Management of mine and tailings seepage water discharge in an intensively used watershed

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Abstract

Uranium mining and milling took place in the German Federal state of Thuringia between the early 1950's and 1990, causing a tremendous environmental impact in a very densely populated area. Following the end of mining a closure and remediation program has been initiated, which is financed by the German Government. The former Ronneburg uranium mine and Seelingstädt milling sites are both situated in the watershed of the Weiße Elster River. Water management of the Weiße Elster River has to ensure the competiting intensive industrial use by geochemical companies, active lignite mining and the uranium mining remediation as well as the recreational function and nature conservation in the frame of the European Water Directive.

An important part of the closure activities is the management of mine and tailings seepage waters with a total discharge of about 1000 m^3/h from both sites. Conventional lime water treatment is applied at both sites to reduce the radioactive and heavy metal content of the waters to be discharged. After treatment the waters still have high salt and hardness concentrations which are critical for the Weiße Elster River water quality. Therefore, discharges are very much constrained in periods of low water flow. These constraints seriously impact the remediation progress and the safe discharge of the overflowing mine water making a stringent water management strategy necessary for the sites depending on the flow conditions in the watershed.

The paper outlines management strategies for the mine water discharge including various activities on site but also watershed scale such as the increase of the river water discharge rate in low flow periods by water resources from upstream storage reservoirs, salt discharge management of the treated mine water, temporal storage of waters but also negotiations for a temporary increase of limit values. The interaction between the water management strategies and the remediation progress is discussed.

Keywords: mine water management, rivershed, salt concentrations, case study

Introduction

Intensive uranium mining and milling had been conducted in the eastern part of Germany between 1945 and 1990. When mining ceased in 1990 the urgent need to handle the legacies of this mining era were apparent. By the decision of the German parliament a remediation programme was initiated in 1991 to be financed by the German government. After two decades of intensive clean-up work physical remediation is close to completion. Management and treatment of contaminated waters, however, must be considered as a long-term task. Especially within the Weiße Elster River watershed water management requires an integral approach since remediation work at the Ronneburg and Seelingstädt sites is interfering with regard to its impacts to the water pathway.

Site characterisation

The Ronneburg uranium mining district in Eastern Thuringia is located at both sides of the water divide between the Weiße Elster and the Pleiße Rivers, which are both tributary to the Elbe River basin. Geologically the district is situated at the so-called Ronneburger Horst, the north-eastern part of the Berga anticline of the Thüringer Schiefergebirge (Thuringian shale highlands), where the host rocks of the mineralized zones are outcropping. Mineralisation was present as lenses and stockworks within a package of slates, magmatites and limestones, together approximately 250 m thick, reaching from upper Ordovician to lower Devonian (Paul et al. 2009). By the end of production in 1990 the mining legacy at the Ronneburg site consisted of a complex underground mine with 40 shafts and an open volume of about 24 million m^3 as well as an open pit with a mined out volume of 85 million m^3. While the open pit was backfilled the deep mine was decommissioned and flooded. Decanting of mine water in the deepest part of the Gessental valley started in 2007 requiring collection and treatment prior to the discharge into the receiving streams. Mine and seepage waters from the Ronneburg district carry high concentrations of dissolved iron, sulphate, heavy metals (Mn, Ni, Co, Cu, Zn, Cd) and radionuclides.

