The Development of Future Lakes in Opencast Mine Residual Pits in the Krušné Mountain Region of the Czech Republic

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Abstract
Frequently, residual mining pits are filled with water to create lakes in the post-mining landscape. In the Krušné Mountains region, a total of 8 large pit lakes will be formed in brown coal opencast mines. The crucial factor is the availability of water for flooding, including prospective use of underground mine water. Other factors include water quality and possible shoreline erosion. Differences in average precipitation and surface water evaporation during and after the flooding process are being studied to optimize the water balance and quality.

Introduction
The residual pits that remain after the discontinuation of opencast mining represent the volume of the excavated industrial minerals as well as the fraction of the overburden material that must be deposited as external dumps before sufficient space is created for internal dumping. Several factors influence the size of the pits, including the depth at which the industrial minerals are found, the thickness of the deposits, and the mining technology employed. The residual pits left after large-scale brown coal opencast mining in the Krušné Mountains (the Ore Mountains) already extend over vast areas and to great depths, and are continuing to grow. The future destiny of the residual pits is addressed in the reclamation and remediation projects, which are detailed and updated repeatedly during the course of mining. There are three basic ways of resolving this issue, namely: (1) filling the pits with overburden and other material, (2) flooding them with water, or (3) leaving the residual pits empty. Considering the locations and the size of the pits associated with present-day brown coal opencast mining, filling them appears to be economically unfeasible. Moreover, filling them with solid materials would require the destruction of dumps that have already been reclaimed and with other adverse impacts on the general environment, such as air pollution (dust), generation of excessive noise, and additional traffic. Leaving the residual pits empty seems to be the cheapest option, but this has several problems associated with it, including public safety, securing the geo-mechanical stability of the slopes, and ensuring proper water management balance. In real terms, this would require permanent pumping of water, since equilibrium balance would only be achieved after the water table level rises to the level of the surrounding surface streams. During the spontaneous, slow rise of water, the shores would be disrupted by erosion and the naturally-occurring grown woods would be flooded. The excavated space without water in it or with a slowly rising water level would see limited utility for a long period. Hence, the optimum solution consists in fast flooding of the residual pits with surface water, which enables variable utilisation of the newly created lakes within a short period after discontinuation of opencast mining. Key issues that must be addressed include the balance of the available water resources as well as their quality, optimizing the utility of the water surfaces, and strengthening the prospective shorelines against erosion by water waves.

Water for the Future Landscape
The possibility of flooding has been proposed for all the major residual pits within both brown coal basins found alongside the Krušné Mountains range. In total, eight lakes would be developed: six in the North Bohemia Brown Coal Basin and two in the Sokolov area (Table 1). These will not be small lakes. The largest will result from the combined “Jiří” and “Družba” mines in the Sokolov area, with a surface area of about 1300 ha. The lakes of the Bílina and Libouš mines will not be much smaller: each will have a surface area of more than 1000 ha. In terms of surface area, these lakes compete with the largest artificial reservoirs and natural lakes within the entire Czech Republic. However, many parts of the prospective lakes will be much deeper. For instance, the Bílina mine lake will be as much

as 200 m deep. The relevant water volumes of these lakes will also be enormous. The issues to be resolved in association with creation of these lakes will necessitate sophisticated approaches.
The R-Princip Most Ltd. was one of the first organisations in the region to deal with these issues, and have worked closely with other contributing organisations and experts, including the ENKI o.p.s. and ENVI Ltd. Třeboň companies, South Bohemian University in České Budějovice, and some of the other brown coal mining companies. Though a number of positive outcomes have been achieved since 1992, there is still a great deal of work to do. The nature of the geology of these brown coal basins makes them significantly different from other mining regions, which means that experience gained abroad has very limited applicability. The differences include irregularly situated coal beds with multiple geological anomalies, the variability and quality of the overburden mass, and the geo-mechanical instability of the dumped overburden masses.

Table 1 *The basic hydro-technical parameters of the residual pit lakes.*

The North Bohemian Brown Coal Basin

Mine Site	Envisaged start of flooding	Water surface area (hectares)	Water volume (Mm^3)	Water depth (m)	
				avg.	max.
Bílina	2037	1 145.0	645.0	56.0	170.0
Chabařovice	in progress	226.0	35.0	15.6	23.3
Ležáky	2007	311.1	68.9	22.4	75.0
ČSA	2020	701.0	236.8	33.7	130.0
Vršany (Šverma)	2050	390.0	73.6	18.8	40.0
Libouš	2038	1 083.2	248.0	22.9	75.8

The Sokolov Brown Coal Basin

Medard – Libík	2010	501.4	138.0	27.5	51.0
Jiří - Družba	2038	1 322.3	514.9	40.6	93.0

The Specific System of Abandoned Mine Workings Water

One of the peculiarities of the area is the fact that in the past, the coal beds were mined using underground mining technologies. An intricate system of flooded and partially flooded abandoned mine workings was created, in particular in the central parts of the North Bohemian Coal Basin, which has had pronounced impacts on resolving the issues associated with prospective lakes to emerge in the places of the residual pits. All of this underground water is now pumped out from two mines: the only operational underground mine in the area, the Centrum mine, as well as from an abandoned underground mine, Kohinoor. This pumping is necessary not only to safeguard the operating underground mine, but also to protect two opencast mines (the Bílina and ČSA mines). Discontinuation of mining in the Ležáky opencast mine will enable this residual pit to be flooded with water in the near future. However, as the depth of the bottom of this mine is above the levels/depths of the currently operated underground mine and the other opencast mines, it was necessary to seal the bottom of this prospective lake so that water from it would not penetrate to the underground environment, which would pose hazards for the mining operations. This seal will also ensure a stable water surface level for the lake.
Another issue that must be resolved: after discontinuation of mining within the entire coal basin and discontinuation of pumping in the abandoned mine workings, the entire system will gradually begin to fill with water due to the rising water table. Some places have already been identified where water will overflow, and it is clear that the foundations of many buildings and structures could be endangered in the Duchcov and Trmice – Ústí nad Labem areas.

