Planning and implementation of environment-friendly phasing out of German hard coal mining under consideration of water-hazardous organic substances

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Abstract

Two hundred years of hard coal mining in Germany ended in 2018. The last two active collieries of RAG Aktiengesellschaft stopped producing hard coal. During the phasing out process one of many challenges will be the reduction of the environmental impact of organic substances. To run the infrastructure fuels e.g. diesel and hydraulic liquids are indispensable. Many of them are water-hazardous but in secure use. Furthermore there are operating fluids which had to be used in the past for safety reasons (e.g. non-inflammable hydraulic liquids containing polychlorinated biphenyls (PCB)) which are now known as toxic. All these fluids can leak and accumulate in the gallery floors of the mine building.

During the process of mine flooding, water can get in contact with those substances and partly mobilize or dissolve them (Denneborg 2018). This is a potential risk for people and the environment. With regard to the Water Framework Directive and the resulting German surface water regulation, the quality of surface water needs to be improved. Hence, the minimization of such substances in mine water discharges and thereby of the environmental impact is an essential part of RAG closedown strategy. RAG addresses this task by deriving a multi-lane concept in cooperation with DMT and the water authorities.

Keywords: Mine Flooding, Remediation, PCB, Organic compounds, Water Framework Directive, Phasing Out, Water-hazardous Substances

Introduction

In mining water-hazardous substances have been used. To avoid environmental impact during phasing out, these substances need to be dealt with according to regulations (Bez. - Reg. 2015). Generally, waste arising underground was collected in designated and labelled containers, transported to specially prepared supply sites above ground and disposed properly (Bundesministerium 1995). In some cases, however, such substances were also subject to losses due to leaks or accidents and, in the case of hydraulic fluids, additional releases due to safety valves.

During and after mine flooding, such anthropogenic water-hazardous substances can be carried along with the rising mine water and discharged to receiving waters. As with PCB, poorly soluble or particle-absorbing substances (e.g. multi-ring PAHs) can predominantly only be transported bound in particulate form. The release and transport processes then behave analogously to PCB and are thus clearly different from the water-soluble compounds.

In addition to mineral oil products and aliphatic compounds, the group of water-hazardous substances also includes monoaromatic (BTEX), polycyclic aromatic hydrocarbons (PAH) and Organochlorine compounds (LHKWs) in the form of e.g. cleaning agents and additives. The vast majority of lubricants were used in closed systems. However, dripping and handling losses are probable. In particular, high-molecular compounds such as 4- to 6-ring PAHs and PCB have a specific binding tendency on particle surfaces in particular to organic substances. This is described by high sorption coefficients and leads to low proportions dissolved in water. PCB are thus predominantly transported bound to particles in water. In contrast to soluble substances, the solids are swirled up in turbulent water flows and sedimented again at low flow velocities.

The processes around turbidity are complex and are strongly dominated by local and variable processes. These are mining activity, type of lithology, sump management etc. in the active mine. For PCB mobilisation it is required that PCB-containing particles get into the mine water. Such erosion processes (turbulences) are a function of the flow velocity and thus of the local site conditions.

Thus PCB release can only take place in unflooded galleries in which either turbulent flow of water or mining activity cause dispersion. Such erosion channels can be seen everywhere in the mines after water enters inclined sections. Once a mine area has been flooded, turbulences and mining interventions in the floors are absent.

Basic concept

A concept to evaluate the extent of underground contamination and its risk on surface water was required. Such a concept was developed by RAG in cooperation with DMT. It is based on the regulatory requirements of water legislation concerning water-hazardous substances e.g. operating fluids. The flowchart presented in figure 1 is the basic tool to fulfil those requirements. In a systematic analysis it is relevant whether and where such operating fluids were used in the mines. Furthermore the possibility to create a hazardous potential during mine flooding is important. According to the risk of contamination and substance properties, different approaches were defined considering mining-specific conditions.

The basic assumption is that all locations, where water-hazardous substances were utilized, bear a potential risk during the flooding process. Accordingly, defined areas