At Seelingstädt uranium ore was milled and processed between 1960 and 1990 producing in total about 110,000 t of uranium. Mill tailings were dumped at the two former open pitss of Trünzig and Culmitzsch. Additional dams were erected around the pit sites to facilitate the total volume of 103 million m^3 of sludges. The pore and seepage waters of these tailings are mostly neutral in pH with high salt contents (sulphate, chloride) hardness as well as uranium concentrations. Dry in situ remediation of the tailings management facilities started with first securing measures in 1991. To date the Culmitzsch tailings pond has been interim covered and partly re-contoured while final covering of the Trünzig pile is nearly finished. Remediation works will focus on the Culmitzsch pond in the following years resulting in additional pore water release due to settlement of the tailings material in the course of contouring and covering (Barnekow et al. 2011). The Weiße Elster River rises about 100 km upstream of the WISMUT sites. Various water reservoirs are used in the upstream for flood protection, recreation and as source for drinking and industrial water supply. Along the river a number of industrial water users and several towns are located influencing the river water quality mainly by their sewage waters. Downstream the WISMUT mining sites the river water is also extensively used while additional influences arise from water discharge due to active lignite mining. These conditions result in conflicting use of the river water within the catchment area imposing strict limits for the water use concerning the amount of water available and its chemical parameters. Figure 1 shows the part of the Weiße Elster River catchment directly affected by the WISMUT remediation sites as well as relevant monitoring points.

The Weiße Elster River catchment area upstream of the monitoring point e-419, is about 2,186 km^2 which is about 40 % of the total area ($5{,}154\ km^2$). The average flow rate is 15.4 m^3/s based on the hydrological period between 1956 and 2000. At both remediation sites water treatment plants are in operation. A lime treatment technology is used to treat the mine and seepage waters to reduce the content of heavy metals and radioactive elements. Table 1 shows some characteristic values of the discharged treated waters.

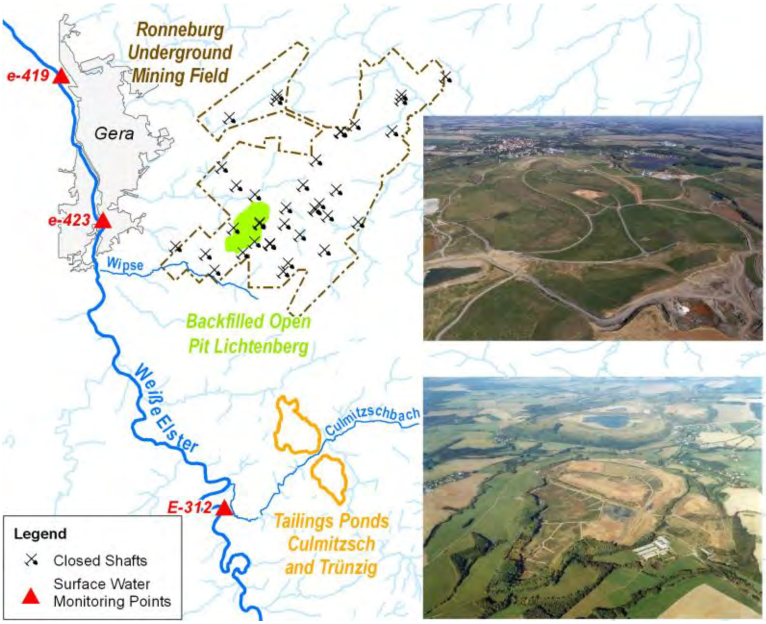

Figure 1 *Location of the remediation sites within the Weiße Elster River catchment*

Discharges from the two remediation sites into receiving streams are allowed at one discharge point respectively. The water discharged from the treatment plants is regulated concerning main parameters such as uranium and species influencing the total salt content. Downstream of the discharge point limit values for uranium and salt contents have to be also met in the receiving streams. These smaller tributaries flow into the Weiße Elster River where for the joint release from both sites again concentration limits for sulphate, chloride as well as the hardness are imposed (measurement point e-423 in Figure 1).

Release limits from the treatment plants are influenced by the water quality of the collected waters as well as the technological conditions. While the emerging loads at the remediation sites are fairly constant, concentrations in the receiving streams and the Weiße Elster River are strongly influenced by the flow regime in the river as well as upstream releases of third parties (monitored at the measurement point E-312- see in figure 1). Management of water collection and treatment at vast remediation sites are therefore strongly influenced also by third parties.

