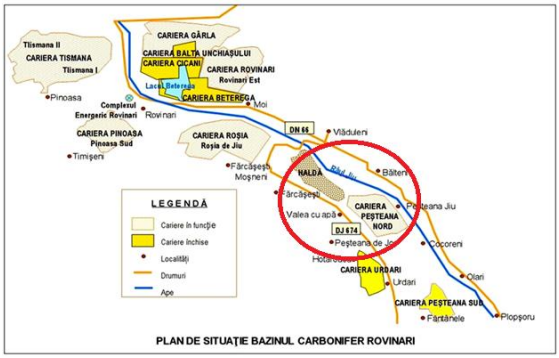

Figure 1. Location of the North Pesteana mining perimeter within Rovinari Mining Basin

North Pesteana mining perimeter is delimited to the North-East by the Jiu River channel, DN66 national road and Vlădeni, Bâlteni, Jiu and Cocoreni villages, to the West of the DJ 674 county road and Fărcăşeşti Moşneni, Fărcăşeşti, Valea cu Apă, Peşteana de Jos, Hotăroasa and Urdari villages, and to the South of the former South Pesteana mining perimeter.

MATERIAL AND METHODS

The geological researches revealed the existence of important lignite reserves in the Jiu river meadow area, located at a relatively small depth of the land surface, which favored the exploitation of the lignite by open-pit mining works.

Din punct de vedere litologic, depozitele din regiune sunt formate în principal din marne, argile și nisipuri, între aceste straturi fiind cantonate straturile de lignit (Figure 2).

The exploitable layers in the North Pesteana area are the V-VIII layers, but the current exploitation works consist of extracting lignite from V ÷ VII layers. (***, C.E.O., 2017-2018)

Figure 2 presents a lithological column of the North Pesteana mining perimeter, which includes the exploitable lignite layers

In order to continue the exploitation of the lignite in the North Pesteana perimeter during the period of validity of the license, it is necessary: to carry out the expropriations, to extend the perimeter and to continue the activity up to the limit of exploitation. (***, APMG, 2016; ***, I.C.S.I.T.P.M.L., 2012)

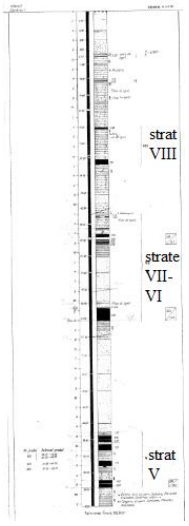

Figure 2 Lithological column

Description of mining activity in the North Pesteana mining perimeter

The opening of the North Pesteana open-pit began in 1980's, through a trench located at the northern limit of the exploitation perimeter, where the deposit conditions were most favorable for the short-term production of lignite. The advancement of the open-pit continued from north to south, the waste rocks resulted being initially stored in the external dump located in the northern part of the exploitation perimeter, and after reaching the base of the pit and as the working front was advanced, the waste rocks were stored in the inner dump. (***, APMG, 2016)

The exploitation activity, starting with 2000's, is based on the exploitation license, issued by the National Agency for Mineral Resources Bucharest under no. 1457/2000, for a period of 20 years (starting with 2004), approved by Government Decision no. 319/2004. In 2012 the "Documentation required for the exploitation license in the extended perimeter for North Pesteana open-pit" 810-519 was elaborated providing for the exploitation of lignite resources by 2021. (***, APMG, 2016)

The surface of the North Pesteana mining perimeter approved to the exploitation license is 1176.20 ha.

In the North Pesteana open-pit, the exploitation method is combined with the transport of the waste rocks into the inner dump and its partial transhipment into the inner dump.

The works from the North Pesteana mining perimeter are carried out in 4 steps of excavation and 4 steps of dumping. Over time, the number of machines used in the open-pit varied as required. Presently, the excavation activity in the North Pesteana open-pit is carried out with 5 excavators, and the resulting waste rocks are deposited in the inner dump with 3 dumping machines. The 2nd step is excavated in sterile, and Steps I, III and IV are excavated in mixed (sterile + coal). (***, I.C.S.I.T.P.M.L., 2012; ***, I.C.S.I.T.P.M.L., 2018)

The lignite is deposited in the Cocoreni coal deposit located on the right bank of the Jiu River where the delivery to the consumers is ensured. (***, C.E.O., 2017-2018)

According to the report of the Ministry of Energy from 2016, the exploitation activity of North Pesteana open-pit ceases in 2023. (***, M.E., 2016)

According to the Mining Law no. 85/2003, the license holder has the obligation to execute and complete the restoration works in the perimeters affected by the mining activities. (***, THE MINING LAW NO. 85/2003)

Description of the hydrogeological structures in the North Pesteana mining perimeter

From the hydrogeological point of view, the underground waters in the region are divided into: groundwater with free level (groundwater) and groundwater with water under pressure, with ascensional or artesian level (Figure 3).