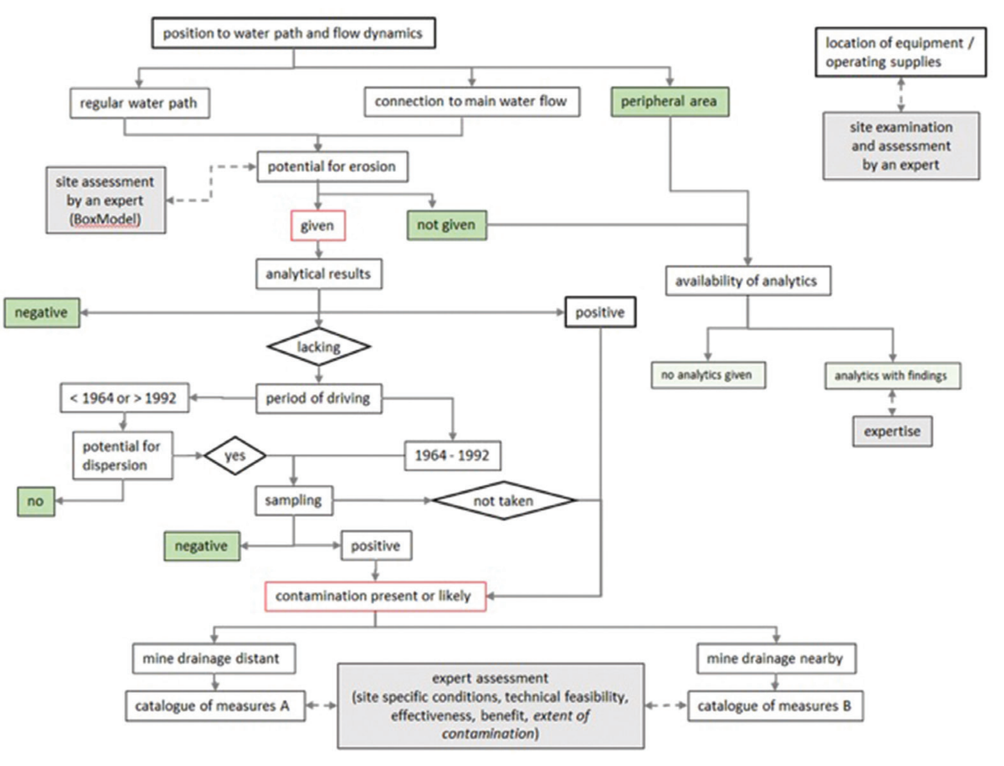

Figure 1 Concept of phasing out under consideration of surface water-hazardous substances.

of concern which surround former and active machine locations are actively checked for contamination. Such controls and resulting rehabilitation measures (covering and/or excavation of areas holding loaded matter) are limited to galleries still accessible. The flowchart guides the evaluator through several steps considering gallery location relative to water paths, erosive potential, period of driving, taking samples and dealing with analytic findings.

Based on this assessment, galleries can be declared as hazard-free or treated according to a defined catalogues of measures. The focus here is on facilities which are operated in accordance with the *Ordinance on Facilities for Handling Substances Hazardous to Water* (AwSV) and other areas in which substances hazardous to water (liquids containing mineral oil, resins, etc.) were handled during the operating phase (Bundesregierung 2017).

When leaks or releases through safety valves have occurred in the past, they were in most cases not locally limited or their distribution was unknown. Furthermore it can be assumed that materials and substances could be distributed by water and by coal during the transport over railway systems. It is therefore necessary to identify and characterise such sites or areas, taking into account the materials, substances and groups of substances used underground. Depending on this assessment, measures must then be derived to control, eliminate or minimise impacts on the water path before it gets dammed. After a final examination, to control the measure, the site can be classified as hazard-free.

Identification of facilities or sites

Today, facility locations are being examined, when withdrawing from the still open mine. This applies to both current and former facility locations. Individual sites with a high risk of contamination by water-hazardous substances are investigated and evaluated by an expert individually. Systems that have been in operation for more than 10 years require special care, as the susceptibility to malfunctions increases with time. However, the practice of site inspections showed that the operating time is not always decisive for relevant emissions. Even in the case of shorter operating periods, relevant

Figure 2 *Example for the examination of the gallery floor around a former winder site.*

contamination of the gallery floor can occur. As a result, all accessible facilities are now being inspected, irrespective if still in use or not. The condition of such sites is very different and varies. As the period of decommissioning increases, the probability of locating the former plant site and finding residues, decreases. The range of the sites being considered can be taken from table 1. These site categories are checked and, if necessary, adapted according to the special features of the machinery used in the various mines. Figure 2 gives an example for the inspection of the gallery soil around a former winder location (red ellipsis). Furthermore it shows an already completed measure to cover the contaminated soil with concrete (green ellipsis).

Particular attention is paid to locations for which there are indications, that equipment containing PCB has been used:

- Facilities which operated with PCB-containing liquids e.g. winders and various hydraulic machines
- Assembly/disassembly areas of full-cut machines during the period of use of oils containing PCB.

These facility locations are evaluated for operating time, substances used and properties of the respective system. With that knowledge the type of loads and possible discharge points of operating materials can be identified. If the installations are still present at the site, leaks are often noticed directly. Furthermore site location relative to future main waterways and with respect to flow dynamics e.g. potential of erosion are taken into account (see figure 1). If necessary, locally limited measures are then derived to eliminate, control or minimise the contamination risk.