Implemented remediation measures at the former mining and milling sites already resulted in a decrease of average contaminant concentrations in the affected river system during the last 20 years (Paul et.al 2008). However, the necessary measures for the stabilisation of the tailings ponds and the finalisation of mine flooding will temporarily lead to an increase of the loads released from both sites. Facing this problem of rising loads due to the ongoing remediation activities WISMUT had to consider a number of management strategies to cope with the described restrictions.

Table 1 *Characterisation of discharged waters from the treatment facilities*

Remediation site	**Water Tratment Capacity (~ Water Discharge)** m^3/h	**Average SO4-concentration in discharged waters (2011)** mg/l	**Average hardness in discharged waters (2011)** °dH	**Average dilution factor in Weiße Elster River**
Background concentration Weiße Elster (E-312)	-	94	8.5	-
Ronneburg mining district	750	2,912	164.4	1:50
Mill tailings site Seelingstädt	300	2,876	94.4	1:125
Downstream concentration Weiße Elster (e-423)	-	200	14.4	-

In order to reduce the long-term impacts a continuous remediation progress has to be ensured. On the other hand mitigation of immediate risk from decant mine waters as well as work efficiency makes the operation of the treatment plants at full capacity as well as the subsequent release of the treated waters inevitable.

Management alternatives

Presently meeting the limit values in the receiving stream is mainly critical during periods of low flow in the surface water streams which is the case especially during the summer months. In addition predictions of the load release due to the necessary remediation works at both remediation sites (Figure 2) indicate that the conditions will worsen and the given limits might force to hold or slow down the remediation progress over a period of several months.

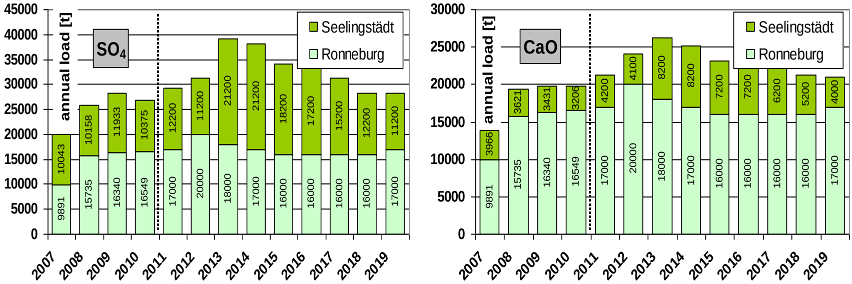

Figure 2 *Measured and predicted released loads of sulphate and hardness (as CaO) based on the planned remediation progress*

Facing the need to consider measures to avoid any impacts on the remediation process the following management alternatives have been evaluated:

- Salinity management in surface streams
- Extension of treatment capacity
- Intermediate storage of treated waters
- Reduction of contaminant water formation
- Storage of clean waters
- De-salination treatment
- Water feeding from upstream storage reservoirs
- Negotiation of temporary limit values

Salinity management in surface streams allows to limit the release of loads by controlling the water quantity discharged based on the flow conditions in the receiving streams. Using available monitoring results procedures were derived to estimate the load of the water upstream of the remediation sites based on the discharge rate continuously measured. Comparing the upstream loads with the maximum loads allowed due to the limit values the total release from both sites is calculated and the operations are adapted to it. Taking into account the uncertainty of the predictions as well as the inertness of the flow system a safety factor was considered to meet the limit values. This procedure allows to optimise the operation but requires to decrease the discharge from the treatment plants as needed. A sequence of measures to decrease the treated volume was determined. Highest priority was given to a continuous treatment of the decant water from the Ronneburg mine because of risk mitigation. As a result the works at Seelingstädt had to be slowed down considerably.

