Post-closure water management in Chelyabinsk Coal Basin (Russia)

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Abstract

In the early 21st century, coal mining in the Chelyabinsk coal basin (Southern Urals, Russia) was terminated. Mining and associated dewatering occurred for over a century across the 1,300 km2 area of the basin.

This paper describes the development of the first regional groundwater flow model for the Chelyabinsk coal basin. Its objective was to assess the consequences of water table rebound and underground mine and open-pit flooding post mine closure. Climate change is accounted for in the model by considering changes in precipitation patterns.

Keywords: Coal deposits, Drainage, Hydrogeological conditions, Mines, Geo-ecological problems, Open-pits, Waterlogging, Landslide, Leakage, Water-carrying utilities.

Introduction

During 1993–1994 in Russia was started restructuring coal industry. This led to closure of 203 coal mining enterprises (188 underground and 15 open-pit mines). The negative consequences of mine liquidation and flooding in Russian coal basins vary depending on a combination of geological, geomorphological, hydrogeological and mining factors (Rybnikova 2020, Rybnikov 2020, Melchers 2015). Similar processes have been observed in other countries (Wolkersdorfer 2008).

The Chelyabinsk coal basin covers an area of 1,300 km^2 and located on the eastern slope of the Ural Mountains (Fig. 1). The landscape of the region presents a gently rolling forest-steppe plain, broken by hillocks and saucer-shaped hollows. In hydrographic terms, the region is characterized by an extremely sparse river network and an abundance of endorheic lake basins with areas ranging from fractions of a hectare to dozens of square kilometers. Rivers are represented by the Miass River in the northern part of the basin (average annual flow rate of 18 m3/s), and the Uvelka River in the southern part (11 m3/s). The other rivers are intermittent, disappearing into swampy lake basins. Over the past 20 years, precipitation has been between 281 mm/year (2021) and 588 mm/year (2014). Average precipitation has been 460 mm/year.

The Chelyabinsk coal basin deposits were discovered in 1832 and their commercial development was started in 1907. The cities of Kopeysk (150,000 people) and Korkino (35,000 people) grew on the basis of the mining settlements near the mines. Coal peak production was reached in the 1960s. Nowadays all opencasts and mines have ceased operation.

The geological structure of the Chelyabinsk coal basin represents as graben within Paleozoic rocks of the eastern slope of the Urals and is filled coal sediments lower Mesozoic ages.

During mining operations, the average annual water outflow rate from all mines and workings reached 2,363 m^3/hour. This water was discharged into three lakes, lake Kurlady, lake Tretye, and lake Kurochkino, and into the river Chumlyak, and the Ulamovo swamp.

The cessation of mine dewatering with the closure of the Kopeysk and Korkino opencast coal mines has resulted in groundwater table rebound with ecological and hydrogeological impacts such as the flooding of the opencast pits, infrastructure, and sinkholes.

Methods

There are three depression cones within the Chelyabinsk coal basin. They are located in the North (Kopeyskiy open pit, "Zentralnaya" shaft), at the center of coal basin (Korkinsky open pit), in the South (Emanzhelinsk). Total water inflow to the north depression cone was 6 times more compare to the central cone (1200 and 200 m3/hour, accordingly). Despite the fact that depth of the Korkinsky open pit is 500 meters an area of the central depression cone was smaller compare to the northern depression cone. During mine development river flow consumption of the Chymlyak river wasn't found and the center depression cone was outside of the river. At the same time in the northern depression cone the Miass river is draining groundwater flow. The flooding forecast for the Korkinsky mine was carried out in the reclamation project (Sokolovsky 2018).

For estimation of flooding rate of the Kopeysk open-pit mine groundwater flow model had been developed. The purposes of modeling were as follows: to predict maximum flood level in the Kopeyskiy open pit, to define the speed and duration of depression cone filling. Groundwater flow modeling was performed using the Processing ModFlow 8 software. The model boundaries were defined by watersheds according to the position of the natural streams and reservoirs for Lake Kurlady in the East, Lake Smolino in the West, and the Miass River in the North (Fig. 2). The total number of blocks was equaled 700 blocks along the X axis and 500 blocks along the Y axis. The block size was determined as 50 × 50 m. The model area was 440 km^2.