Such measures are coordinated with the district government are based on site inspections. The implementation or completeness of these measures is checked and approved either by the Environmental Engineer of RAG or by an independent expert.

The process is documented and based on a list of system types. This list is agreed with the Arnsberg district government. The location, type of system, used substances and the inspection by an independent expert or the environmental engineer of the mine are recorded. Furthermore the results of the assessment as well as the implementation of the required measures are documented (see figure 1). This is supplemented by individual expert reports for the system locations, describing the respective situation and the measures to be carried out. Examination practice of past years has shown that more than half of the investigated sites were contaminated and required remedial

Table 1 *Types of facilities operated with water-hazardous substances and evaluation of contaminations during the first inspection.*

Facility / Site	Water- hazardous substances used investigated	Not yet investigated	Contamination			
			no	low	high	Total
Belt conveyor drives	Gear oil	18	32	22	4	76
Other drives	Gear oil	0	2	6	0	8
Shaft cellar	HFC/Gear oil	6	0	4	0	10
Shaft swamps	Divers	3	0	1	0	4
Pumping stations	Diverse oils	5	0	0	0	5
Electric control rooms	Switchgear oil	0	0	1	1	2
Intensive traffic areas	Diesel/HFC/Mineral oil	4	0	0	1	5
Train stations	Diverse oils, Diesel	11	0	5	2	18
Refuelling station	Diesel	2	2	3	3	10
Locomotive mainten.	Diesel/Used mineral oil	5	0	1	1	7
Cleaning station	Oil-bearing water	3	1	1	0	5
Workshops	Diesel/HFC/Mineral oil	0	1	2	0	3
HD pumping stations	HFA/Mineral oil	2	0	1	1	4
Winder locations	Hydraulic oil	6	2	5	1	14
Resin mixing stations	2-component resin	4	0	0	1	5
Total		64	40	52	15	171

measures (see table 1). Hence these areas were declared as hazard-free afterwards.

Diffuse loads of organic matter

Due to intensive transport and material relocation processes (conveyor systems, means of transport, water and weather flows), parts of a mine that are far away from site locations can be affected. Such contaminations are therefore difficult to localise and isolate. Due to mostly low concentrations these diffuse substance contents do not influence mine water quality significantly. The composition of the gallery ground material with high clay contents, organic substance contents and small grain sizes can sorptively bind such substances and reduce the mobilisation.

Nevertheless such low concentrations become recognisable and relevant when sufficiently strong analytical methods are used e.g. analytics of PCB. The analytical findings in the µg/kg range show that low loads are present at many points of a mine. The focus of the examination distributed across the mine is on the period in which PCB were used in underground hard coal mining from. From 1964 up to the 1980s PCB was a component of hydraulic fluids. Subsequently, PCDM-containing replacement fluids were used until approximately 1992. These fluids do not differ significantly in their environmental relevance from PCB. In the following period neither PCB nor PCDM were used. The presence of PCB in the concerned mine can therefore have various causes:

- The coal fields were excavated during the period of use of PCB/PCDM-containing equipment (conventional road header, full-cut machine).
- The coal fields are within the sphere of influence (main haulage routes, waste weather, mine water) of mining areas in which work was carried out with PCB/PCDM-containing equipment.

The assessment of the mobilization and discharge of diffuse material loads is highly related to the later mine-flooding. Therefore specific measures are considered and documented in special reports.

General evaluation and measures

After localisation of contaminated sites specific measures are carried out. These are damming, removal, remediation or covering, e.g. either with gravel (flexible in relation to bottom lifts) or concrete (partly with

