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Ecological assessment of Uncle Sam Gulch Creek water quality under conditions of acid mine drainage

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Abstract

The current stage of subsurface use development is accompanied by an annual increase in post-mining territories. This is partly due to a change in funding priorities in this area and their widespread reorientation to the search for alternative sources of raw materials to ensure the development of modern high-tech industries. One of the biggest threats to the environment in this development is the deterioration of the freshwater quality due to poor management of abandoned mining areas. And one of the most significant problems is often created by acid mine drainage.

As a part of the study, information on the current environmental state of a past American mining territory located near Basin, Montana, USA, was analyzed and summarized; a conceptual exposure model was created regarding the studied natural and technogenic interactions; systematization and data updating on temporal and spatial changes in the qualitative characteristics of surface waters that are in direct contact with the abandoned mine were carried out; the level of efficiency of implemented reclamation works on the territory was determined.

The results of the water quality environmental assessments proved that the measures taken thus far are absent of a sufficient level of effectiveness for its full rehabilitation. To accelerate the process of changing the water quality of the investigated water object, both in terms of condition and degree of purity, a combination of a passive treatment system coupled with an artificial reduction of acid mine drainage volumes was suggested.

Keywords

environmental assessment, acid mine drainage, conceptual exposure model, pollution coefficient, ecological indices, water quality class, passive treatment system

Introduction

About two billion tons of metal are used in the world every year (Endangered Earth, 2019). Such volumes of consumption determine the ceaseless work of the Geological Services. Their main goal is the search and exploration of new deposits, as well as the liquidation of those ones that have reached the stage of depletion or have become unprofitable for other reasons defined by the principles of world economic development. Until recently, qualitative management of abandoned mining areas often did not appear in the development plans of mining regions as a top priority, remaining in the list of secondary tasks. As a result, this attitude had its side effects, which still significantly affect not only the state of the environment but also create additional risks for the population. The *topic is relevant* since abandoned mines often cause changes in natural landscapes and disturbance of large areas of arable land. They are also a permanent source of soil, underground and surface water pollution with heavy metals and other toxic products (mercury, arsenic, fluorine, etc.). In some cases, when the impacts reach critical thresholds, this leads to the emergence of ghost towns, which, with rare exceptions, remain like that forever.

Statement of the problem and its connection with important practical tasks. One of the greatest threats to freshwater quality in the United States is considered to be acid mine drainage from the abandoned mining sites described above (U.S. Environmental Protection Agency, 2013a). The last several decades (since the adoption of environmental protection laws in the 1970s) have resulted in the following:

- the active optimization of restoration works in such areas with the involvement of maximum available funding;
- searching for additional sources of financing;
- the maximum elimination of bureaucratic obstacles for the implementation of works aimed at solving the problems of groundwater and surface water pollution.

The projects on Superfund sites (allocated in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980) (Public Law 96-510, 1980) require significant financial investments annually in order to not only implement a number of actions to level the damage caused to the environment but also to control its changes (Safranov T., 2003). The purpose of that is to monitor the effectiveness levels of implemented measures and, if necessary, make adjustments to the remediation plan.

In the frames of this study, the former Basin mining area (Fig. 1), which is one of the numerous sites in the western United States where active mining took place decades ago, was examined. In particular, the author's attention was drawn to the state of water bodies located in the immediate vicinity of abandoned mines and the tendency of pollution to spread throughout the basin of the Boulder River. Uncle Sam Gulch Creek, which is in close contact with the abandoned Crystal mine, was chosen as the direct *object of the study* (Fig. 2).