The groundwater flow model has two-layer stricture. The upper layer is associated

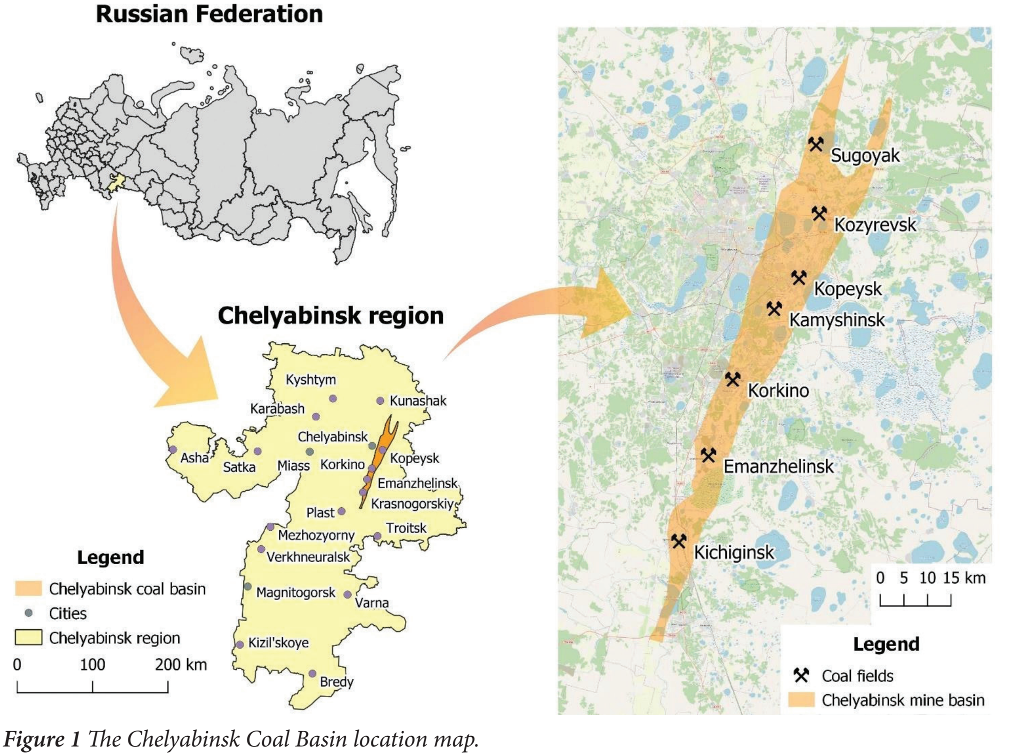

Figure 1 The Chelyabinsk Coal Basin location map.

with Eocene-Upper Cretaceous sediments (argillites), and the bottom one is confined to Triassic-Jurassic deposits (sandstones with interlayers of clays and gaizes). The first layer thickness was defined as 50 m and the second as 100 m. Hydraulic conductivities of the top layer vary from 0.2 to 1 m/day and from for the bottom layer 0.05 to 0.15 m/day, accordingly. The groundwater recharge modulus is taken to be 1.25 L/s per square kilometer. The model was calibrated based on the mining period with stable mine water inflows (steady-state solution). The model storage parameters for transient flow of open-pit flooding process were calibrated in the model by simulating the flooding period from 2010 to 2021. Forecasting for flooding rate of the Kopeysk open pit was aimed

