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MINING ECOLOGY AND SUBSOIL MANAGEMENT

Flooding of Open Pit and Underground Mines in the Chelyabinsk Coal Field: Consequences, Problems and Solutions

L. S. Rybnikova[a]*, P. A. Rybnikov[a], and A. Yu. Smirnov[a]

[a]*Mining Institute, Ural Branch, Russian Academy of Sciences, Yekaterinburg, 620075 Russia*
**e-mail: luserib@mail.ru*

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Abstract—The authors examine the present-day hydrogeological situation and its post-mining phase forecast in the Chelyabinsk Coal Field. Geotechnical facilities in the areas of Krasnaya Gornyachka Mine and Kopeisk and Korkino Open Pit Mines are discussed. The problems to arise during flooding are identified. The hydrological forecasts and an action plan to prevent underflooding in the study areas are presented.

Keywords: Hydrogeological conditions, geoecological problems, water removing, drainage, flooding, underflooding, coal fields, landslide, leakage, water supply pipes.

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INTRODUCTION

The post-mining phase necessitates the search for new methods to manage the territories disturbed by mining [1–5]. The closure of facilities with a long mining history is the reason for the formation of a difficult environmental situation [6–9], which is determined by some factors.

First, the balance and structure of surface and groundwater flows change during the water removing, qualitative composition of the hydrosphere is formed with involvement of new agents [10, 11].

Second, flow charts with the roof caving are usually used in mining, which provokes the development of geomechanical processes, formation of caving zones and the Earth's subsidence [12, 13]. After the end of mine operation, the water removal is ceased and the cone of depression is filled gradually, which causes underflooding of the area and mine water discharge [14, 15]. The flooding of open pit mines is accompanied by landslides if pitwalls contain unstable rocks.

Frequently, residential and industrial buildings are historically located in close proximity to mines (sometimes even within the mining lease); therefore, hydrogeoecological problems of old industrial areas become very acute at the post-mining phase. At the same time, in many cases it is difficult to determine which factors—natural (features of the geological structure, geomorphological conditions, water content of the period) or man-made (cessation of water removal) lead to underflooding of the territory, especially in the areas at a considerable distance from post-mining objects.

This paper aims at analyzing the ecological and hydrogeological situation within the Chelyabinsk Coal Field after mining open pits and underground mines upon cessation of water removal, as well as justifying the measures to reduce the negative environmental impact.

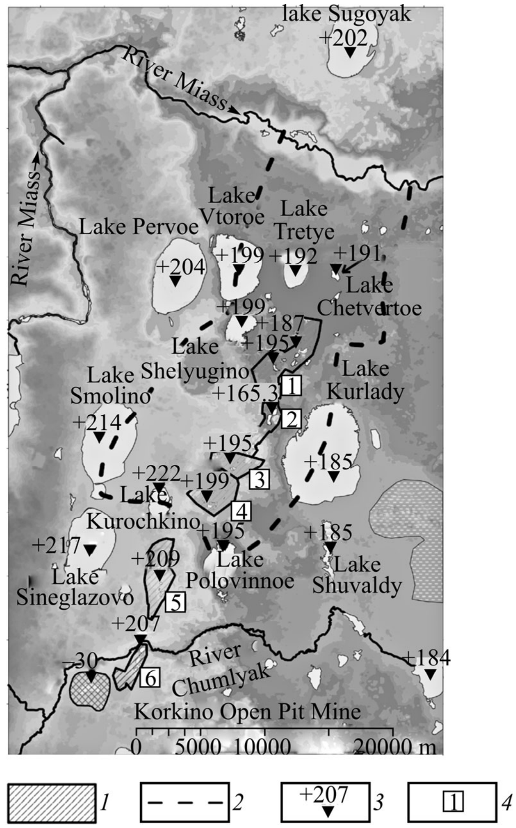

Fig. 1. Layout of mine fields and hydrographic network of the area: *1*—mining lease; *2*—boundary of water catchment area of mines in the northern part of the Chelyabinsk Coal Field (geofiltration model boundary); *3*—water mark in water bodies; *4*—mine fields (1—Krasnaya Gornyachka Mine; 2—Tsentralnaya Mine; 3—Kapitalnaya Mine; 4—Komsomolskaya Mine; 5—Oktyabrskaya Mine; 6—Kalachvskaya Mine).