Figure 1 *Basin mining area (U.S. Environmental Protection Agency, 2013b)*

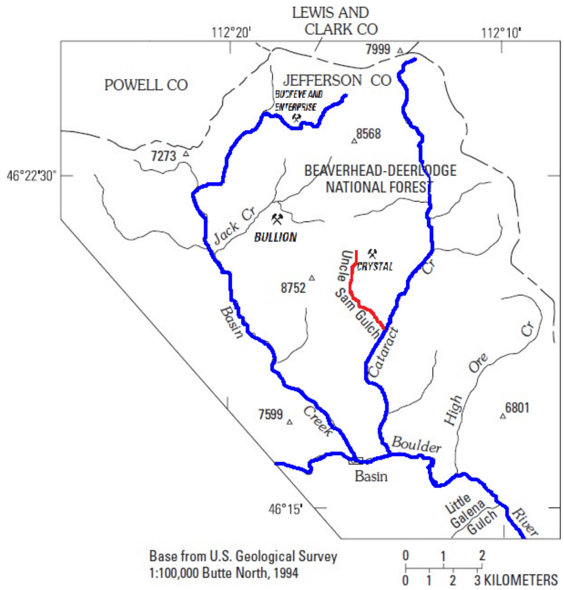

Figure 2 *Boulder River basin*

Analysis of recent research

The abandoned mining site is located north of the town of Basin in Jefferson County, Montana, within the Northern Rocky Physiographic Province, in the Cataract River watershed. According to archival data, in this area, mining works were concentrated on the development of veins of quartz, tourmaline, pyrite, galena, sphalerite, arsenopyrite, chalcopyrite and siderite (Becraft et al.,1963). And within the boundaries of the Boulder batholith, gold, silver and copper were extracted. Over a period of 55 years (1902-1957), $11,700,309 worth of minerals were mined here (MBMG, 1960). At the same time, mining works at the Crystal mine continued, albeit intermittently, until the end of the 1960s, leaving as a legacy of such activity a number of significant environmental problems that are still being solved by the country's leading agencies (USGS, EPA, DEQ, MBMG, U.S. Bureau of Reclamation, Montana Department of Natural Resources and Conservation, etc.) (U.S. Environmental Protection Agency, 2013b).

The chronology and activity of measures aimed to improve the general ecological condition of the studied territory began in 1980 (MBMG, 1995). During the first 20 years, the main focus of work here was an extensive study of the area and an assessment of all existing risks, ranking them according to the degree of urgency. According to those results, the public health risk associated with arsenic and lead became a priority task to be solved.

The primary sources of pollution that provoked this risk were identified as the numerous scattered rock dumps that were accumulating during the active stage of the mining facility operation and ore processing in the city of Basin at the end of the 19th century and into the beginning of the 20th (MDEQ, 1996). Historically, such tailings were often located near water; a majority of the material accumulated there was represented by:

- *waste rocks* removed from the mine. Their composition varied greatly depending on the period of mining works and the specific area where these activities were carried out (its geology). Some of them contained potential contaminants at levels similar to background ones, while others were highly mineralized ore material with high concentrations of hazardous elements.
- and *waste from ore extraction by milling* or other methods.

Such conditions, as well as the specific meteorological history of the region (heavy amounts of precipitation (Fig. 3) contributed to the leaching of potentially dangerous elements into soils, surface and groundwater waters (Osadchy V., 2013).

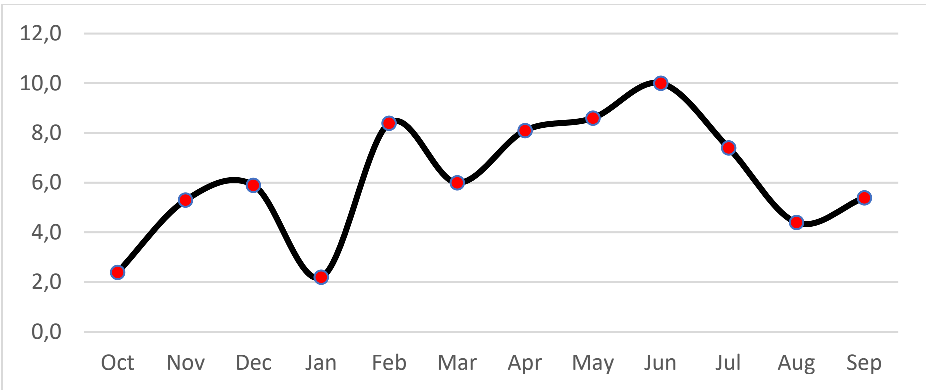

Figure 3 *Average amounts of precipitation (cm/month) in the Basin region*

In turn, this caused the degradation of vegetation (Daubenmire, R., 1959) (due to the increased concentration of metals in the environment), a decrease in the pH level, and the development of erosion processes in the areas where such waste is accumulated.

Permanent acid mine drainage was also added to the list of problems (Martin D., 1992). The most probable source of its formation is the active oxidation of pyrite, galena, and sphalerite, widely distributed here. The volumes of acidic leachate significantly exceed the natural buffering capacity of the host rocks. As a result, the mine water released from the adit is characterized by high concentrations of potentially toxic trace elements and a low pH level (Jennings et al., 2000). As of today, monitoring works still record their regular discharge from the abandoned Crystal mining facility (its bore pits and tunnels) (Figs. 4, 5).