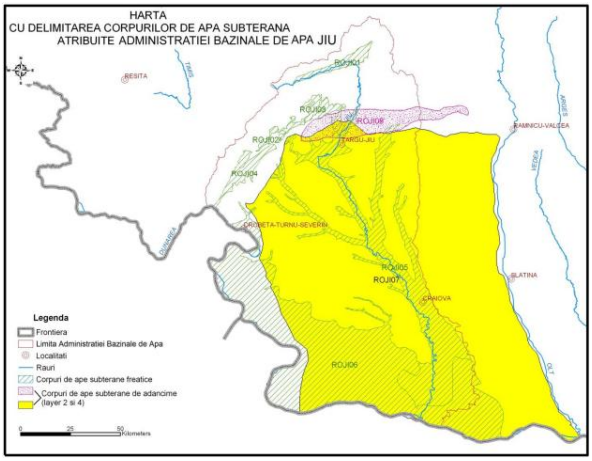

Figure 3 Delimitation of underground water bodies (***, JIU BASIN ADMINISTRATION, 2008)

At Rovinari Mining Basin, the phreatic horizon is located in the quaternary alluvial deposits forming the meadow and lower terraces of the Jiu Valley. Water pressure horizons are cantonized in the intercalations and sand banks located in the bed and the roof of the lignite layers. Hydrogeological exploration drills have highlighted several deepwater aquifer horizons, the debiting potential of which varies widely, due to the grain size of the sand. In general, the aquifer layers situated under the local erosion base are ascensional and determine the basic hydrostatic level in the mining basin area. The aquifer horizons in the lignite complex do not have a continuous spread, the research drills emphasizing their lentiliform character. (HUIDU, 2000; PASCU, 1983)

In Table 1 are presented the hydrogeological parameters of the North Pesteana mining perimeter in the Rovinari basin. (ROTUNJANU AND LAZĂR, 2014)

Table 1

Hydrogeological parameters of the North Pesteana perimeter (ROTUNJANU AND LAZĂR, 2014)

Open pit	Aquifers	Hydrogeological parameters							
		The character of groundwater	Filter coefficient k_f (m/day)	Coefficient of cede capacity kc (%)	Piezometric pressure H (m col. H_2O)	Water inflow coefficient k_a (m^3/t)	Specific flow q (m^3/zi)	Thickness of the screen h (m)	Degree of tectonization (accidents /ha)
North Pesteana	Phreatic horizon	free level	15,0 – 20,0	0,2 – 0,3	-	12,87	30 – 200	-	reduced
	Complex V – VI	ascensional	0,3 – 1,0	0,05 – 0,1	50 – 80		5 – 50	0 – 10,0	reduced
	Bed ot V^{th} lignite layer and artesian	artesian	1,0 – 3,0	0,15	70 – 150		10 - 70	5,0 – 15,0	reduced

The large area of infiltration and the permanence character of the water sources contributed to the accumulation of considerable (practically inexhaustible) groundwater reserves in the Dacian formations. (***, I.C.S.I.T.P.M.L., 2012)

The water sources of aquifers are represented by atmospheric precipitation, superficial waters (Jiul, Jiu tributaries) and waters from neighboring aquatic horizons. The discharge of these aquifers is done by natural drainage in the southern area of the region, through artificial dewatering, in the dewatering systems of the exploitations and in the collecting fronts for water supply or by the ascending drainage through semipermeable formations. (HUIDU, 2012)

Description of hydrotechnical and dewatering works

The exploitation of the lignite reserves in the North Pesteana perimeter was possible only after the execution of the hydrotechnical and dewatering works. These works were summarized in Table 2.