1. CHELYABINSK LIGNITE FIELD

The Chelyabinsk Lignite Basin is located on the eastern slope of the Urals, covering an area of 1300 km^2. The maximum width of the coal-bearing structure is 14 km, the depth is up to 4 km [16].

The area belongs to the Irtysh Watershed District. A feature of hydrography is an extremely rare river network and abundance of drainless lake basins ranging from fractions of a hectare to dozens of square kilometers (Fig. 1).

The river Miass flows along the northern edge of the field (average annual discharge 18 m^3/s). The rest of the rivers have intermittent flow and are lost when they flow into swampy lake basins. The relief of the area is a slightly hilly forest-steppe plain that borders the peneplain of the eastern slope of the Urals in the west and gradually descends in the direction of regional drains, it has pit-and-mount basin character.

Until 2006, the field was mined by Chelyabinskugol. After its liquidation, assets of the enterprise were purchased by Chelyabinsk Coal Company. At the end of the 20th century, coal reserves amounted to 523 Mt.

2. HYDROLOGICAL FORECAST AND UNDERFLOODING PREVENTION

Water removal from Krasnaya Gornyachka Mine was stopped in July 2003. In 2004–2008, in accordance with the reclamation project, a system of drainage ditches was built to prevent underflooding. The water flows from the flooded areas through this system into the water body of open-pit mine layer VIII-2.3 (lowest part of the mining lease) and from there, it is pumped to lake Tretye (Fig. 2).

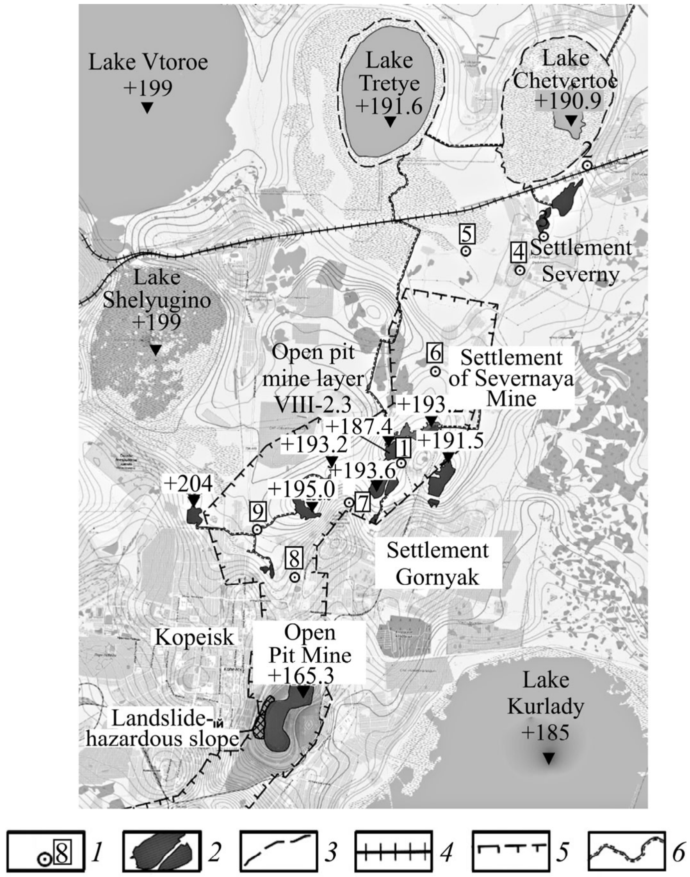

Fig. 2. Situation diagram and arrangement of geotechnical facilities in the area of Krasnaya Gornyachka Mine: *1*—number of observation borehole; *2*—flooded open pit mines and sinkholes; *3*—outline of lakes as of 2003.; *4*—railway; *5*—mining lease boundary; *6*—drainage ditches.

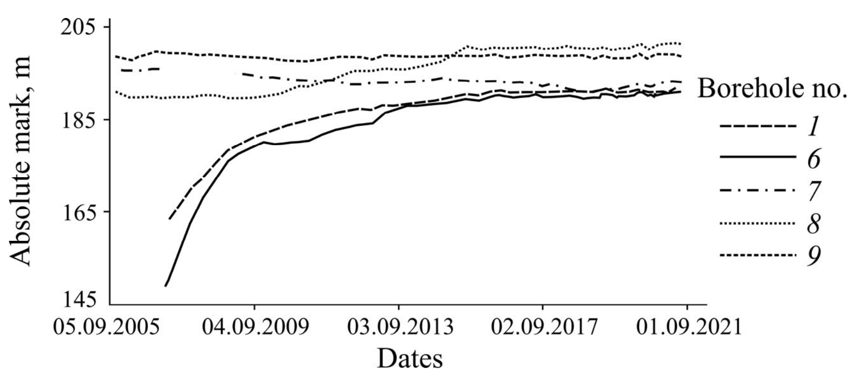

Fig. 3. Change in water levels in the boreholes of central (*1*, *6*) and southern (*7*, *8*, *9*) parts of Krasnaya Gornyachka Mine field (dates format dd.dd.yy).

