Evaluation of mine water rebound processes in European Coal Mine Districts to enhance the understanding of hydraulic, hydrochemical and geomechanical processes

Sebastian Westermann[1], Tansel Dogan[1], Bastian Reker[1], Peter Goerke-Mallet[1], Christian Wolkersdorfer[2,3], Christian Melchers[1]

[1]University of Applied Sciences TH Georg Agricola, Research Institute of Post-Mining, Herner Straße 45, 44787 Bochum, Germany
[2]Lappeenranta University of Technology, Laboratory of Green Chemistry, Sammonkatu 12, 50130 Mikkeli, Finland, christian@wolkersdorfer.info
[3]South African Research Chair for Acid Mine Drainage Treatment, Tshwane University of Technology (TUT), Private Bag X680, Pretoria 0001, South Africa

Abstract The mine water table has been rising in many hard coal mining areas. Important insights have been gathered concerning the hydrodynamic, hydrochemical and geomechanical changes that accompany a mine water rebound. This contribution provides an overview of a current survey. This survey aims at developing a deeper understanding of the processes which allows to derive generally applicable causal relationships based on it. Such interdependencies are then to be transferred to the Ruhr area in order to contribute to an improved forecast regarding the possible impact a mine water rebound will have on the environment.

Key words mine closure, mine water rebound, hard coal mining, Ruhr area

Introduction

Germany looks back at a long tradition of mining. Currently, approx. 180 Mt/a of lignite are being extracted in open-pit mines and more than 500 Mt/a of minerals are being mined, too (VRB 2016). Coal, salt and ores have been mined for centuries at different depths in underground mining. In 2018, when the last two collieries will close in North-Rhine Westphalia, the hundreds of years of hard coal mining in Germany will be history. The end of the active exploitation of hard coal, however, does not mean the end of the mining operator's responsibilities. In the future, the operator will be responsible for a sustainable and environmentally acceptable mine water management. In Germany, the expressions 'perpetual burdens' or 'perpetual tasks' are two terms that express the scale of this responsibility. Those include the long-term retention of the mine water table at an environmentally acceptable level, poldering measures to regulate the ground water table close to the surface as well as the decontamination of ground water at formerly contaminated colliery sites (e.g. caused by former coking plants). For many years now, concepts have been developed by the mining companies to solve those issues and to continuously enhance those solutions (RAG 2014).

Mine water management in both active and closed mines

Often, as in the Ruhr area, mines are, connected by an underground network of galleries and drifts. Mine water retention does not only mean to keep the mine workings dry where the resources are won, it also means to protect the mine workings at productive mines against a mine water inrush from closed mines nearby. For that purpose, mines are compiled to form water districts which are hydraulically interconnected.

Depending on its morphological location and the hydrogeological properties of the deposit and its overlying rock, the dewatering of a mine is done by enabling a free drain of mine water via the adits or by actively removing mine water using pumps. Thus, the dewatering in the southern former coalfield of the Ruhr area has been done by draining mine water over the galleries into the river Ruhr and its tributaries (Melchers et al. 2015, 2016), whereas in the central and northern parts of the Ruhr coal mining area, the geomorphological conditions require the mine water to be actively pumped from the shafts.

Mine water rebound in underground mines

Once the exploitation of resources is abandoned and the closure of the mine is completed, the removal of the mine water can be reduced or even finished, provided the (hydro-)geological, mining and ecological circumstances allow for that. The water which continues to flow into the open underground mine workings, but is no longer pumped, results in the mine water table to rise therein and in the overlying rock. The spatio–temporal process of the mine water rebound depends on the geological and hydrogeological properties of the deposit and its overlying rock, the changes of both caused by the mining activities, and finally the geometry of the mine workings. Most of these effects have been extensively studied and described in Wolkersdorfer 1996 and 2006.

This rise in the mine water table can result from the reduction or cessation of the pumping activities and is then called ´passive´ or ´internal flooding´. Yet, mine water rebound can also be initiated and even accelerated by the influx of water, which is called ´active´ or ´external flooding´. Generally, the course of the mine water rebound can be controlled by means of pumps that either remove the mine water, so to slow down the rising velocity or by pre-setting the height of the mine water table. If no pumps are kept on site and no permanent draining adits are in place, there will be an uncontrolled mine water table rebound up to a level, where the inflow and outflow volumes equalize. In Germany, legal stipulations were implemented more than twenty years ago that prohibit an uncontrolled rise of the mine water table (BBergG 1980).