Table 2

Description of hydrotechnical and dewatering works (Huidu, 2012; ***, I.C.S.I.T.P.M.L., 2012)

Water sources		Hydrotechnical and dewatering works	Technical specifications
Surface	Jiu river	Deviation and regularization (Figure 4 - left)	Length of regularized section: 28,5 km (between Vârț and Plopșoru villages); trapezoidal channel; slope inclination 0,4-0,8 %; the width of the minor bed: 50-50 m; the width of the major bed: 150-210 m; maximum projected flow, Q_{max}=1040 m^3/s
	Ceauru storage basin	Accumulation for the mitigation of flood waves	Surface: 1.200 ha ;volume: 150 mil. m^3
	Plopului Valley	Regularization	Length of regularized section: 8,4 km; maximum projected flow, Q_{max}=183 m^3/s
	Călugăreni stream	Regularization	Length of regularized section: 296 m; maximum projected flow, Q_{max}=52 m^3/s
	Cioiana stream	Regularization	-
Underground		Waterproof screen	Built in the meadow area on the right bank of the Jiu River; depth 14-15 m (30 m in patches); width 50-60 cm; length 13 km; waterproof material: bentonite mud embedded in marl
		Preliminary dewatering	It was carried out with dewatering trenches and drills; purpose: reduction of groundwater pressure
		Parallel dewatering	Simultaneously with the dewatering works; is done with drills executed on the contour of the open-pits and in advance of the working fronts, as well as with the dewatering trenches; 4 drills on the eastern boundary, outside of the waterproof screen influence area; amount of discharged water:16.500 m^3/day, under conditions without rainfalls
		Natural dewatering	Is done through the slope of the open-pit
Groundwater and surface waters		Arrangement of sumps and pump stations (Figure 4 - right)	Collection of dewatering waters, infiltration and surface leakage; evacuation of water to the outside of the open-pit by pumping into the collecting channels (Fântânii Valley, Plopului Valley, Jiu River)
		Channels for collecting, conducting and discharging dewatering waters, infiltration and superficial waters	The channels were made with waterproof materials (perennial concrete)

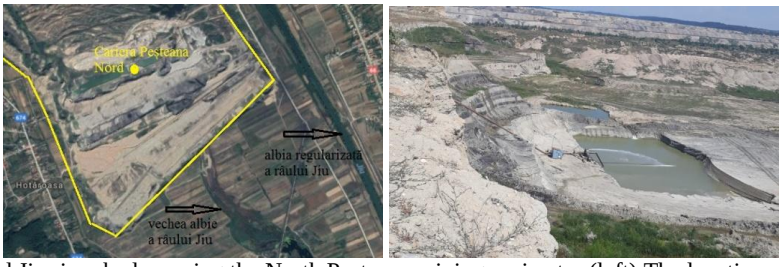

Figure 4 Old Jiu river bed crossing the North Pesteana mining perimeter (left);The location of the sumps on the base of the North Pesteana pit (right)

The hydrotechnical and dewatering works have led to a radical change in water flow patterns, especially underground, with a negative impact on the aquifer resources in the region from a qualitative point of view.

However, according to the literature (ROTUNJANU AND LAZĂR, 2014), the North Pesteana mining perimeter presents hard and very hard hydrogeological conditions with a large inflow of water, which has a special advantage in the conditions of flooding of the remanent voids.

Groundwater quality

The main source of water that can contribute to flooding of the remanent void of the North Pesteana pit is the underground water. In order to determine the subsequent directions of use of lake or of the lake's water, it is important to know its quality.

Considering the lack of recent analysis reports regarding on the groundwater quality in the North Pesteana mining perimeter, but also the continuity of aquifers within the Rovinari mining basin and the similar lithological constitution (which highlighted the same types of rock layers but of different thicknesses) it was established that from a qualitative point of view, the underground water has the same characteristics throughout the Rovinari basin. Therefore, the quality of the water discharged from the Roşia de Jiu perimeter, partly located in the Jiu River meadow area and at relatively small distance from the North Pesteana mining perimeter, was considered. Table 3 presents the values of the main groundwater quality indicators compared to current standards. (LAZAR, 2016)

Table 3

Groundwater quality (LAZAR, 2016)