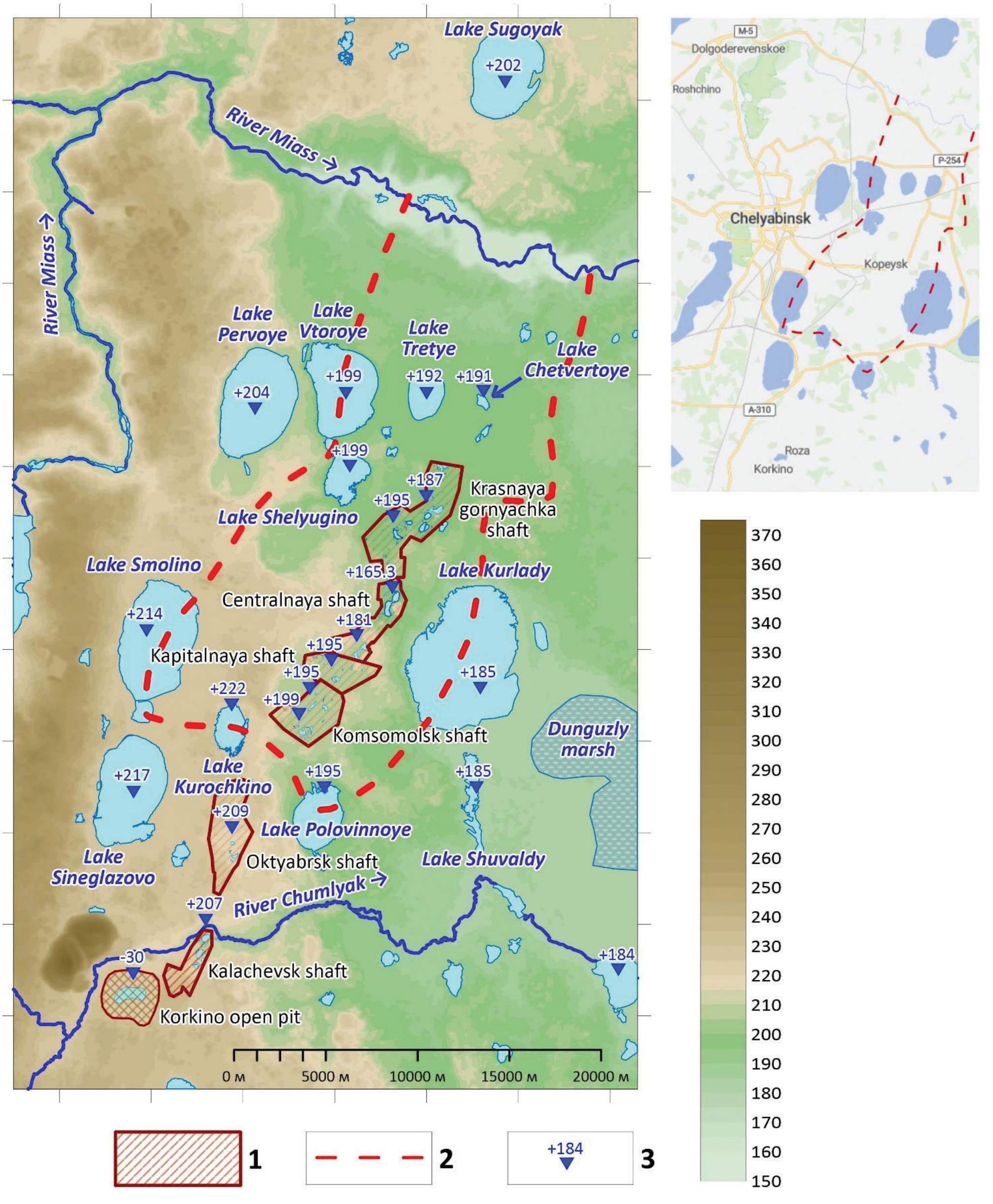

Figure 2 Hydrographic network of the region and minefield location map. 1 – mining allotment; 2 – mine catchment area boundary in the northern part of the Chelyabinsk Coal Basin (groundwater flow model boundary); 3 – reservoir water level mark.

under three scenarios: without taking any actions; for the open pit filled to half storage capacity (with stabilization of the open-pit's western side prone to sliding); and complete backfilling of the open pit. To determine the influence of the period's precipitation, we considered three scenarios (for half-filled open pit): 10 years of high precipitation; normal precipitation over the entire flooding period; 10 years of low precipitation. The maximum flooding value is the same for all scenarios at 194.5 m.

Results

Kopeysk open-pit mine, shaft "Tsentralnaya". The facilities of this opencast are located within the city's developments and industrial infrastructure. The flooding of the Kopeysk open-pit mine has been going on since 2004; drainage from the shaft "Tsentralnaya" was stopped in 2006. The western side of the open pit is occupied with an industrial plant. Several landslides have occurred here during the flooding. After the largest landslide in 2015, the daylight surface near the plant's territory subsided by 15 m. It was established that there had been leaks of hot water from the plant's cooling tower, discharged onto the terrain. This led to the flooding of the territory and waterlogging of the previously backfilled mass on the side slope, which provoked further landsliding. The slope of the landslide area was stabilized by backfilling in the spring of 2019. After the shutdown of the cooling tower, leakage ceased, and no movements of the ground reference marks have been recorded since then.

Based on the modeling results was shown that the open-pit flooding (starting from 2021) will make 70 years without organization any actions and will make 5 years with complete backfilling of the open pit (Fig. 1). Provided that any measures will be taken to stabilize the western slope of the open-pit the water mark will be reached at 194.5 m (in scenarios of 50% filling of the mined-out space) in 25 years with a probability of 70% (Rybnikova 2023). In case of combination of unfavorable factors (e.g., a series of years with high precipitation) the water mark will be reached in 6 years. If very low precipitation years will be repeated (such as 2021) the flooding will continue for 31 years.

