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Information Supply of Hydrotechnical Reconstruction Concept of Stebnyk Tailings Storage (Ukraine)

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ABSTRACT

The ecological condition of the Stebnyk tailings storage during the period of its operation and the development of the processes of filling it with brines to a critical level are analyzed. It is shown that the main reason for the current state of crisis of this object is its incorrect operation and the lack of an effective system for collecting and removing atmospheric water. The concept of hydro-technical reclamation of the tailings storage through the creation of the Stebnyk hydropark has been developed. The proposed technical solutions for the hydro-technical reclamation of the tailings storage include proposals for the design of a network of direct distribution and outlet channels on the territory of the already dry section No. 1, for the unloading of section No. 2. The design of the hydro-technical system "tailing storage – direct distribution and outlet channels channels" is based on a mathematical model of the water balance in conditions of continuous replenishment of ground and surface water and an increase in their level. The proposed hydro-technical network will provide control over the level of brines and discharge of water from the tailings storage facility. Geoinformation technologies were used to visualize the proposed technical solutions for the hydro-technical reclamation of the tailings storage. The implementation of the developed project proposals will ensure an environmentally safe hydrodynamic state of the "tailings storage – direct distribution and outlet channels" system, which will eliminate the threat of brine overflow through the protective dam, as well as the threat of dam breach and brine flow into water objects. Hydro-technical reclamation will ensure the environmental safety of human activities and water ecosystems of the water network of the Dniester river basin.

Keywords: reclamation, ecological safety, GIS, potash salts, catastrophic ecological situation

INTRODUCTION

In recent decades, a catastrophic ecological situation has developed in the salt mines of the western regions of Ukraine. Emergency situations (ES) at the salt mines of the Carpathian region (Kalush City, Solotvyno urban-type settlement, Stebnyk City) are caused by the complication of mining-geological, ecological, and socio-economic conditions, as a result of the inherited complex ecological violations and imperfect technologies for the operation and conservation of unprofitable mines and quarries, mainly by flooding, with the activation of dangerous exogenous geological processes. At the same time, the development of karst-collapse and landslide processes during the closure of the Solotvyno, Kalush, and Stebnyk salt mines led to destructive deformations of more than 2,500 buildings, accelerated migration of toxic substances into the basins of the transboundary rivers Tysa and Dniester, which are sources of drinking water supply for 10 million persons on the territory of Ukraine, Romania and Moldova.

The ecological safety of Stebnyk mining and industrial district (MID) is due to the negative impact of mining activities on the environment after to the low culture of subsoil use [Rudko and Shkitsa, 2001; Bidira, et al., 2022; Pohrebennyk and Dzhumelia, 2020; Kumari and Maiti, 2019; Dyakiv et al., 2015; Rokochinskiy et al., 2020; Baberschke et al., 2019a; Baberschke et al., 2019b; Lee et al., 2017; Wang et al., 2021]. Untimely and incorrect scientific-technical, mining-technical, monitoring and environmental protection measures created the prerequisites for the emergence of environmental problems for the population of the territories of potassium salt extraction. A potential danger of the influence of the enterprise is created by underground mining operations, which are centers of karst formation, as well as tailings storage. Erosion of salt-bearing dumps by atmospheric precipitation, overflow of the tailings storage with mineralized solutions and atmospheric precipitation cause the spread of geochemical halos of soil salinity, pollution of underground and surface water. Scientific and technical substantiation and development of technologies for hydrotechnical reclamation of the tailings storage, followed by the application of phytoremediation measures, is expedient for the optimization of Stebnyk post-mining geosystem and the stabilization of the ecological situation.

The relevance of hydro-technical reclamation of the Stebnyk tailings storage facility is due to the man-made destabilization of the geosystem of the potash deposit. The importance of stabilization and ecological rehabilitation of the territory of salt mines in the Carpathian region takes on special importance in the context of the Association Agreement between Ukraine and the European Union, since Article 362 states that the parties to the Agreement will pay special attention to issues of a transboundary nature [Association Agreement].

Territories and objects disturbed during the development of minerals must be brought to a state that is safe for people and suitable for economic use in accordance with the Mining Law of Ukraine. Special attention should be paid to the prevention of man-made ecological disasters caused by technical-operational, climatic, and hydrogeological factors, as happened in 1983 when brines of potash salts from Stebnyk tailings storage destroyed the entire water ecosystem of the upper reaches of the Dniester River basin.

Statement of the problem

The exploitation of the Stebnyk deposit of potash salts led to multimillion-dollar losses, threats to health and deterioration of living conditions for people, and a decrease in biological diversity of the Dniester River basin. The imperfect technology of field development, using traditional methods without taking into account ecological requirements, led to the acceleration of the processes of dissolution of haloides, led to the activation of subsidence of the earth's surface, and the karst collapse phenomena. The scale of manifestations of karst and related processes is huge. Not only the territories of the mines but also extensive areas beyond their boundaries were in the zones of danger of failure.