Crit. No.	Quality indicator	UM	Maximum admissible concentration NTPA 001/2005	Determined values
1	PH	mg/l	6,5 – 8,5	7,12
2	CBO5	mg/l	25	11,55
3	CCOCr	mg/l	125	25
4	Fixed residue	mg/l	2000	172
5	Chloride	mg/l	500	10,6
6	Sulphates	mg/l	600	46
7	Calcium	mg/l	300	38
8	Magnesium	mg/l	100	12
9	Phenol	mg/l	0,3	0,12
10	Iron	mg/l	5	0,1
12	Suspensions	mg/l	35	34

According to the analysis report, it is noted that the quality of the water from the dewatering works corresponds to the existing standards. Once the aquifer formations are dewatered, there is a hydrodynamic entrainment of the fine particles from the rock massive, which results in a high value of the suspensions, which in the present case is approaching the permissible limit. However, the suspensions only temporarily affect the quality of the water so that a simple decanting operation considerably improves its quality.

Modeling the remanent void of North Pesteana open-pit

Figure 5 presents the situation of the North Pesteana open-pit at the end of the activity and the final configuration of the longitudinal section of the remanent void. Taking into account the location and development of the North Pesteana open-pit in the Jiu River meadow, the volume of the remaining void will be equal to the sum of the volume of sterile material deposited in the outer dump and the volume of extracted mineral substances.

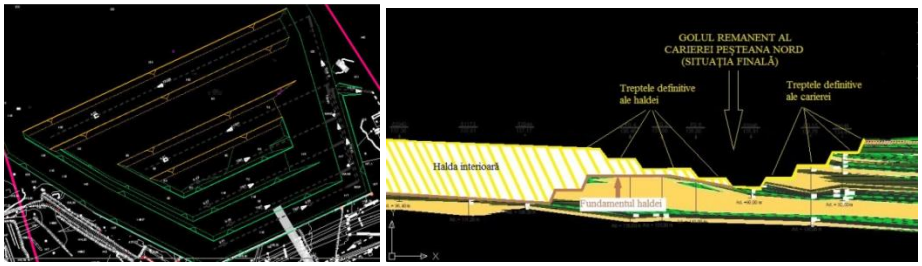

Figure 5 The Final Situation Plan of North Pesteana open-pit (left); Longitudinal section (right) (***, I.C.S.I.T.P.M.L., 2018)

The 3D modeling of the remanent void of the North Pesteana open-pit was made using the GEOVIA Surpac software, the most popular geological and mining planning software, which supports ground-based exploration and exploitation operations (Figure 5). (***, GEOVIA SURPAC SOFTWARE) Also, a discharge channel of water from the lake has been modeled, which is intercepted by the existing collector channel, Plopului Valley. He directs the surplus water from the lake in the regularized course of the Jiu River.

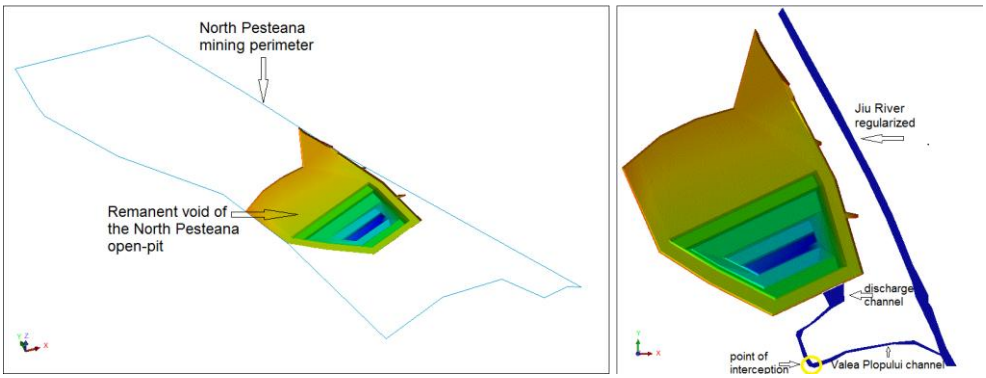

Figure 5 Shaping of the remanent void of the North Pesteana open-pit (left) and shaping of the discharge channel (right)

Using the Geovia Surpac software, based on the model created, the volume of the remanent void was determined, considering its flooding up to 134 m (Table 4).