In the central and southern sections of the mining lease, the process of filling the depression cone is almost completed (Fig. 3). The occurrence depth of groundwater varies from 1.7 to 12.7 m The steady value of the water level in flooded sinkholes and open pit mines is 192.2–195.1 m.

During the period after the water removal cessation, the number and area of water-logged spots that formed in natural topographic lows did not change. To prevent underflooding of settlements during the snowmelting and heavy precipitation, it is necessary to pump out melt and rain water from lower areas.

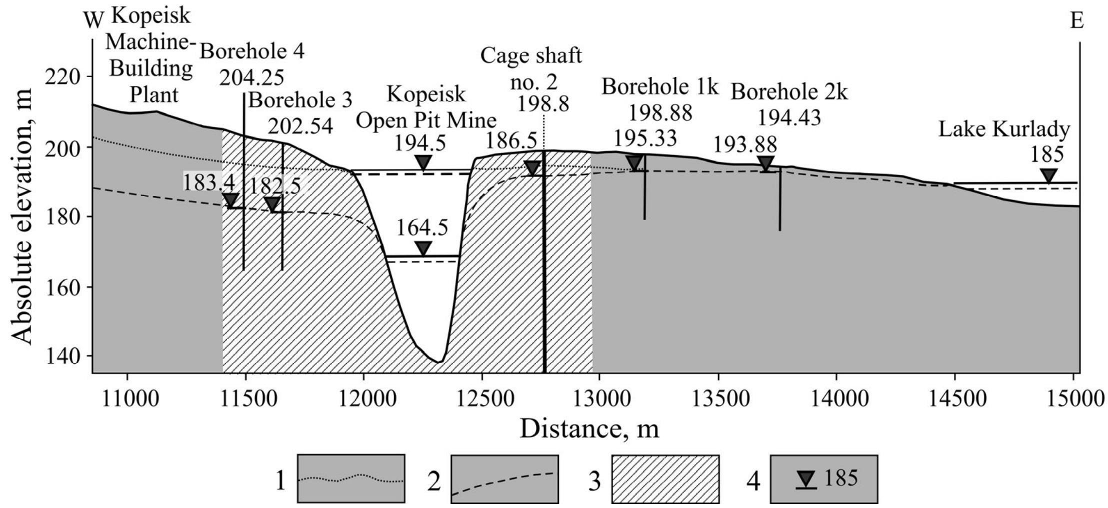

Fig. 4. Schematic sectional drawing along the line Kopeisk Machine-Building Plant–Kopeisk Open Pit Mine–Lake Kurlady: *1*—predicted groundwater level; *2*—actual groundwater level; *3*—mining lease of Tsentralnaya Mine; *4*—absolute water level.

Kopeisk Open Pit Mine has been flooded since 2004, dewatering from Tsentralnaya Mine was stopped in 2006. On the western side of the open pit mine, there is an industrial site of Kopeisk Machine-Building Plant and a residential area of the city of Kopeisk (Fig. 4). Several landslides occurred in this area, the largest one in 2015, after which the day surface near the territory of Kopeisk Machine-Building Plant sank by 15 m. In spring of 2019, the slope of the landslide area was strengthened by earth filling. Currently, the Ural branch of VNIMI carries out geomechanical monitoring of this territory, there are no movements of ground benchmarks.

The rise in the water level in the open pit mine is much slower than in the side section and in the shaft of Tsentralnaya Mine due to the constant increase in water table area in the emerging water body and due to evaporation, the volume of which exceeds precipitation in the water balance.

A geofiltration model was developed to estimate the rate of flooding of Kopeisk Open Pit Mine. The model boundaries were determined in accordance with the position of natural watercourses and water bodies: lake Smolino in the west, lake Kurlady in the east, river Miass in the north. The number of blocks was 700 along the X-axis, 500 along the Y-axis, block size—50×50 m. The model area was 440 km^2. Numerical filtration modeling was carried out in Processing ModFlow 8 software environment [17].