Example of a mine water rebound

The presented example of a mine water rebound (fig. 1) can be divided into three stages. The first commences after the decommissioning or reduction of the pumping rate; it can be identified by a quick rise of the mine water table ('initial phase'). During the ongoing course, there is a more or less even rise of the mine water table provided the hydrodynamic conditions of the mine workings to be flooded are homogeneous ('intermediate phase'). Changes of the hydrogeological properties, e.g. once the mine water reaches the base of the overlying rock, are reflected by the course of the graph ('heterogeneities'). With the growing decrease of the potential difference between the current and the natural water tables, the speed of the mine water rebound decreases successively, too ('final phase'). The mine water

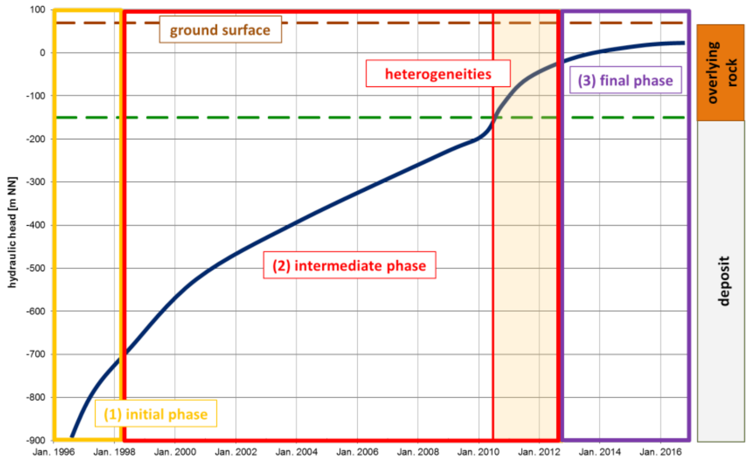

Figure 1 *phases of a mine water rebound*

table ceases to rise once it has reached equilibrium between inflow and outflow or the level of a dewatering adit.

Potential influence on the environment as part of a large-scale mine water rebound

The rise of mine water table can be accompanied by risks for people, ecology and infrastructure. Especially, if this rise is not controlled as regulating mechanisms have not been established or if this is not noticed as no measuring points have been defined. Figure 2 shows a selection of possible areas and their challenges which mining companies, authorities and scientists will have to tackle after closing a mine but also in respect of the mine water table rise (Kretschmann 2016, Kretschmann & Hegemann 2016).

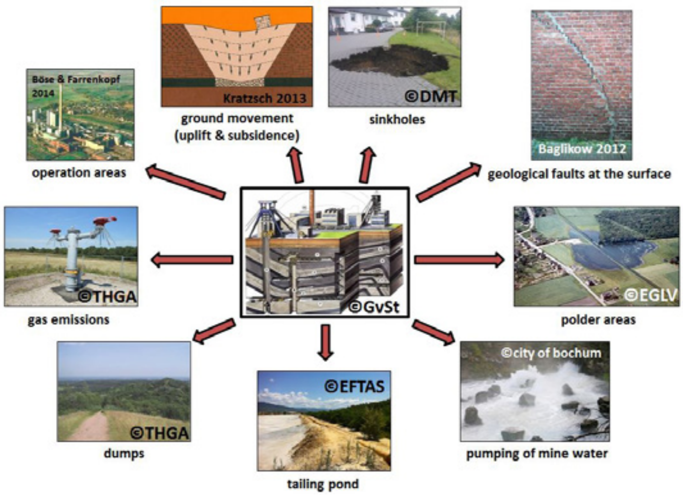

Figure 2 *Action fields connected to post-mining*

In order to make the potential environmental impact predictable and thus manageable, a deeper understanding of the processes which are occurring is needed. This process understanding has three parts:

- Hydraulics & hydrodynamics,
- Hydrochemistry,
- Geomechanics.

In the following section, the essential foundation of those processes will be outlined; this description is by no means exhaustive.

Hydraulics & hydrodynamics

The speed of the mine water rebound is mainly influenced by the cumulative flows of the deep water and the infiltration water and by the cavity volume that can be used as storage. With the ongoing mine water rebound, the rise velocity decreases successively as the cumulative flows of e.g. deep water are gradually suppressed by the rising mine water. There, the spatial distribution and the temporal development of the cumulative flows might affect the formation of a density layering in the mine workings that is stable over a long period of time (Melchers et al. 2015, Wolkersdorfer 2016).

Looking at finished or highly advanced mine water rebounds, it can be shown that the (hydro-) geological properties of the deposit and its overlying rock have immediate influence on the hydrodynamic processes which are going on underground due to the mine water rebound. For example, observations from the Ruhr area have shown that the rebound speed of the mine water pressure level increases with reaching the base of the low-permeable clay marl rocks of the Emscher formation (Upper Cretaceous), as the cavity volume that can be used for storage decreases (fig. 1).