Considering that from North Pesteana open-pit a daily volume 16500 m^3 of water is evacuated (***, C.E.O., 2017 - 2018), it can be stated that at the moment of the cessation of the exploitation activity and the stopping of the dewatering systems, this volume of water will contribute to the flooding of the remanent void of the open-pit. Thus, it is possible to assess the minimum duration of flooding since in fact the hydrostatic water pressure will cause a decrease in the water flow that supplies the lake with the restoration of the aquifer resources and the elevation of the hydrostatic level, so the actual flooding duration will be higher. Therefore, based on the calculations, the minimum flooding duration was 9.8 years. The surface of the lake at a height of 134 m is estimated at about 265 ha.

Table 4

Total volume and surface area and volumes and surface area by elevation

From [m]	To [m]	Volume Avg. [m^3]	Cumulative Volume [m^3]
50.0	55.0	0	0
55.0	60.0	114489	114489
60.0	65.0	295197	409686
65.0	70.0	362809	772495
70.0	75.0	417065	1189560
75.0	80.0	821823	2011383
80.0	85.0	1329958	3341341
85.0	90.0	1552713	4894054
90.0	95.0	2632380	7526434
95.0	100.0	3190165	10716599
100.0	105.0	3344395	14060994
105.0	110.0	4154230	18215224
110.0	115.0	4330918	22546142
115.0	120.0	5322081	17868223
120.0	125.0	8756933	36625156
125.0	130.0	12185533	48810689
130.0	134.0	10337348	59148037
Total	-	59148037	-

According to the data recorded on 8 November 2018 on the volume of the most important reservoirs in the Romania, their average volume is 80,6 mil. m^3. (***, ANAR, 2018) Compared to the average volume of the main reservoirs in Romania, the volume of the North Pesteana artificial lake accounts 72.5% of the average volume and provides a significant water reserve for the country.

RESULTS AND DISCUSSIONS

Taking into account the short period of activity of the North Pesteana mining exploitation (maximum 6 years), a number of possibilities for the recovery and re-use of the degraded land are considered, the objective being the sustainable development of the region.

When the mining activity ceases, the dewatering works are stopped. Remanent voids with very high depths have a high natural opportunity of flooding naturally, taking into account the high probability that they intersect small or deep aquifers. (NYARI AND LAZAR, 2017) As a result, the underground and surface water flows to the remanent void and floods it until the water level in the lake and groundwater level reaches a new state of equilibrium. To this flooding process contributes significantly the precipitation. Depending on the flow rate of groundwater or surface water and the amount of precipitation, the period of water filling of a remanent void can vary between a few years and several decades. (CASTENDYK AND EARY, 1999)

After mining activity has ceased, it is important to look at the possibility of restoring underground water resources as the issue of the potential hydraulic remediation of aquifers can become real under the condition of closure of open-pits. The factual data show, however, that in the area of the North Pesteana mining perimeter, the groundwater aquifers can be partially restored, even within a year with significant precipitation (HUIDU, 2012), the physical and geographical conditions being favorable to the accumulation of significant reserves of groundwater and their permanent renewal. (VLADIMIRESCU, 1978)

Following the assessment of the opportunity of flooding of the remanent void of the former open-pits in Rovinari Mining Basin, it has been revealed that the remanent void of the North Pesteana pit presents a high flooding opportunity. (NYARI ET AL., 2017)

The remanent void of the North Pesteana pit presents the natural conditions for flooding naturally with an inflow of water from aquifers and rainfalls within an acceptable period of time so that the essential works that involve effort and financial resources are the stabilization of the definitive slope of the remanent void and the modeling and harmonious integration into the landscape. (NYARI AND LAZAR, 2017)

Directions of using the artificial lake and its benefits over the region

In the case of the remanent void of the North Pesteana pit, its flooding is the only economically favorable option.

Taking into account the specific of the area and the development strategy of the region, the appearance of a water mirror can be of major importance. The economic specific of Gorj County is an industrial-agrarian one. Tourism has an appreciable development potential, but it is currently in its infancy. (***, CJ GORJ, 2012) It is also possible to adopt new strategic directions for the development of the region.

With a wealth of knowledge in the field of engineering and environmental protection, a series of recommendations have been made on the utility of the lake, highlighting its benefits both locally and regionally. Among the many possibilities of use, we list those that bring the most important benefits.

Considering that the remanent void of the North Pesteana pit is located in a region where climatic history has highlighted many dry periods or dry years which have adversely affected agricultural productivity (APOSTU ET LAZAR, 2017) such a lake can be used as a water reservoir for crop irrigation during dry periods.