The second environmental threat is the Stebnyk tailings storage, where waste from the chemical enrichment factory was transported through pipelines. The tailings storage facility is located on the northeastern outskirts of Stebnyk City near the Solonytsia River (the right tributary of the Tysmenytsia River). According to the technological solution, the hydro-technical structure is man-made reservoirs covered with dams, into which liquid waste from flotation beneficiation of ores was dumped. In the tailings storage facility is accumulated 11.2 million m^3 of waste. Waste causes salinization of groundwater, reservoirs at the sites of storage ponds and sludge storage facilities, which occurs through the infiltration of brine through their bottoms, sides, and foundations of dams. In addition to brine, the tailings storage contains about 20 million tons of solid phase - salt-clay waste from flotation beneficiation [Bilonizhka and Dyakiv, 2009].

Today, the level of brines in section No. 2 of the tailings storage facility of Stebnyk mining and chemical enterprise "Polymineral" reaches the maximum permissible level. An average of 1,612,000 m^3 of atmospheric precipitation falls on the entire area of the tailings storage annually, and about 572,000 m^3 evaporates from it, i.e., the excess water is 1,040,000 m^3 per year. The total volume of waste together with atmospheric precipitation grew in the tailings storage by an average of 1,368,000 m^3 per year [Bilonizhka and Dyakiv, 2009].

It should also be taken into account that during heavy rainfall, excessive water saturation of dams and overflow of mineralized solutions through ridges of dams is quite possible. Taking into account the significant content of soluble salts in dams, there is a threat of their critical water saturation with subsequent catastrophic destruction. The growing risk of a hydro-technical accident is evidenced by the fact that karst processes continue to develop along the dam in the territory of the tailings storage, which leads to the formation of subsidence and filtration of brines through the body of the dam with surface and underground water pollution. The breakthrough of brines from the tailings storage facility may lead to catastrophic transboundary pollution of the Dniester River runoff, similar in its negative consequences to the destruction of the tailings storage facility in 1983.

Therefore, it is necessary to urgently develop and implement measures to reduce the dynamics of the increase in the level of highly concentrated brines in the tailings storage and create a monitoring system for the condition of a potentially dangerous facility.

Background

The analysis of studies on the environmental problems of mine workings of potash mineral fertilizers indicates the existence of a fundamental basis of the phenomenology of ecological safety of the salt-mining regions of the Pre-Carpathian region [Rudko and Shkitsa, 2001; Goshovsky et al., 2002]. The authors [Haydin et al., 2012] summarized the numerical, in-depth, and detailed, but fragmentary and scattered results of geo-ecological studies of the salt-extracting mining complexes of the Pre-Carpathian region. The works of M. D. Grodzinsky, E. A. Ivanov, and I. P. Kovalchuk, etc. are devoted to landscape, geological, and geographical studies of the influence of the mining industry on the environment. The works of Y.M. Semchuk, E.I. Kryzhanivskyi, S.S. Korynya etc. are devoted to the problems of ensuring environmental safety at the stage of liquidation of potash mines. The works of G.I. Rudko, A.M. Haydin, I.I. Zozulia, V.O. Dyakiv and etc. are devoted to the issue of engineering protection of salt and sulfur deposits in the Pre-Carpathian region. The results of the study of brines in flooded potash mines of Pre-Carpathian region are presented in the work [Haydin et al., 2012].

A general description of the current ecological state in the area of influence of Stebnyk MID is described in a number of scientific works [Varlamov et al., 1971; Dyakiv at al., 2015; Ivanov, 2018]. During 1967-1988, waste from the concentrator factory of Stebnyk potash plant accumulated in the tailings storage of Stebnyk MID. The enrichment factory produced potassium-magnesium mineral fertilizer (calimagnesia ($K_2SO_4 \cdot MgSO_4$)) with a K_2O content of up to 17–18%. The technological scheme of the processing of potassium-magnesium ores of the Stebnyk deposit consisted in dissolving potassium salt rocks with hot water, settling the insoluble clay residue, and separating the clarified highly concentrated oil from the sediment and crystallization of calimagnesia from it. However, the polymineral composition of potash ores and their high content of clay material (10-15%, sometimes up to 20%) greatly complicated the technology of their processing. Practically, this technology turned out to be very imperfect. The waste contained not only clay material, undissolved polyhalite, and halite, but also oil with a high content of sodium chloride and potassium-magnesium salts.