One effect of a mine water rebound is the migration of gases (including methane). The low dissolution quality of gases in liquids means that gas floating freely in the mine workings and the adjacent rock mass is displaced by the trapped mine water and can discharge at the surface, e.g. at shafts or faults. According to recent insights from the Ruhr basin, the release of gas stops once the seam-bearing layers have been flooded (Melchers 2008).

Hydrochemistry

Due to its genesis, mine water commonly has a higher mineral content than ground water close to the surface. Mine water in hard-coal mining areas often has substantially increased levels of iron and sulphate due to the oxidation process of disulphides (pyrite, marcasite, chalcopyrite). The temporal development of the hydrochemical composition shows in most cases, after the mine water rebound has been completed, an early rise of iron and sulphate concentrations which fall again to their background values ("first flush") after their maximum values have been reached (usually after decades or centuries) (Younger 1997).

Where the mine water table rises, the higher mineralised mine water can come into contact with drinking water resources used in water management and supply if hydraulically active connections between the mine workings and the overlying strata exist (e.g. via exploration boreholes or inappropriately abandoned shafts); such contact may cause drinking water contamination. Due to the (hydro-)geological properties of the deposit in the central and northern part of the Ruhr basin, where thick and impermeable clay marl rock layers of the Emscher formation exist, a rise of the mine water table into the overlying strata of the Emscher formation is highly unlikely (Hahne & Schmidt 1982, Baltes et al. 1998, Coldewey et al. 2016). Thus, the risk of the drinking water and groundwater reservoirs being negatively influenced by rising mine water has been drastically reduced in areas where thick and hydraulically effective geological barriers are in place (Heitfeld & Rosner 2015).

Geomechanics

The mine water rebound causes an increase in the buoyancy forces and also to a swelling and subsequent increase in volume of clays. In many former mining areas ground heavings caused by those phenomena can be observed. The heaving movements usually occur at large scale and – according to the observations so far – make up a one-digit percentage figure of the subsidence volume (Preuße et al. 2015). In most cases, the ground heavings occur evenly and are not linked to damage-relevant effects. The only damage on structures caused by a mine water rebound known so far was observed in the Erkelenz coalfield in Germany. The reason for this was a flood induced reactivation of a large fault which led to heaving differences of both sides of that fault (Baglikow 2010). Another case was reported by Oberste-Brink (1940), where ground heaving was observed in the Wittener Mulde, Germany.

Study to evaluate the processes of mine water rebound

Currently, a study at the University of Applied Sciences TH Georg Agricola (Research Institute of Post Mining, Germany) is supposed to provide the basis for a deeper understanding of the scientific foundations needed for a sustainable concept to ensure long-term and environmentally acceptable mine water rebound in the hard coal mining areas of North-Rhine Westphalia and Saarland. This evaluation will provide a systematic, uniform and comprehensive analysis of closed and ongoing processes concerning mine water rebound in European hard coal mining areas. This study is based on the initial results published in Melchers & Dogan (2016).

In a first step, coalfields in the following European areas will be examined in detail regarding the experience made with processes of mine water table rises:

- Germany (southern Ruhr area, Saar area, Ibbenbüren, Aachen-Erkelenz, Saxony),
- United Kingdom (East Fife, Northumberland, East Pennines),
- France (Lorraine),
- Netherlands (South Limburg) and
- Poland (Upper Silesia).

In a second step, the evaluation can be applied to other hard coal mining areas (e.g. in Spain) or other types of deposits (e.g. spar or ore). Regarding the hard coal mining areas, the key parameters of (hydro-)geology, mining activities and mine water rebound will be recorded systematically.

The evaluation focuses on the analysis of the spatio–temporal course of the mine water rebound and the related influences and interdependencies on the following: both the quantitative and qualitative changes of the mine water to be drained; the ground movements caused by the processes, and gas migrations close to the ground surface. This overall evaluation intends to identify generally applicable causal relations of mine water rebound, to separate the locally specific conditions and to transfer the insights to other hard coal mining areas where mine water table rises are imminent. This objective applies in particular to the Ruhr area, the Saar hard coal mining and the Ibbenbüren colliery.

Conclusion and outlook

The insights gained and the deeper understanding of the course mine water rebound takes help to develop strategies and measured for long-term mine water management that can be optimised in alignment with sustainable, environmental and economic aspects. Any recommendations for a comprehensive monitoring will be agreed accordingly.

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