Figure 4

Figure 5

Discharge of acid mine drainage water from the Crystal mine

The active collection of actual data on soils and waters gave a clear and detailed picture of the territory, and from the beginning of the 2000s, the transition to the active phase of works aimed to eliminate the modern consequences of the mining processes of the past began.

In an effort to minimize all the mentioned risks and problems, the following was carried out:

– removal and replacement of contaminated soils from residential private plots and numerous ore dumps;
– active landscaping of all renewed areas;
– introduction of control measures regarding the future use of territories that, for one reason or another, remained inaccessible during reclamation works.

Highlighting unresolved parts of the overall problem. With the mentioned actions, as well as by changing the water supply sources of the nearest settlements (there are no wells that would be used for drinking water supply within a radius of at least 5 km away from the problematic area), the risks to human health were significantly reduced, reaching an acceptable level. Nevertheless, the state of the environment, particularly that of the water, is still causing concerns and requires more attention.

At present, observation of changes in the state of the studied water object is mainly based on the comparison of concentration data at specific control points and not the river as a whole. In addition, this approach does not take into account the combined effect of contaminants, each of which is considered separately. For these reasons, among the tasks which are of current interest are the systematization and analysis of the totality of available multi-temporal information with the aim of:

– establishment of complex pollution coefficients' at specified points (both - taking into account toxic priority and without it);
– defining a generalized environmental index based on integral assessments of the complex characteristics and contents of specific toxic substances.

This will make it possible to provide the project's investing parties with more specific and accessible characteristics of the problematic entities, where everything with secondary importance is rejected, and a narrowed (mathematically) circle of data remains in focus. By doing this, the real needs of reclamation works will acquire qualitative reasoning, and the choice of suitable alternatives will be based on more fundamental principles.

Formulation of article goals. This study is based on the results of Uncle Sam Gulch Creek monitoring over the past five years (including the current 2022 year). The main goals are: tracking changes in the main hydrochemical, tropho-saprobiological characteristics, and contents of specific toxic substances; establishing regularities of water quality changes in temporal and spatial aspects, as confirmation of the effectiveness of the reclamation work done to date; assessment of existing alternatives for these restoration activities within the studied territory and substantiation of the most effective one, based on the obtained results of environmental assessments.

Presentation of the main material

Focusing on the specified natural and technogenic interactions, as well as official data presented by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 2013a), the current state of the territory might be described in the form of the following conceptual model (Fig. 6). Specifying the essence of the formulated chains of "damage effects" on various spheres of the natural environment and living organisms, special emphasis should be placed on the following:

– danger caused by erosion and runoff processes, which is primarily conditioned by the destruction of riverbank material, which contains arsenic and a number of various metals, which are entering the water flow directly.
– discharge of groundwaters into the river system, which is accompanied by the threat of sedimentation, co-sedimentation and absorption processes that transform free metal ions into less mobile forms. As a result, arsenic and a number of various metals remain in solution and are transported until they are deposited in the surrounding soils (including shallow alluvial aquifers) or until they enter more powerful flows of surface water, worsening their quality characteristics.

In such conditions, the main pollutants, the volumes of which are of particular concern and still require efforts to reduce and control, are aluminium, arsenic, cadmium, copper, iron, lead, manganese, and zinc. Their spread is greatly facilitated by the dense hydrographic network of the territory. Thus, Uncle Sam Gulch and Jack Creeks (see Fig. 2), which are the primary receivers of the main mass of pollutants coming from the already abandoned Crystal and Bullion mines, are discharged into the large high mountain streams Cataract Creek and Basin Creek, which in turn flow into the Boulder River. As a result, the poor quality of the first ones significantly changes the characteristics of several large water bodies (more than 120 km long). The Boulder River connects downstream with the Jefferson River, and thus contamination has the ability to spread well beyond the delineated historic mining area. As an illustrative example/confirmation, the data obtained in 2001-2005 might be considered. During that period, the concentrations of dissolved copper, as well as total cadmium and zinc, exceeded their control values in Uncle Sam Gulch Creek by 360 times (Nimick, D., Cleasby, T., 2000; USGS, 2004). And at the same time, the level of pollution with the specified contaminants, in addition to sulphates, in the mouth of Cataract Creek was five times higher than in its upper reaches. The latter is a direct confirmation of the influence of acid mine drainage and rocks, which were carried by the inflow in an already diluted form (Nimick, D., Cleasby, T., 1998; CDM, 2005).