During the operation of the mining and chemical enterprise, more than 25.5 million tons of "tailings" – liquid waste from the flotation beneficiation of ores – were accumulated, of which 4.2 million tons were in the liquid phase. "Tailings" are fairly stable finely dispersed suspensions. They accumulate and are stored almost indefinitely in tailings storage, which have become a constant threat to environmental disasters. The first emergency situation occurred in 1983 when after the flooding of one of the mines at the enterprise, underground voids were blamed. Then, on September 14, 1983, after a heavy rain, the earth dam of tailings storage No. 2 between pickets 7 and 8 broke through. A huge mass of highly concentrated brine and solid waste (silt) flowed into the basin of the Solonytsa River, and from it – into the Tysmenytsa River and further into the Dniester River and the Black Sea. The total mass of the release was more than 5 million tons of brines, the salt content of which reached 335 kg/m^3 . It was a mudflow with powerful hydraulic pressure. A huge mass of salt waste polluted the entire surrounding area (rivers, gardens, fields, forests), which harmed the flora and fauna of the area, as well as the hydrobionts of the Solonytsia, Tysmenytsia, Dniester rivers, and the Black Sea. The accident highlighted all the shortcomings of the technologies for storing industrial waste from the production of potash fertilizers and arranging the tailings storage facility.

As a result of the unauthorized discharge of brines from the tailings storage facility of Stebnyk MCE "Polymineral", which was carried out on July 26-30, 2008, water was polluted due to the ingress of 16,700 m^3 of dissolved brines into the hydrographic network of the Solonytsia-Tysmenytsia-Dniester rivers. The content of pollutants in wastewater exceeded the permissible standards of sulfates – by 25 times, chlorides – by 6 times, mineralization - by 18.5 times [Regional report]. The authors [Revega, 2006; Petrochenko and Petrochenko, 2022; Ivanov, 2018] established that the soluble parts of salt rocks contain trace elements – Bromine, Iodine, Manganese, Boron, Strontium, Barium.

The work [Carcavilla, et al., 2009; Ivanov, 2018] analyzed the ecological problems of restoration of post-mining geosystems in the areas of extraction and beneficiation of potash salts of Transcarpathia, suggested reviewing some incorrect project decisions regarding the conservation of Stebnyk Mining and Chemical Enterprise. The authors [Mokryi et al., 2018] developed the concept of environmental safety of the hazardous waste management system of Stebnyk tailings. The block model of the environmental safety monitoring system is substantiated. It is proposed to develop an ecologically and economically acceptable strategy of hazardous waste management on the basis of effective control of the material balance of brines and the creation of a specialized enterprise with technological complexes for the processing of ore and accumulated brines of Stebnyk tailings storage. The infrastructural and investment strategy for sustainable development of Stebnyk MID was developed by the authors [Mokryi et al., 2018].

The works [Wang et al., 2021; Rokochinskiy et al., 2020; Dyakiv et al., 2015; Carcavilla et al., 2009; Alexandrowicz, 2006; Bidira et al. 2022; Pohrebennyk and Dzhumelia, 2020; Wang et al., 2022; Ozbay et al., 2021; Zhyrnov et al. 2021] describes the algorithm for leaching, karstification, and self-isolation of easily soluble salts from near-surface salt-clay deposits of the sides and base of the tailings storage. The authors of [Lee et al., 2017; Rokochinskiy et al., 2020; Kumari and Maiti, 2019; Fazekašová D. et al., 2021; Černoch and Košťál, 2019; Vergara et al., 2022; Kosichenko and Baev, 2020; Dzhumelia and Pohrebennyk, 2021] started work on the restoration of the biotic cover of the territories adjacent to Stebnyk tailings storage. The dynamics of edaphic conditions studied in the considered works should be taken into account when designing reclamation works and phytomelioration of Stebnyk man-caused relief. The authors of [Tsaitler et al., 2009] substantiated the need to develop a reclamation and phytomelioration project for Stebnyk tailings storage using cultures of mixed composition. Biogroups were created in devastated areas with the mycorrhized planting material of common oak and red oak. This will ensure the endo-ecogenetic successional stage of phytoremediation of Stebnyk tailings storage.

According to information sources, in recent years, an emergency environmental situation has arisen at Stebnyk MID, which resulted in the loss of an operating mine, a complete emergency shutdown of the salt mining enterprise, degradation of the landscape, the emergence of a destabilized terrain, and the development of huge karst sinkholes even outside the mining diversion, and the breach of the tailings storage. The tailings storage constantly pollutes the basins of the Solonytsia, Tysmenytsia, and Dniester Rivers with brine, the excess of which, more than 1 million m^3/year, is formed as a result of precipitation exceeding evaporation. There are also direct economic losses: about 1 million hryvnias is spent annually on the supervision and maintenance of the tailings storage facility. The ecological problems of Stebnyk tailings storage facility attract the attention of the public and have been repeatedly covered in the mass media, as they have acquired nationwide and international significance due to their scale and socio-economic consequences.