The upper layer of the two-layer model is limited to sediments (Eocene-Upper Cretaceous aquifer), the lower layer—to Triassic-Jurassic deposits. The thickness of the first layer is 50 m, the second one—100 m. Permeability coefficients vary for the upper layer from 0.2 to 1 m/day; for the lower layer—from 0.05 to 0.15 m/day. A digital relief model was used to correctly set the hypsometry of aquifer surface. The rate of underground water flow was accepted 1.25 l/s per square kilometer [18].

The model was calibrated according to the mining period at the time of stable mine water inflows (stationary solution). The period from 2010 to 2021 was reproduced on the model to calibrate the capacitive parameters that determine the unsteady character of open pit mine flooding.

Forecasting tasks were aimed at estimating the flooding rate of Kopeisk Open Pit Mine in the implementation of three scenarios: without any activities; when carrying out measures to strengthen the western side of the open pit mine (earth filling half of the open pit mine); complete earth filling of the mine (Fig. 5a). Three scenarios were considered to determine the influence of the water content (assuming that half of the open-pit mine was filled): 10 years of increased water content; normal water content during the whole flooding period; 10 years of low water content (Fig. 5b).

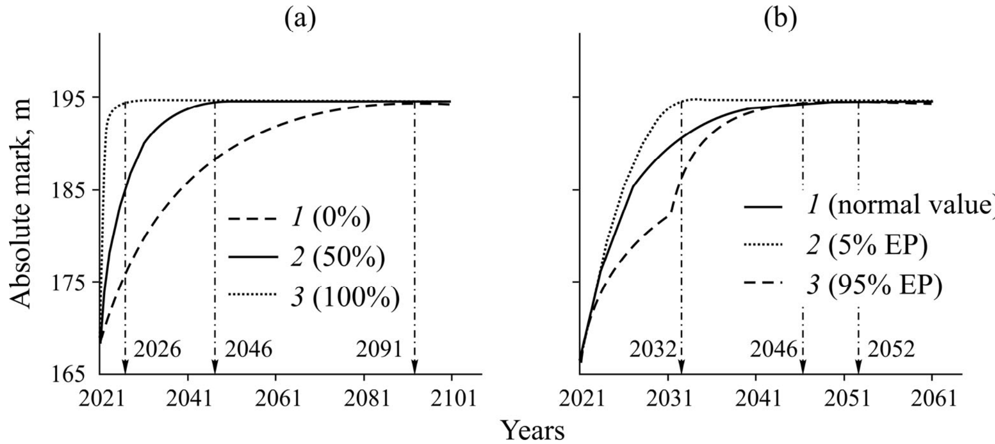

Fig. 5. Forecast of flooding of Kopeisk Open Pit Mine for different scenarios, taking into account: (a) change in filling degree of mined-out space (*1*—without filling; *2*—filling 50%; *3*—complete filling 100%); (b) change in water content (*1*—normal water content; *2*—high-water period 5% of exceedance probability (EP) for 10 years; *3*—low-water period 95% of EP for 10 years). The number at the arrow indicates the year when the limit mark is reached.

The maximum flooding is the same for all scenarios, it is + 194.5 m. The time of flooding counted from 2021 will be 70 years without taking any measures and 5 years with complete earth filling of the open pit mine.

When carrying out activities to strengthen the western side of the open pit mine (50% filling of the mined-out space), the water level in Kopeisk Open Pit Mine + 194.5 m will be reached in 25 years with a probability of 70%. If there is a combination of unfavorable factors (several years with high water content), this mark will be reached in 6 years. If there is a period of years with very low water content (such as 2021), flooding will continue for 31 years.

To exclude underflooding of surface objects located at absolute marks of 193.0–195.0 m on the shore of lake Kurlady, it is necessary to maintain the water level in the flooded open pit mine no higher than the absolute mark of + 190.0 m. About 1 Mm^3 of water per year must be pumped out by implementing one of two measures: introduce a floating pumping station with a capacity of 220 m^3/h during the warm season; involve a submersible water removing system with a capacity of 130 m^3/h (flow rate of water removal from the open pit and underground mine is 266 m^3/h).

Provided that leakages from water supply pipes are eliminated, there is no threat of underflooding to the territory of machine-building plant at present and in the future.