The effectiveness of measures implemented in the past and their impact on the surface water quality changes is usually monitored by comparing data on the concentrations of the most dangerous pollutants of the current year with those from the previous year. If we analyze their contents over the last five years (MBMG, 2021) (Figs. 7, 8), then in most cases, a clear downward trend is observed.

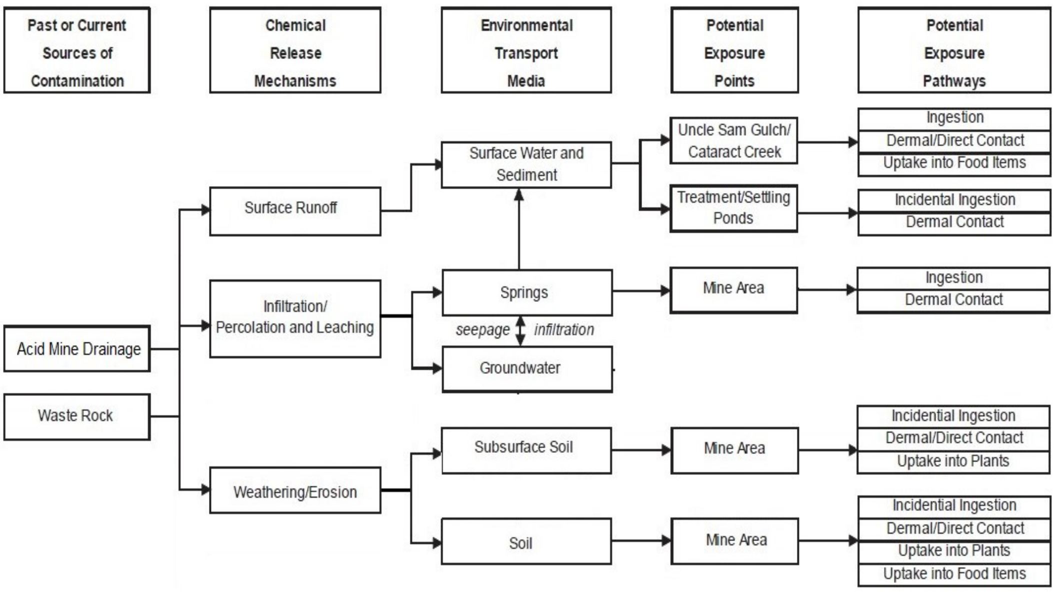

***Figure 6** Conceptual exposure model (made on the basis of the suggested in U.S. Environmental Protection Agency, 2009, 2013b models, with a focus on the investigated environmental problems)*

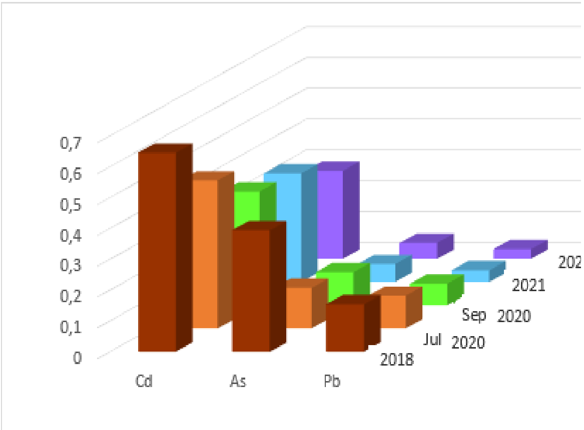

Figure 7

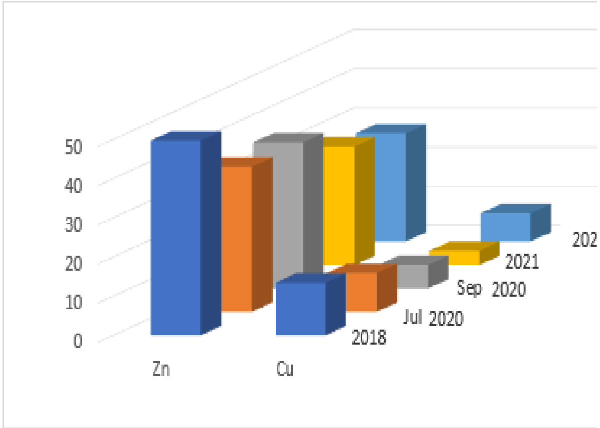

Figure 8

Concentrations (mg/L) of priority pollutants in Uncle Sam Gulch Creek

Another problematic indicator is the pH level. A significant decrease in pH was previously observed in the waters of Uncle Sam Gulch Creek, but in the last few years, this indicator began to increase with waters going from acidic to a little bit closer to neutral (Fig. 9).