The basis for solving the environmental problem caused by Stebnyk tailings storage and determining the directions for its implementation can only be the scientific and technological justification of the hydrotechnical reclamation of the man-made landscape through the creation of Stebnyk Hydropark.

Purpose – scientific and technical substantiation of the hydrotechnical reclamation of the tailings storage through the creation of Stebnyk hydropark.

Task – development of pre-project proposals for the creation of a hydrotechnical network for the interception of surface water from the catchment area located above and the removal of atmospheric precipitation, in order to prevent an emergency situation caused by a possible rapid rise in the water level in the tailings storage and a breach of the dam.

Object of research – hydrochemical and hydrophysical processes of the formation of the level of brines in Stebnyk tailings storage, which exceeds the permissible norm by several times and their level is rapidly increasing.

Subject of research – structural and technological solutions for the design of direct distribution channels, and water discharge structures, to reduce the hydrodynamic pressure and prevent the breach of the Stebnyk tailings dam and the flow of brine into the Dniester river network.

MATERIALS AND METHODS

Research methods are based on a systematic, scientifically based analysis of theoretical studies, generalization and systematization of experimental data. To identify the tailings storage, the technology of landscape spatio-temporal forecasting of exogenous geological processes and filtration phenomena of brine penetration through the thickness of the dam was applied. The inventory of the hydrodynamic state of the tailings storage facility is based on the accounting of the influence of natural and anthropogenic factors on the hydrochemical and hydrophysical parameters of the dynamics of brine filling up to a critical level. The inventory of the tailings storage facility was carried out on the basis of visual observations and inspection of the object and analytical works – data analysis of documentation, interviews of personnel, using European methods [Ivanov and Kovalchuk, 2020; Vykhryst et al., 2018].

The design of the hydro-technical system "tailing storage – direct distribution and outlet channels" is based on a mathematical model of the water balance in conditions of continuous replenishment of ground and surface water and an increase in their level. To visualize the proposed technical solutions for the hydro-technical reclamation of the tailings storage, geo-information technologies, software complexes, and tools for analyzing the proximity of geospatial objects are used.

RESULTS AND DISCUSSION

Based on the results of identification and inventory studies, ecological monitoring of the area of influence of Stebnyk tailings storage, it was established that the main cause of its harmful impact on the environment is the inefficient technology of processing polymineral ores, which led to the formation of a huge amount of waste, which became the cause of an ecological disaster. The tailings storage is currently an extremely powerful, if not the largest, source of pollution (salinization) of the aquifer, surface watercourses, and soil cover in the studied area. Improper operation and the lack of an effective system for collecting and draining atmospheric water became the main reason for the current crisis state of the facility.

When using the accepted field development technology, the liquid waste was pulp from clay material, undissolved polyhalite, and halite, and brine with a high content of NaCl and potassium-magnesium salts. In the tailings storage, on the one hand, precipitation of the solid phase – clay and undissolved salt minerals – and on the other hand, crystallization and precipitation of halite in the lower, highly mineralized part of the water column. The volume of waste was 900 m^3 per day and, accordingly, 328 thousand m^3 per year. The salt content in tailings brine increases with depth from 157.55 g/l on the surface of the salt pool to 436.98 g/l in its bottom part [Bilonizhka and Dyakiv, 2009]. The characteristics of brine and its chemical composition are given in Table 1.

The tailings storage facility consists of two sections with a total area of about 125 hectares (Fig. 1). The area of the first section, which contains the solid phase of enrichment waste, is 69 hectares. The second section is filled with brine and divided by a bridge into two sections – the southern section, with an area of 28.9 hectares, and the northern section, with an area of 26.9 hectares.

According to the data of PJSC Stebnyk Mining and Chemical Enterprise "Polymineral", the tailings storage facility is currently filled to a critical level, which increases the risk of a dam breach and the flow of brine into the Dniester river network. The level of brines in the tailings storage facility is recorded at the mark: section No. 1 – 310.64 m (permissible 312 m); section No. 2 – 303.38 m (allowable 304 m). The level of brine in section No. 2 is approaching the absolute mark of 304 m (maximum permissible), which creates a threat of overflow through the protective dam, or a threat of a breach of the dam and damage to the protective hydrotechnical structure. The problem of overfilling the capacity of the tailings storage facility by the enterprise was previously proposed

Table 1. Salt composition of brine from the Stebnyk tailings storage facility, g/l, section No. 2, southern section [Bilonizhka and Dyakiv, 2009]