External boundaries of the model are impermeable except the Miass river and the Kurlady lake where the groundwater flow is discharged. Incoming model balance terms are infiltration and leaks from water-carrying communications in city areas. Outcoming model balance terms are evapotranspiration, discharge into the Kurlady lake and the Miass river, filling the volume of the Kopeyskiy open pit. The groundwater flow is directed to the open pit during the flooding process. When the volume of the Kopeyskiy open pit will be filled, the groundwater flow will direct

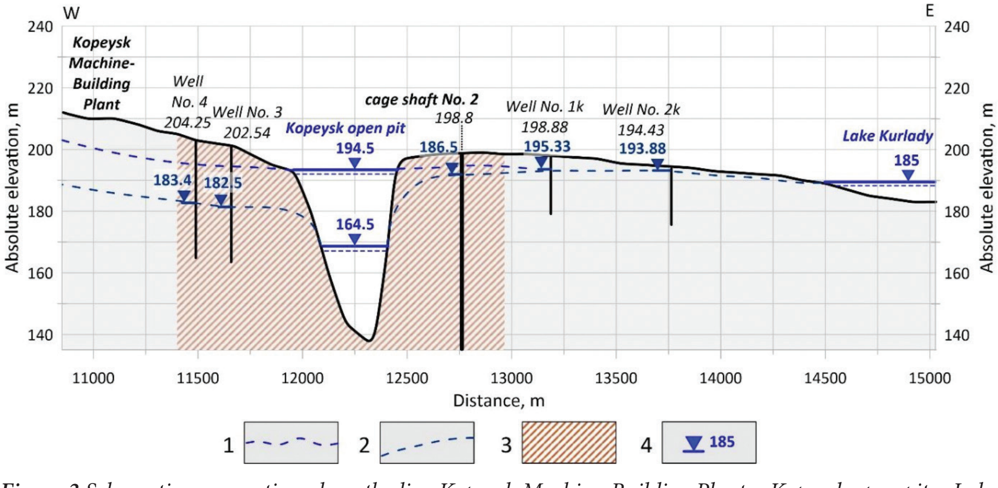

Figure 3 *Schematic cross section along the line Kopeysk Machine-Building Plant – Kopeysk open pit – Lake Kuraldy. 1 – current groundwater level; 2 – predicted groundwater level; 3 – mining allotment for the shaft Tsentralnaya; 4 – absolute water-level elevation.*

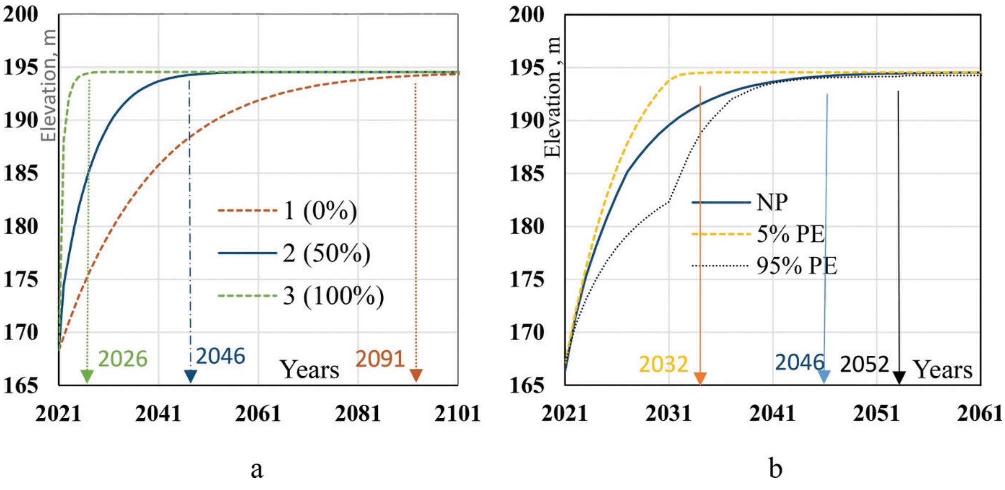

Figure 4 *Prediction of Kopeysk open pit flooding for different scenarios allowing for: a degree of pit backfilling (1—without backfilling, 2—with 50% backfilling, 3—with 100% backfilling); b variation in natural water recharge (1—normal period (NP), 2—water-rich period with 5% probability of excess for 10 years (5% PE), 3—water-short period with 95% probability of excess for 10 years (95% PE). The number at the arrow means the year of peak water mark.*

to the open pit, Kurlady lake and the Miass river. The local watershed between the lake and the open pit will be kept, groundwater flow from the open pit into the Kurlady lake won't be proceed.