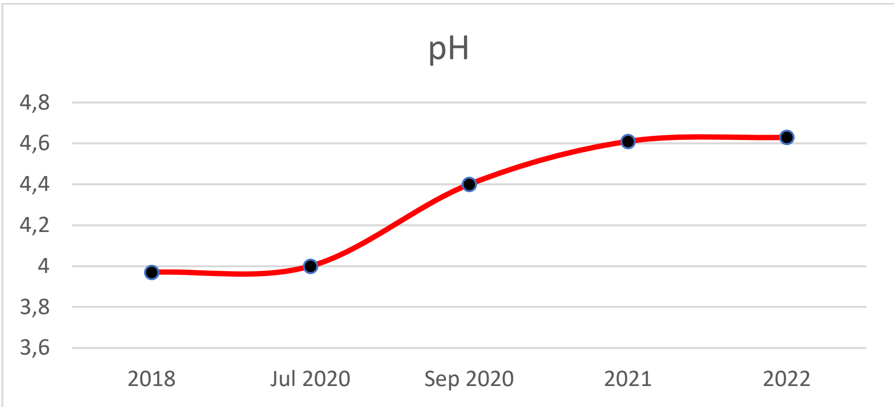

Figure 9 *Change of the pH indicator over time*

In other words, there is a trend towards improvement. However, the key issue in the context of this study is the speed and general effectiveness of these changes relative to the entire water body.

In the process of determining modern (2022) spatial changes in the river water quality, an integral assessment (Urasov et al., 2009; Musaelyan, S., 1989) of the object was carried out. It included the complex use of hydrochemical indicators obtained in the laboratory (by the use of ICP-MS analysis) and the establishment of pollution criteria (defined in Table 1a) (1) along the entire length of Uncle Sam Gulch Creek.

$$X = \frac{\sum\left[\left(\frac{N_i}{C_{i,d}}\right)\times\varphi(i)\right]}{\sum\varphi(i)} \tag{1}$$

where N_i – pollution indicator value; i – pollution indicator number in the rank order of m indicators; $C_{i,d}$ – indicator standard (maximum permissible concentration); $\varphi(i) = i / 2\ i - 1$ – the weight function; $\Sigma\varphi(i)$ – given number of indicators (Urasov et al., 2009).

The main focus was made on the previously mentioned pollutants of interest. As part of the experiment, the calculation was carried out using the following ranking criteria: local priorities regarding the levels of the harmfulness of one or more elements were taken into account, and the ratio of determined concentrations and maximum permissible concentration (Circular DEQ-7, 2019) (MPC) (Table. 1).

The obtained results were correlated with the corresponding integral scale, according to which the qualitative assessment of the water environment pollution extent along the river length can be described as follows. The section of the river above the location of the mine is characterized by relatively clean, harmless waters, where high levels of heavy metals, radionuclides, and other pollutants are not typical. Downstream, after merging with a small unnamed tributary and at a distance of several tens of meters (but still above the mine), the obtained coefficients are interpreted as those which are typical for a small level of pollution. This can be explained by the partial introduction of additional pollution by the tributary, which, as a result of diffusion processes, slightly changes the qualitative characteristics of Uncle Sam Gulch Creek (USC). Below the confluence of the creek and the acid mine drainage flow, the unloading of which occurs on a constant basis, the pollution coefficient makes a sharp jump. From this point to the moment of confluence with Cataract Creek, the quality of the water environment was assessed as catastrophic.

Regardless of certain differences in the resulting final calculations of the coefficient, in conditions of applying different approaches to the ranking process, the results do not contradict each other, falling into the same ranges of qualitative interpretation of the pollution extent. And this fact is an additional confirmation of the obtained data reliability.