Depth, m	$Ca(HCO_3)_2$	$CaSO_4$	$MgSO_4$	$MgCl_2(Na_2SO_4)$	KCl	NaCl	The amount of salts	Content of K-Mg salts, %
0.1	0.16	0.68	27.14	11.91	24.68	92.98	157.55	40.45
0.5	0.09	0.75	39.23	1.21	24.67	121.97	187.92	34.65
1.0	0.12	0.71	42.12	4.58	26.42	135.56	209.51	34.91
1.5	0.19	0.68	44.99	9.09	29.55	124.83	208.79	40.05
2.0	0.16	0.68	45.00	4.54	29.66	129.83	209.87	37.74
2.5	0.25	0.61	65.06	(20.10)	36.23	142.87	265.12	45.79
3.0	0.32	0.54	107.99	(16.59)	55.39	191.32	372.15	48.36
3.5	0.27	0.61	119.13	3.63	63.30	203.02	389.96	47.72
4.0	0.23	0.61	122.00	10.46	67.24	210.59	411.13	48.58
4.5	0.24	0.61	119.13	9.33	65.23	202.34	396.87	48.80
5.0	0.19	0.64	125.37	6.66	67.25	204.02	404.13	49.31
6.0	0.23	0.61	126.26	8.23	67.25	202.14	404.72	49.85
9.0	0.27	0.58	122.30	(46.74)	69.04	198.00	436.98	54.49

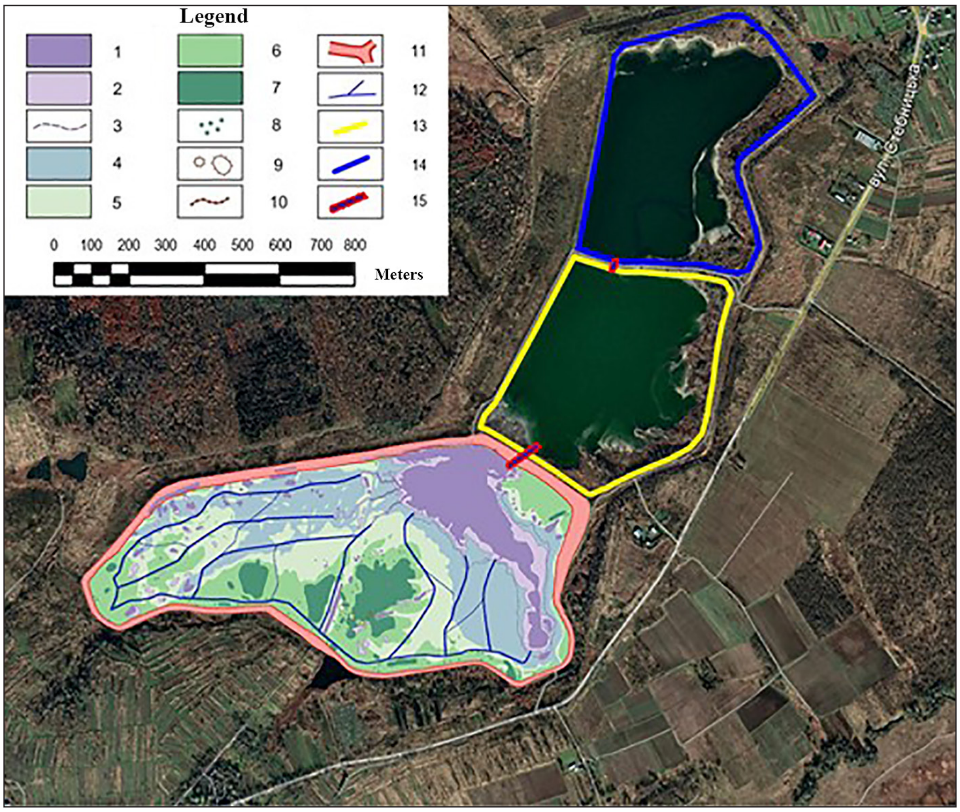

Figure 1. Ecological and cartographic model of the hydro-technical network of the projected Stebnyk hydropark: 1 – saline reservoirs of medium depth; 2 – shallow saline reservoirs; 3 – the boundary of the reservoir during periods of intense rainfall; 4 – flat strongly salty surfaces, almost without signs of vegetation; 5 – flat, slightly raised saline surfaces of maps with a meadow-swamp stage; 6 – flat raised slightly saline map surfaces with a shrub-grass stage; 7 – flat raised low-salt map surfaces with a tree-shrub stage; 8 – individual trees; 9 – mounds; 10 – steep-walled pits at the site of drained reservoirs; 11 – steep and flat surfaces of the upper parts of dams according to [National standard] section No.1, which contains the solid phase of enrichment waste, 12 – the proposed network of hydraulic channels; 13 – border of the southern part of section No. 2; 14 – the border of the northern part of section No. 2; 15 – siphon pipelines with regulating valves and chambers with flow meters for supplying brines from the northern to the southern section of section No. 2.