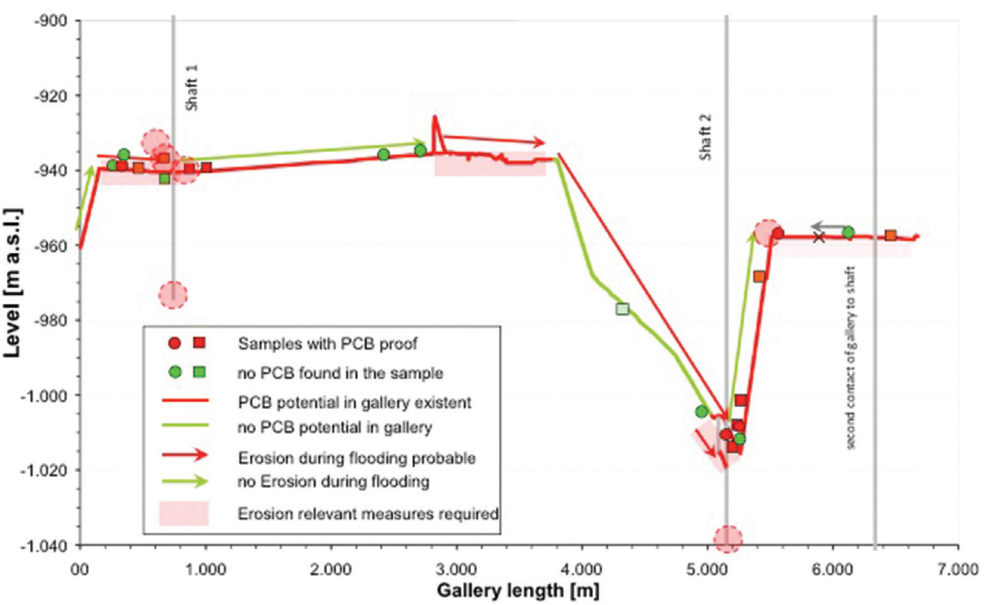

Figure 3 *Example for analysis of PCB contamination and erosion potential in galleries around a mine water pumping station to be abandoned.*

steel reinforcement The specific approach for the evaluation of potential or verified PCB contamination considers mobilisation processes during the flooding process (see figure 3). To prevent or minimize possible turbulent water run-off and erosion of the roadbeds large-scale effective measures can be taken. Figure 3 shows an exemplary site examination of mine workings in the surrounding of two still open shafts. Often the construction of weirs and pipelines, that bypass the sensitive sections of the gallery, is a viable and effective measure. Covering the long routes, with several kilometres of length, was a non-practicable approach.

It can be stated, that mine water from flooded mining areas has only a low content of dissolved water-hazardous substances. This manifests it the low contents of mineral oil hydrocarbons (MFCs usually < 0.1 mg/L) in mine water which came from already dammed mine fields. This was surveyed by a regular monitoring since 2008. Accordingly this value meets the requirements of the *Ordinance on Mining Water* of 0.1 mg/L (test value) or 0.2 mg/L (percolate water). These low test values can be explained by the fact, that MFCS are well bound to the fine-grained and organic substances, contained in the materials of the gallery basis. These are therefore only available to a limited extent for dissolving processes.

Conclusion

For the planned phasing out process from the mine building and the drainage sites, the methodology described here is intended to contribute to the identification of contamination hot spots. If necessary, it helps to derive measures for the elimination, control or minimisation of environmental impacts to receiving waters. The described catalogue of measures is intended to avoid an impairment of mine water quality with water-hazardous substances. It is important that neither locally limited nor diffuse contaminations in the mine, affect surface water negatively by discharge of mine water.

At the sites investigated so far, operating substances hazardous to water were found to varying degrees. These are diesel oil, lubricating oils, hydraulic oils and greases. A contamination with these substances would be reflected by the water monitoring parameters hydrocarbon index and PCB / PCDM.

If a contamination is locally distinct, contaminated materials are largely removed and disposed of (remediation). In case of unfavourable site conditions, which prevent the complete removal of the substance or where localisation/confinement is difficult, safety measures are carried out. Measures like steering water flows and controlling mine flooding are suitable to prevent particle leaching. The Measures are proposed by an expert, realized by the company RAG, checked and documented by an expert and finally approved by the district government. The basic concept presented here enables the mine operator to systematically address the extent of underground contamination by water-hazardous substances. Thereby the risk of surface water contamination is reduced significantly.

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References

Bez.-Reg. Arnsberg (2015) Regelung zum Umgang mit Sachen und betrieblichen Einrichtungen beim Rückzug aus dem Grubengebäude" (§22a ABBergV)

Bundesministerium der Justiz und Verbraucherschutz (1995) Bergverordnung für alle bergbaulichen Bereiche (Allgemeine Bundesbergverordnung – ABBergV) § 22a Anforderungen an die Entsorgung von bergbaulichen Abfällen

Bundesregierung (2017) Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen (AwSV) vom 18. April 2017. – Bundesgesetzblatt Jahrgang 2017 Teil I Nr. 22, ausgegeben zu Bonn am 21. April 2017, p. 905–955

Denneborg, M (2018) Mögliche Umweltauswirkungen von Abfall- und Reststoffen in Steinkohlenbergwerken in Nordrhein-Westfalen.- Grundwasser im Umfeld von Bergbau, Energie und urbanen Räumen, 26. Tagung der Fachsektion Hydrogeologie e. V. in der DGGV e.V., Ruhr-Universität Bochum, 21. - 24. März 2018