Table 1a Water quality assessment according to the pollution criterion (X)

Control site	Indicators		As	Cd	Cu	Pb	Zn	Al	Fe	Mn	Pollution criterion (X)
USC-1		C/MPC	1,4	0,31	0,26	0,37	0,08	0,48	0,58	0,13	
	With priorities	Rank	2	1	4	3	5	7	6	8	0,58
		ϕ	1	1	0,5	0,75	0,31	0,11	0,19	0,06	
		ϕ* (C/MPC)	1,4	0,31	0,13	0,28	0,03	0,05	0,11	0,01	
	Without priorities	Rank	1	5	6	4	8	3	2	7	0,67
		ϕ	1	0,31	0,19	0,5	0,06	0,75	1	0,11	
		ϕ* (C/MPC)	1,4	0,1	0,05	0,18	0,01	0,36	0,58	0,01	
USC-Trib		C/MPC	2,6	1,28	0,22	0,44	0,75	0,18	0,06	0,05	
	With priorities	Rank	2	1	4	3	5	7	6	8	1,15
		ϕ	1	1	0,5	0,75	0,31	0,11	0,19	0,06	
		ϕ* (C/MPC)	2,6	1,28	0,11	0,33	0,23	0,02	0,01	0,003	
	Without priorities	Rank	1	2	5	4	3	6	7	8	1,19
		ϕ	1	1	0,31	0,5	0,75	0,19	0,11	0,06	
		ϕ* (C/MPC)	2,6	1,28	0,07	0,22	0,56	0,03	0,01	0,003	

Table 1b Water quality assessment according to the pollution criterion (X)

Control site	Indicators		As	Cd	Cu	Pb	Zn	Al	Fe	Mn	Pollution criterion (X)
USC-2		C/MPC	2,4	1,6	1,78	2	0,43	0,68	0,58	0,15	
	With priorities	Rank	2	1	4	3	5	7	6	8	1,68
		ϕ	1	1	0,5	0,75	0,31	0,11	0,19	0,06	
		ϕ* (C/MPC)	2,4	1,6	0,89	1,5	0,14	0,07	0,11	0,01	
	Without priorities	Rank	1	4	3	2	7	5	6	8	1,73
		ϕ	1	1	0,75	1	0,11	0,31	0,19	0,06	
		ϕ* (C/MPC)	2,4	0,8	1,33	2	0,05	0,21	0,11	0,01	
Crystal Mine		C/MPC	88,4	2080	1006,67	33,6	340,83	87,7	159	84,17	
	With priorities	Rank	2	1	4	3	5	7	6	8	712,03
		ϕ	1	1	0,5	0,75	0,31	0,11	0,19	0,06	
		ϕ* (C/MPC)	88,4	2080	503,33	25,2	106,51	9,59	29,81	5,26	
	Without priorities	Rank	5	1	2	8	3	6	4	7	869,30
		ϕ	0	1	1	0,06	0,75	0,19	0,5	0,11	
		ϕ* (C/MPC)	27,63	2080	1006,67	2,1	255,63	16,44	79,5	9,21	
USC-3		C/MPC	2,4	272	104,22	7,2	47,58	8,52	3,8	11,58	
	With priorities	Rank	2	1	4	3	5	7	6	8	87,29
		ϕ	1	1	0,5	0,75	0,31	0,11	0,19	0,06	
		ϕ* (C/MPC)	2,4	272	52,11	5,4	14,87	0,93	0,71	0,72	
	Without priorities	Rank	8	1	2	6	3	5	7	4	105,57
		ϕ	0	1	1	0,19	0,75	0,31	0,11	0,5	
		ϕ* (C/MPC)	0,15	272	104,22	1,35	35,69	2,66	0,42	5,79	

Considering the positive dynamics shown in Figures 7-9 and the characteristics established by the previous method, the question of the effectiveness of the above-described works aimed to improve the ecological condition of the territory arises acutely. The assessment of this effect can be considered through the prism of the rate of the water environment qualitative changes' flow in the water environment of Uncle Sam Gulch Creek. For these reasons, another methodological approach was used (Snizhko S., 2001; Kolesnik A., 2009), designed for ecological assessment of the surface water quality according to the relevant categories. (Romanenko V. D., et., 1998).

The water quality assessment was carried out using monitoring data obtained downstream from the Crystal mine, where the diffusion processes had already occurred for the last five years. Generalized ecological indices (Ie), which were calculated, included the analysis of three blocks of indicators: salt (hydrochemical), tropho-saprobiological (sanitary & ecological) characteristics and contents of specific toxic substances (Table 2). The first block includes indicators of the ions' sum, sulfate and chloride contents. The second saprobiological block includes pH levels, and values of the dissolved oxygen, phosphates and suspended substances' contents. The block of specific toxic substances is represented by data on arsenic, cadmium, copper, lead, zinc, nickel, iron and manganese.