The Korkino open-pit mine. The Korkino mine is the deepest opencast coal mine in Eurasia: its depth is 493 m, more than 3 km long on the surface, and 2.5 km wide. Over the period of operation for 70 years (since 1934), it produced 250 million tons of coal and excavated 1.5 billion tons of ground material. The excavation volume amounted to about 3 billion m^3. The mine ceased operation in 2017. In addition to open-pit production, the Korkino deposit was also worked by the underground method at the shaft Korkino. The first major landslide occurred in 1945 on the northwestern side; the shaft Korkino was condemned as unfit for use, and the buildings collapse has begun. A decision of resettle Roza village and Korkino city settlements and phase out the open-pit facilities was made.

Endogenous fires occurred regularly in the open-pit's sides, the consequences of which were felt at a distance of dozens of kilometers. For the purposes of reclamation, a project was developed that provided for the filling of the mine workings and preventing spontaneous combustion by backfilling such zones with material based on tailings from the Tominsky Mining and Processing Plant (Sokolovsky 2018). At present, a 14-km long slurry pipeline is used for filling open-pit. This technique resolves several environmental problems at once: copper porphyry ore extraction and processing wastes are utilized; fires are extinguished; reclamation of the man-made workings is carried out.

The backfilling of the open-pit is planned to be completed by 2045. By then, open-pit will contain 479 million m3 of backfill

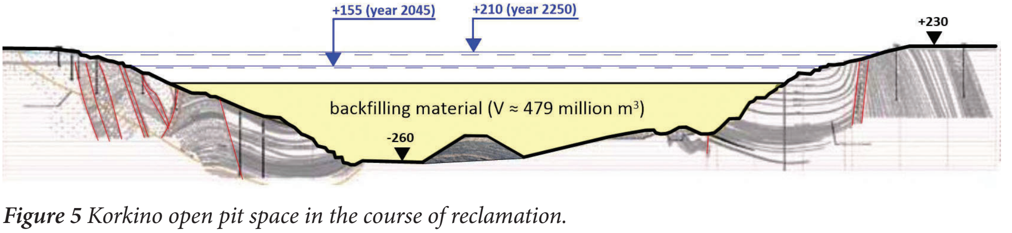

Figure 5 *Korkino open pit space in the course of reclamation.*

and 212 million m3 of water and the water mark will reach +155 m (Rybnikova 2023). The estimated flooding level of the Korkino open-pit will be no higher than +210 m. The groundwater inflows will occured 200 m^3/hour and the flooding time from +155 m (water surface area of 4.7 km^2) to +220 m (water surface area 7.4 km2) water mark will take at least 200 years.

Conclusion

The flooding of the Kopeysk open-pit to the maximum level of +194.5 m will continue until 2091. It is necessary to prevent the water level in the open pit from rising above the level of +190.0 m to prevent the flooding of the residential developments on its eastern side of the Kopeysk open-pit. Mining activity was not the main cause of landslide slope waterlogging and adjacent area flooding.

Reclamation of Eurasia's largest Korkino opencast mine is being conducted by backfilling of the mine workings with material based on tailings from the Tominsky Mining and Processing Plant, which are delivered to the open pit via a slurry pipeline. The backfilling of the mined-out workings is planned to be completed by 2045 at a mark level of +155 m. Estimated flooding level of +210 m will occurred no earlier than 2250 year.

It has been shown for the first time that the cause of an urban area flooding is the geological and geomorphological structure of the territory characterized by the presence of natural lakes and poor drainage of the area.

The combination of geological structural features with geomorphological conditions, hydrometeorological factors and mining methods leads to the formation of new hydrogeoecological conditions at the post-operational stage, which may last for dozens and hundreds of years. Due to the filling of the cone of depression, man-made reservoirs are formed, areas are flooded, and landslide processes develop. At the same time, lakes that form due to mine drainage tend to dry up, and the quality of the water in them deteriorates radically.

Acknowledgements

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