The Process of Flooding with Water

What is the current situation? Since June 2001, the Chabařovice mine pit is being flooded with water. It was the first major pit chosen for flooding and now has some two-thirds of its volume flooded. Flooding of the Ležáky mine pit will start as early as 2008. The Medard mine residual pit in the Sokolov area is another residual pit where flooding should start in the near future. Flooding of the remaining pits will begin later on (around 2010, as far as the ČSA mine is concerned, whilst flooding of the other pits will only start after 2035).

The Quality of Water

Initially, it was expected that high acidity (low pH) would be the greatest water quality issue of concern. This was based on experience gained in particular in the Lusatia brown coal basin in Germany, where lakes with very low pH values are found. This is caused mainly by the fact that both the Lusatia coal beds and the sandy (permeable) overburden contain pyrite and marcasite. In our coal basins, only the coal deposits are pyritic; the overburden mass consists mostly of clay materials. Despite this observation, in our initial proposals we recommended that the coal deposits be sealed so that they would be isolated from the lake water. This would, however, have meant that large volumes of overburden would have had to be moved, which would have been expensive. In the course of time, we have proven that eutrophication processes pose by far a greater danger in terms of lake water quality. This observation applies in particular to the relatively shallow lakes, such as the Chabařovice mine lake, where the circumstances are aggravated by the fact that poor quality water is being used for flooding.

The Chabařovice Mine Lake

The Chabařovice mine lake will be the smallest lake of its kind in the area. The main issue of concern is its relatively shallow depth (with a maximum depth of 22 m and an average depth of 15.5 m). Given these parameters, only a small-volume hypolimnium layer will be created, with insufficient oxygen to suffice for the periods of summer stratification. As a result, phosphorus will be readily released from the sediments into the water column, with the potential of fast eutrophication of the lake. At this mine, mining was discontinued too early due to a governmental decree on territorial environmental limits. In terms of mining technology, this mine could serve as a model, with its proper arrangement and design of mining faces and dumping platforms. However, in terms of prospective reclamation and revitalisation of the relevant area, this technology does not create favourable conditions. In terms of morphology, the lake and its shores are too monotonous, which is not a good precondition for proper water quality and other parameters associated with this.

The Importance of Monitoring

Before the start of flooding a pit, attention has to be paid to both the quality of the water to be used for flooding and the development of water quality in the lake itself. A water quality monitoring system has been established in both the tributaries and at chosen points within the lake. Multiple essential parameters are being measured at predetermined depth intervals, and the fish species and flora in the lake are being tracked. Since the nearby Krušné Mountains streams have insufficient flow rates to fill the pit, supplemental water is being provided from the residual pit watershed and water pumped from the abandoned mine workings; the lake itself is sealed and does not allow spontaneous inflow of abandoned mine workings water. So far, the development of water quality has been favourable. Nevertheless, there is a concern that the envisaged use of the lake for leisure activities on a massive scale, potentially inappropriate developments in fish species, and/or accidental pollution of the incoming water streams will negatively impact the lake water quality. Experience acquired at the Chabařovice mine lake will be applied during flooding of the other residual pits.

It is also worth mentioning that as early as 1993, we initiated continuous monitoring at the Barbora mine lake (in the Oldřichov u Duchcova area). After mining ceased some 35 years ago, spontaneous flooding of this pit occurred (which was on a much smaller scale than the currently operated opencast mine pits), primarily with ground water permeating from coal bed outcrops below the Krušné Mountains foothills. The lake that emerged has very good water quality and is used mainly for recreational purposes.

Protection of the Shoreline

Protection of shorelines from water erosion caused by high waves is another issue to be addressed in residual pit lakes because of the size of the lakes. Because the lakes will be filled with water relatively slowly due to the limited water resources available, the lake shorelines will have to be protected continually as water levels rise. The protection is being designed, and gradually implemented, relying on technical instruments along with additional biological measurements made just after discontinuation of mining and again after dumping of the overburden material. This is a rather costly process. In the past, the R-Princip Most Ltd., through a grant-sponsored project, proved that it was possible to use its mining equipment as early as the final phases of the mining process in such a way that the resulting conditions would ensure the protection of the shorelines in a more effective and less costly manner.

Water Resources for the Prospective Lakes

In the Sokolov Coal Basin, both lakes can be filled within a very short time with water from the Ohře River. The resources used to flood the prospective lakes in the North Bohemian Coal Basin will be a combination of water from the Bílina River, the Krušné Mountains streams, water pumped from the Ohře River, and, to some extent, water from the abandoned mine workings. Flooding in the North Bohemia Coal Basin is much more complicated than in the Sokolov Coal Basin and flooding will, in many instances, be prolonged to such an extent that it will be on the verge of reasonable acceptability.

The Function of the Lakes in the Post-Mining Landscape

The residual pit lakes should provide major benefits for the areas degraded by surface coal mining. Before the Industrial Revolution, the countryside of the coal basin had been a water-logged area with a small closed water cycle. Nowadays, this area, which is, moreover, within the Krušné Mountains rain shadow, suffers from low rates of atmospheric precipitation; therefore, extraordinary care and effort in terms of environmental protection are required. The residual pit lakes, together with appropriate reclamation of the area affected by mining, revitalisation of water streams within the basin area, as well as other complex interventions in the area should offer substantial improvements to the general environment. At the same time, good environmental conditions should provide recreation and sporting activities for people there.

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