The territory of the town of Kopeisk is located at higher elevations; therefore, underflooding of the town has no connection with flooding of the open pit mine, but is caused by leakages from water supply pipes. The total volume of water supply in Kopeisk urban settlement is 15.2 Mm^3/year. Network losses reach 5.8 Mm^3 (38%), which exceeds the total water removal from Krasnaya Gornyachka and Tsentralnaya mines. A large amount of water loss is caused by dilapidated water supply networks, the wear of which is more than 80% [19].

Korkino Open Pit Mine is the deepest in Eurasia, its depth is 493 m, its surface length is more than 3 km, and its width is more than 2.5 km. The operation of this mine was stopped in 2017. In addition to open pit mining, underground operations were also carried out at Korkino field. In 2005, commercial coal reserves to a depth of 630 m amounted to 33 Mt, which could provide the open pit with work for 23 years. For this, it was necessary to space the sides of the open pit mine, relocate the inhabitants, transfer the industrial site and the plant. However, movement of the open pit sides became more active (first major landslide on the northwestern side occurred in 1945), the shafts of

Korkino Mine were recognized as emergency, buildings began to collapse. It was decided to gradually close the mine and relocate part of the inhabitants from settlement Roza and town of Korkino. Endogenous fires were regularly recorded in open pit sides, which affected not only the ecology of the town of Korkino. The whole region, including the city of Chelyabinsk, suffered from smog and a pungent odor during tailwinds.

For the reclamation of Korkino Open Pit Mine, Russian Copper Company (RCC) developed a project that provides for filling the mine working and eliminating spontaneous combustion zones with backfill material based on the tailings from Tominsky MPP (pipeline with a length of about 14 km) [20]. Over 5 years, 556 km^2 of spontaneous combustion zones were localized. As a result, emissions decreased by 26 times: from 950 t in 2017 to 36 t in 2021.

According to the project, the mined-out area will be completely filled with backfilling material by 2045. By this time, at a water level of + 155 m, the open pit will contain 479 Mm^3 of backfilling mixture and 212 Mm^3 of water. The maximum level of flooding at Korkino Open Pit Mine will be no more than + 210 m (for comparison, see flooded Kalachevskaya Mine located to the north-west), with groundwater inflows of about 200 m^3/h, the flooding time of the open pit from the mark + 155 m (water surface area 4.7 km^2) to the mark + 220 m (area 7.4 km^2) will be at least 200 years.

CONCLUSIONS

To prevent water-logging of the northern part of Kopeisk and settlements, a unique unparalleled water disposal system was built. Through a pumping station and a twenty-kilometer system of ditches and settling tanks, water that accumulates in mining-disturbed areas is pumped into river Miass. If the drainage system is properly maintained and water level in the lake of open pit layer VIII-2.3 is kept + 180 m in accordance with the project for closing down Krasnaya Gornyachka Mine, there is no risk of underflooding due to water removal cessation.

Kopeisk Open Pit Mine will be flooded up to the limit mark of + 194.5 m until 2091. To prevent underflooding of geotechnical facilities on the eastern side, it is advisable to maintain the water level in the flooded open pit not higher than the absolute mark of + 190 m. There is no underflooding threat to the territory of Kopeisk Machine-Building Plant provided that leakages are eliminated and there is no water discharge on the landslide slope The territory of the town of Kopeysk is underflooded by man-made leakages from water supply pipes.

Korkino Open Pit Mine is reclaimed by filling the mined-out space with backfilling material based on pipeline-delivered tailings from Tominsky MPP. The engineering solutions help to fundamentally improve the ecological situation; strengthen the landslide-hazardous slopes of the open pit and stop endogenous fires in its sides; dispose of mill tailings from Tominsky MPP. It is planned to complete the filling of the mined-out area with backfilling material by 2045 at a water level of + 155 m; however, final natural flooding to a mark of + 210 m will occur no earlier than 2250.

The duration and character of post-mining phase are determined by a combination of natural and induced factors: features of the geological structure, geomorphological and hydrometeorological conditions, as well as the flow chart and technology of mining. As a result, new hydrogeoecological conditions are formed, when technogenic water bodies arise due to depression cone filling, territories become underflooded and landslide processes develop. In addition, surface water bodies that existed for decades due to mine water removal are drying up, while the water quality in them is undergoing significant changes because of evaporative concentration. The duration of the post-mining phase can reach tens and even hundreds of years.

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