The water level in the lake was deliberately set at a height of 134 m, even though the I.C.S.I.T.P.M.L. shows that the local conditions allow the hydrostatic level to be restored up to a heigher level (135 m). This choice was made with the purpose of feeding the Jiu River by executing a spillway (in the area of the former Jiu riverbed) and a discharge channel to take over the surplus of water from the lake and discharge it into the Jiu River throught the Plopului Valley. (Figure 6).

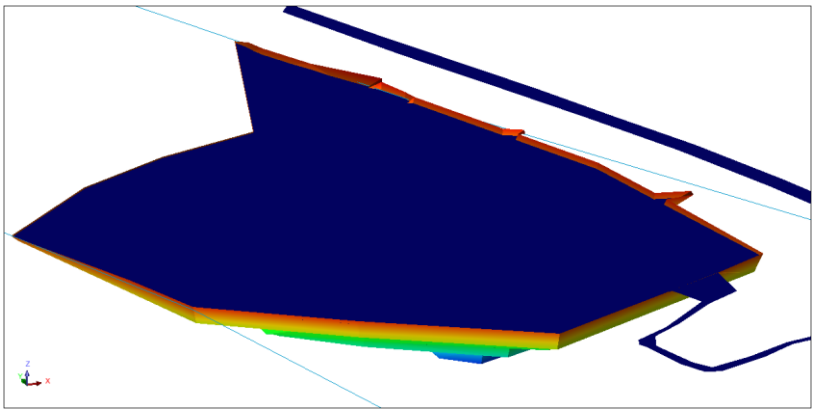

Figure 6 3D view of the "North Pesteana Artificial lake" project

This measure provides a number of benefits, as follows:

- a part of the Jiu River water can be captured and used to irrigate agricultural land located on the administrative territories of the downstream localities without having a negative impact on water in terms of quantity;

- due to the permanent nature of deepwater aquifers, they will continue to feed the lake, so while surface and groundwater flows are greatly reduced during periods of drought, they can be fed with water from the lake;

- the water in the lake will contribute to the systematic improvement of Jiu River water quality, which will have positive health effects, and water treatment spending for drinking water is considerably reduced;

- the flooding of the remanent void is done in line with the restoration of the aquifer resources, which has special advantages for the development and maintenance of the newly installed vegetation, the crops, the fruit trees, etc. (APOSTU AND LAZAR, 2017)

If sustainable development is based on tourism, the lake can be used for recreational activities and may include facilities such as beach, picnic areas, sports grounds, swimming and water sports, etc. This type of use can also ensure the economic development of the region.

Another direction of use of the lake is the pisciculture. This activity supports sustainable fishing, helping to reduce the pressure on natural fish stocks. The quality of the water in the North Pesteana lake is good and very good, but it is necessary to carry out studies on the fish species that are recommended to avoid any problems of inadaptability.

Regardless of the type of use, it is necessary to implement safety measures and to carry out rehabilitation and modeling works for harmonious integration of the lake into the landscape.

CONCLUSIONS

Therefore, there are a number of possibilities for the use of lakes formed in the remanent voids of the former lignite open-pits. There is also the possibility of combining types of use as long as they complement each other.

From the hydrological and hydrogeological point of view, the remanent void of the North Pesteana pit presents a high opportunity of flooding naturally, in an acceptable period of time.

Regarding the sustainable development of the region, the formation of an artificial lake in the remanent void of the North Pesteana pit can have considerable benefits, depending on the future directions of its use: the reintegration of the degraded land into the landscape, the rehabilitation of the land and of the environment, the advantages over the vegetation and the crops, source of water for irrigation of agricultural crops on adjacent land, economic development, etc.

The mirror of the North Pesteana artificial lake was set at a height of 134 m. The construction of the discharge channel in the Jiu river has a precise purpose with many important advantages, including: water quality improvement, positive effects on the course of the Jiu River from the quantitative point of view, the possibility of using the water from Jiu for irrigation of the agricultural crops downstream of the North Pesteana lake during periods of drought.

From a quantitative point of view, compared to the average volume of the main 39 reservoir lakes in Romania, the Pesteana Nord artificial lake provides an important and

strategic resource of surface water, which can be exploited during periods of drought both at the local level and regional.

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