to be solved by different authors in different ways. The first is the dosed temporary discharge of brines into the Dniester river water network during the flood period, which is absolutely unacceptable, taking into account the high mineralization and toxicity of the brines and the low water level of the water network. The second is the increasing the height of the dam of the protective hydro-technical structure, which is also unacceptable because the mechanical stability of the dam is broken due to the active penetration of brines through the thickness of the dam. The third is the pumping of brines from the tailings reservoir into the developed karst voids, which is also unacceptable, as it leads to the activation of karst collapse phenomena in the adjacent territories. The hydrogeological and engineering-geological conditions of operation of the Stebnyk tailings storage facility are complicated. Therefore, it is necessary to develop and implement methods, concepts, and technical solutions that will be aimed at preventing the level of brines in the tailings storage from exceeding and the occurrence of negative consequences for the environment, the population, causing material damage.

In order to prevent an emergency situation due to a possible sharp rise in the water level in section No. 2 of the tailings storage facility, it is necessary to urgently carry out hydro-technical measures to organize the interception of surface water from the catchment area located above and the removal of atmospheric precipitation falling on the area of the tailings storage facility. To ensure the environmental safety of section No. 2, hydro-technical reclamation of the tailings storage facility through the creation of Stebnyk hydropark, the development, and implementation of the project of hydro-technical structures is expedient. The concept of the implementation of the hydro-technical reclamation project of Stebnyk tailings storage facility is presented in Figure 2.

The proposed technical solutions for the hydro-technical reclamation of the tailings storage facility include proposals for designing a network of direct distribution and outlet channels on the territory of the already dry section No. 1, for the unloading of section No. 2 (Fig. 1). Clarified water from section No. 2 should be diverted to the channels by spillways, which can be made as horizontal bypass pipes in the body of the internal dam. The drainage algorithm