Tab. 2 Water quality environmental assessment

Indicators	2018				Jul. 2020				Sep. 2020				2021				2022			
	Value	Index	Class	Category	Value	Index	Class	Category	Value	Index	Class	Category	Value	Index	Class	Category	Value	Index	Class	Category
I block - hydrochemical (salt)																				
Sum of ions (Ca, Mg, K, Na, HCO3, Cl,SO4) (mg/L)	701,8	3,33	2	3	593,8	3,33	2	3	550	3,33	2	3	501	3,33	2	3	459,8	3	2	3
Chlorides (mg/L)	0,68				0,61				0,66				0,58				0,7			
Sulfates (mg/L)	623,1				517,3				484				435				383,1			
II block - tropho-saprobiological characteristics																				
Ph	3,97				4				4,4				4,61				4,63			
Suspended matter(mg/L)	875,98				726,07				670,14				587,51				542,85			
Dissolved O_2 (mg/L)	7,28	4,75	3	5	7,48	4,75	3	5	7,84	4,5	3	5	7,88	4,5	3	5	7,78	4,5	3	5
Phosphates (mgP/L)	0,019				0,019				0,019				0,019				0,019			
III block - specific toxic substances' content criteria																				
As (µg/L)	394,56				132,36				107,04				58,43				51,45			
Cd (µg/L)	645,53				479,77				368,17				351,64				384,64			
Cu (µg/L)	13425				9931,48				6007,41				3628,94				7254,61			
Pb (µg/L)	157,15	6,75	5	7	106,21	6,75	5	7	69,96	6,63	5	7	37,86	6,5	5	7	30,56	6,5	5	7
Zn (µg/L)	49675				37042,48				37300,15				30260,26				27674,17			
Ni (µg/L)	36,09				32,1				29,06				22,78				25,58			
Fe (µg/L)	57910				42100				40743				29492				18675			
Mn (µg/L)	11078				10020				10887				9252				7649			

According to the mineralization criterion, until 2021, the waters of Uncle Sam Gulch Creek, which flows into the Cataract Creek, were defined as fresh, oliho-galena. Changes in this leading indicator occurred very slowly over the years, so clear temporal regularities were not recorded. However, two years ago, the gradual slight decrease of mineralization reached a threshold, after which the water started to be classified as fresh hypo-galena one.

The analysis of the calculated index ratios shows that the greatest contribution to the total pollution of Uncle Sam Gulch waters belongs to specific indicators, and the parameters of the salt composition contributed the least. Ecological and sanitary indicators occupy an intermediate position.

The use of the such expanded scope of studied parameters significantly distinguishes this approach from the previous one and requires the use of a slightly different classification of surface water quality (Tsos O., 2017; Romanenko V. D., et., 1998). Due to the obtained results of the performed analysis, supported by the appropriate calculations (with regular mathematical approximation), waters of the studied creek are allowed to be identified by the class - 3 and category – 5 (according to Romanenko et al., 1998 classification). According to their natural condition, they are defined as satisfactory and mediocre, and according to the degree of their cleanness (pollution), they are moderately polluted.

However, considering the indicator values' changes in the temporal aspect in a more detailed way (without approximations), gradual changes are noted starting from September 2020. The latter is still insufficient for a fixed change in the general class and category of water quality within Uncle Sam Gulch Creek. But, at the same time, they are sufficiently obvious to record the gradual transition for its waters from the fifth quality category to the fourth, within which the water is characterized as totally satisfactory by their natural condition and slightly polluted according to the degree of cleanness.

Trophicity and saprobity became additional parameters regarding which qualitative shifts began in the same period. This is caused by noticeable fluctuations in sanitary and ecological (tropho-saprobiological) characteristics, which at the present time hold an intermediate position between the two categories according to the classification. Regarding the prevailing type of trophicity – a smooth transition from eu-polytrophic to eutrophic is happening. Saprobity, in its turn, gradually passes from α-mesosaprobic to β-mesosaprobic and, accordingly, from α'-mesosaprobic to β''-mesosaprobic.

Based on all obtained results, it can be concluded that despite the noted positive dynamics of changes and regardless of the applied environmental assessment methods and approaches, the current rate of improvements still cannot be considered sufficient to ensure the full-fledged ecological safety of the studied area.

The lack of rapid changes in the water environment quality might be explained by the fact that in recent years priority has been given to measures aimed at solving the problem of soil pollution by waste rocks (Mitzi R., Haynes T., 1999; Godfrey A. 2003). The territory disturbed by the mining operations of the past and its modern consequences was mainly considered from the perspective of:

- stabilization of artificially created areas where dumps were concentrated;
- reconstruction or terracing of their excessively steep slopes;
- control of surface water flow in order to reduce the problem of erosion.