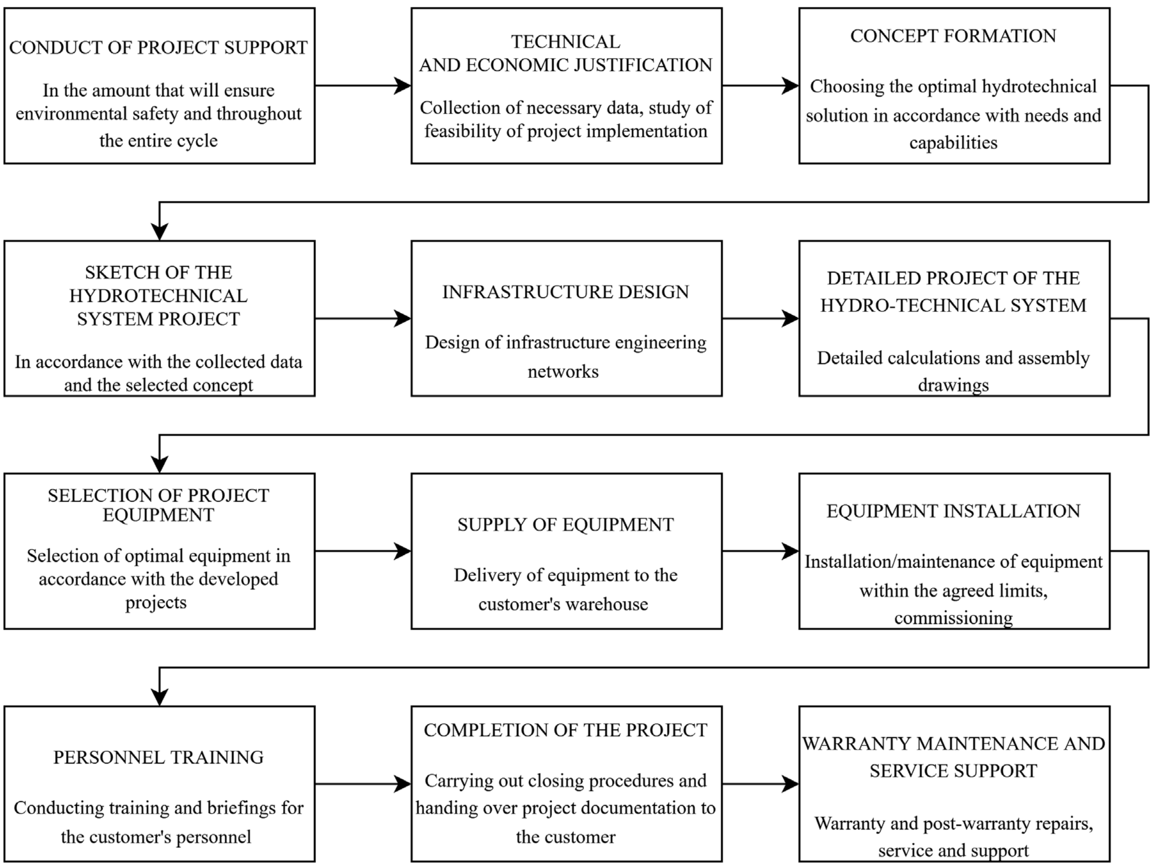

Figure 2. Diagram of the implementation process of the hydro-technical reclamation project of Stebnyk tailings storage facility

includes a gradual lowering of the brine level first from the southern section, followed by a subsequent lowering of the level in the northern section. Existing siphon pipelines with regulating valves and chambers with virgin flow meters are used to supply brine from the northern to the southern section No. 2. Preference should be given to structures that allow adjustment of the spillway threshold mark. The throughput capacity of spillways must ensure the removal of a dangerous volume of clarified water from the tailings storage facility. Drainage structures of the tailings storage facility must be designed in accordance with SNiP 2.04.02, SNiP 2.04.03, SNiP 2.06.05, DBN B.1.1-25, DBN A.2.2-1.

Structural and technological decisions on the design of direct distribution channels and water discharge facilities should be made taking into account engineering-geological, hydrogeological, topographic, and seismic conditions. Consideration the relief of the area, the transport length, the width, and depth of the channels, and the soils of the base of the projected water network, with the determination of the schemes of transportation of clarified water, will ensure an ecologically safe hydrodynamic state of the system "tailing storage – direct distribution and outlet channels".

When designing the hydro-technical network of structures made of materials whose characteristics can change significantly over time, as well as under the influence of climatic and other factors, measures must be taken to prevent the development of destructive processes in structures and foundations. The material used for the construction of direct distribution and outlet channels, and water discharge structures must be strong, durable, and corrosion-resistant in relation to clarified water from the tailings storage facility. It is necessary to take into account the climatic conditions when choosing the construction of channels.

The proposed hydro-technical system consists of a tailings storage facility and direct distribution channels, a discharge facility, which are determined based on the results of calculating the water balance of the projected network (Fig. 1). The annual water balance of the "tailings storage facility – direct distribution and outlet channels" system must be developed taking into account the characteristic seasons (summer, winter, spring) for an extended period of operation, before the implementation of technologies for the use of waste stored in the tailings storage facility.

Clarified water must be diverted from the tailings storage facility using direct channels, and overflows, which will also accumulate surface runoff, the design of which is carried out in accordance with DBN B.2.4-1, SNiP 2.01.14, SNiP 2.04.03, DBN B.1.1-25. The estimated primary maximum water consumption should be calculated taken into account the annual probability of excess (security), which is handled in accordance with the consequences class (responsibility) of the accumulators [Rokochinskiy et al., 2020; National standard; Kowalewski and Śpiewanowski, 2020]. For consequences class CC3 (significant consequences) – 0.1%, for subclass CC2-1 (medium consequences) – 1%, for subclass CC2-2 (medium consequences) – 3%, for class CC1 (minor consequences) – 5% , verification maximum costs – respectively 0.01%, 0.1%, 0.5%, 1%. According to the local conditions of the relief, the surface runoff of water must be taken into account in the water balance of the "tailings storage – distributional diversion channels" system. When designing water drainage structures, direct distribution and outlet channels, the estimated annual probability of exceeding the maximum water consumption is assumed to be 10%.

The water balance equation (for a certain time Δt) of the designed hydro-technical system, under conditions of continuous replenishment of groundwater and an increase in its level, has the form:

$$\mu\Delta H = J_n + f_k + N - (v_t + v_n - n_1) + + (v' - v'_0) + (C_1 - C_0) + Q_1 - Q_2, \quad (1)$$

where: J_n – the amount of water that is diverted from tailings storage No. 2 to unload the dam;
f_k – the amount of water that enters the network of direct distribution and outlet channels through filtration;
N – the amount of precipitation falling on the soil surface of tailings storage facility No. 1;
v_t – the amount of moisture consumed by plants (transpiration);
v_n – the amount of moisture evaporated from the soil;
n_1 – the amount of moisture that comes from the surface of groundwater when it is shallow;
v' – the amount of excess surface water that enters the hydro-technical system and is retained in it due to irregular water intake, flooding during floods, the inflow of stormwater and melt water, etc.;
v'_0 – runoff of excess surface water not absorbed by the soil beyond the boundaries of the reclaimed massif and discharge of water beyond the boundaries of the system;

C_1 – moisture reserve in the soil of the reclaimed massif above the groundwater level at the beginning of the considered time interval Δt;
C_2 – moisture reserve in the same layer of the soil, which can be kept in it without flowing into the groundwater and corresponding to the maximum field moisture capacity of the soil;
Q_1 – underground inflow within the boundary of this area of groundwater, including the possibility due to the inflow of filtration waters from nearby flooded;
Q_2 – outflow of groundwater beyond the boundaries of the reclaimed massif in the water intake, or towards neighboring lands by lateral spreading.

The change in the groundwater level ΔH (mm) is taken as the average for this massif. The average is also the lack of saturation to full moisture content or water yield of soils μ [Bochever et al., 1965].

The proposed hydro-technical system is a significant addition to the dust suppression system in section No. 1 of the tailings facility and takes into account local climatic conditions. Reducing dust emission is a means of protection against tailings pollution of atmospheric air, plants, soil, and surface water. Dust suppression technologies are provided at tailings storage facilities, since air pollution may occur with a wind speed of more than 5 m/s exceeding the MPC of pollutants outside the sanitary protection zone (SPZ). As practice shows, environmental problems associated with environmental pollution by eco-pollutants from tailings ponds arise both during the operation of enterprises and after their decommissioning [Trakhtengerts. 2015; Alexandrowicz, 2006]. Harmful substances enter the environment from tailings due to dust formation, deflation, and migration into surface waters and underground aquifers. Dust formation and deflation make the main contribution (80%) to environmental pollution from tailings. Deflation leads to the blowing of particles from the surface layer, which can be transported to a considerable distance and settle in places where the lifting force of the wind is weakened.

The dimensions of the zone of secondary pollution can reach 1 km or more from the tailings storage. Over the years, internal dams build-up, which affects the distance of dust from their surface. This leads to the need to increase the size of the sanitary protection zone of the tailings storage facility, the possibility of deterioration of the sanitary and hygienic situation. The probability of an ecologically dangerous situation is increasing not only at the location of the tailings storage facility. Due to the increase in the level of the content of heavy metals in vegetation, the migration of eco-pollutants along biological chains occurs, as well as the suppression of the vital activity of most plants and animals. It is known that when the amount of dust is removed by more than 58 kg per month on 1 ha, the effect of suppressing the vital activity of most plants and animals in the area is observed. Therefore, it is necessary to constantly monitor the state of the sludge fields, ensure the hydrological balance of the tailings storage facility, ensure protection against wind deflation of environmental pollutants from the surface of the tailings storage facility.

To effectively control the dust generation of section No. 1, it is necessary to maintain the minimum possible basin area for the entire period of operation. Wetting and fixation of the dust-emitting surface will be ensured by maintaining a constant water level on the surface of the designed hydraulic system of channels. The most effective technology for dust suppression is phytomelioration, implemented by creating a plant cover on the surface of the tailings storage. The recommended phytomelioration method of dust suppression is based on the results of studies of the vegetation cover of section No. 1 [Ivanov and Kovalchuk, 2020] and own experience of phytomelioration of man-made landscapes [Righi et al., 2020].

CONCLUSIONS

Stebnyk tailings storage facility is a complex, long-term hydraulic engineering facility that is not only under the influence of the natural environment, but also many social and economic factors (distribution of responsibility in emergency situations, departmental subordination, human factors). Management of a tailings storage is a dynamic, complex, and interconnected system that requires an integrated "state-business" approach to environmental protection from the destructive consequences of accidents throughout the entire life cycle of a tailings storage. For the possibility of further functioning of the tailings storage facility, it is necessary to put into operation an effective system of collection and removal of atmospheric precipitation. Since this is the main condition for the possibility of operating the tailings storage facility in the future.

The developed concept of hydro-technical reclamation of the tailings storage facility through the creation of the Stebnyk hydropark will make it possible to ensure: control over the level of brines and discharge of water from the tailings storage facility; absence of violations of the ecological balance and quality characteristics of water and water bodies; scientifically based values of pollutant concentrations and water quality indicators in the proposed hydro-technical network; compliance with sanitary and hygienic norms in the locations of water supply sources and water use; ecological safety of people's life and water ecosystems of the water network of the Dniester river basin; achieving and maintaining the appropriate ecological and chemical state of surface and underground water bodies. The proposed hydro-technical network will perform a significant dust-suppressing function, as it will reduce the area of dust emission from the dry surface of section #1 of the tailings storage.

The practical implementation of the developed project proposals will ensure an ecologically safe hydrodynamic state of the "tailings storage – direct distribution and outlet channels" system, which will eliminate the threat of brine overflow through the protective dam, or the threat of dam breach and brine flow into the Dniester river network.

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