At the same time, the solution to surface water pollution problems was deferred until the creation of optimal projects that would have the maximum impact on its ecological state. According to the EPA (2013a) report, the only action which has been implemented within the studied area is the use of a special drainage structure aimed at collecting mine waters. But, as can be seen from the obtained results, this is not enough without additional measures.

Also, the list of restorative actions planned for implementation in the nearest future includes:

- design and reconstruction of the Uncle Sam Gulch Creek, part of which is in direct contact with the boundaries of the mine field, stabilization of its banks and vegetation;
- design and construction of a passive treatment system.

According to the plan, the completion of the mentioned design will be completed in 2023, after which the rest of the operative actions will be started. The measures aimed to minimize the direct contact of the creek with the adit, as well as the redirection of collected polluted water for partial treatment, are considered by the implementing organizations through the prism of long-term efficiency. However, according to the authors, solving the problem of water pollution within the studied territory should be carried out not only for the purpose of cleaning but also for its gradual adaptation to these changes. Combining various alternative approaches is more appropriate than focusing on one, albeit the most economically beneficial, from the implementation point of view. The complexity of measures will provide a favourable basis not only for the artificial improvement of the water environment quality but will also give the necessary impetus to restore the assimilative capacity of the territory, which was disturbed during the times of active mining operations.

After analyzing the alternatives presented in the EPA (2015) reports, it was assumed that the combination of the adopted option with the construction of a special plug in the lower Crystal mine shaft would have the most positive effect of all other possible combinations. Both approaches have their strengths and weaknesses:

– *semi-passive treatment system* - will not require regular maintenance, but it will still be necessary at different stages with different time intervals. And the effectiveness of its work will depend precisely on the level of responsibility for carrying out these preventive works. In addition, the implementation of this system will not contribute to the control of the acid mine drainage release. Its maximum capability is the capture and high-quality processing of point emissions, the volume of which is fairly small. However, at the same time, the predicted level of efficiency in removing polluting components reaches 90%.
– *a special plug in the shaft* – will ensure the sealing and will block the main volume of acid mine drainage leakage. But its reliability is closely dependent on the extent of solidity, which is influenced by a number of other additional factors (the chosen construction method, the condition of the rocks around the adit, etc.). Installing a plug is not a guarantee of reducing the toxicity of leaks, but it will contribute to the decrease of the polluting components' mobility.

The logic of building both structures on the studied territory and combining them into a single reclamation system is explained by the possibility of establishing a close interconnection between them. The latter will perform the function of a safety valve and shock absorber between them.

The flooding caused by the plug will reduce the possibility of air entering the mine, reducing oxidation and the formation of acid drainage. This will automatically reduce the pressure on water resources. At the same time, the volumes of pollution from less important groundwater discharge points will create less load on the constructed passive treatment systems, thereby increasing their efficiency. Slowing down, in this way, the flow of specific contaminants together with acid mine drainage to the planned sulfate-reducing biochemical reactor, aeration systems, clarification ponds and the discharge channel will contribute to a systematic decrease in the river's toxicity level.

And in the case of solidity violation of the mentioned plug, the passive treatment system may qualitatively dampen the full-water flow of the acid mine drainage, which will be released from the mine without allowing it to completely discharge into the river.

Aligning the index ratios of all three blocks of indicators that were used to assess the water in this research will be convincing evidence of the qualitative adaptation of the natural environment to new realities. This levelling can be monitored by the results of multi-vector environmental assessments and regular surface water monitoring studies.

Conclusions

The resource- and energy-intensiveness of outdated technologies used in mining operations of the last century led to significant environmental changes, critical violations of the environment and the balance of the biosphere, especially within post-mining areas. A typical representative of the latter is the former Basin mining area. It is well studied geologically, but the ecological aspect is currently at a stage of constant change due to the beginning of reclamation works. Determined by the calculated pollution coefficients and integrated ecological index, Uncle Sam Gulch Creek water quality indicates the absence (at the current stage) of a sufficient level of effectiveness of the measures taken in relation to the aquatic environment. First of all, such a conclusion is conditioned by insignificant changes in the hydro-ecological state of the studied river system, which leaves Uncle Sam Gulch Creek on the list of those requiring significant restoration investment. To speed up the progress, an intensification of remediation works with the use of extended approaches is recommended. The suggested combination is considered the most promising for achieving, if not surpassing, then satisfactory indicators of water quality in the shortest period of time; while also reaching a "fairly clean" category level of cleanliness.

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