An *extension of treatment capacity* is a costly measure but offering the necessary additional flexibility. However, contaminated waters accrue continuously and have to be stored in case of limited capacities. At the Ronneburg site the water decant from the mine considerably increased. To finalise remediation additional measures have to be implemented requiring a significant drawdown of the mine water table. This made an extension of the capacity of the water treatment plant from 500 m^3/h to 750 m^3/h necessary. While during the following about 5 years the full capacity is needed for mine water management in the long term intermediate storage of waters in the mine during low flow periods will allow to remain well under the concentration limit values set in the receiving streams. Thereby less water than the average water balance requires is pumped from the mine and treated during low flow periods while more water is taken out during the remaining time. Nevertheless the resulting temporary fluctuation of the mine water table might adversely influence the long-term contaminant release from the flooded underground mine due to additional mixing and aeration of the mine water body.

Intermediate storage of treated waters would allow to run the treatment plants on full capacity over the entire period. The storage of the treated water would require the construction of additional ponds. Predictions show that these ponds would need to have a capacity in excess of 0.5 million m^3 and need to be placed at both sites. Apart from cost issues and the need of a lengthy permitting process no appropriate area is available at the remediation sites to construct storage reservoirs of such dimensions. As outlined before, in the long term the storage of waters in the Ronneburg underground mine will be a useful alternative but will be available only beyond 2015 when the water level in the mine will be sufficiently lowered.

Reduction of contaminant water formation is a major aim of the entire remediation work. Due to the vast areas of the mining and millings sites in addition to mine and seepage waters also surface waters are collected from both former operational areas as well as the surface of tailings and waste rock piles. To use the available treatment capacity more effectively the untreated release of clean waters from already remediated parts is pursued. This, however, has no effect on the loads to be released and therefore does not ease the general problem of restriction by the concentration limits in the receiving streams. On the other hand *storage of clean waters* would allow to add water for dilution under low flow conditions. As an effective measure again huge storage volumes would be required. Nevertheless, at the Seelingstädt site a small basin (50,000 m^3 volume) resulting from cover material winning is used as temporary storage for uncontaminated surface waters. As outlined before the availability of areas as well as water sources for this alternative is strongly limited.

Extensive studies were conducted to identify possible treatment technologies to influence the released loads e.g. by *De-salination treatment*. The available technologies as well as their limitations were determined by a literature review as well as laboratory experiments taking into account the site conditions. Different treatment options were considered utilising chemical or physical methods. Chemical methods based on adding of lime or $BaCl_2$ were found extremely costly due to chemicals consumption and sludge formation which would have to be disposed. Physical methods such as evaporation or membrane filtration require a proper handling of the residues. Because the residues would be radioactive no adequate solution for their disposal could be found. In addition the limited period of operation of such a treatment facility resulted in the decision that these technologies are not appropriate under the given conditions.

Due to intensive industrial use along the Weiße Elster River dams were erected in the upper part to provide drinking and processing water as well as to regulate the river discharge in low flow periods and under flood conditions. Negotiating with the operators of these storage reservoirs an additional w*ater feeding from upstream storage reservoirs* was agreed on a contractual basis. Thereby the operators guarantee a minimum discharge at the Weiße Elster River section receiving the discharges from the remediation sites. This minimum level is about 0.5 to 1 m^3/s higher than the normal discharges in the low flow period.

In addition to the technical measures WISMUT negotiated a *temporary increase of limit values* for the most critical parameter of hardness with the responsible authorities. In addition to the involvement of downstream users of the river water the ecological aspect is a major issue. Downstream various conservation areas are situated which are protected in the framework of the European Council Directive on Conservation of natural habitats and of wild fauna and flora (92/43/EEC). An extensive biological monitoring of these areas documenting any adverse effect of the increased concentrations was considered as precondition for a temporary increase of the limit value for hardness. In case of a deterioration compensation measures will be required. Due to the number of interested parties and the extent of the influenced downstream river stretch these negotiations were extremely difficult and time consuming. It is required by law that all reasonable measures are taken to avoid the increase of concentrations in the river. A limited period of the concentration increase and the expected long-term reduction of the impact from the sites as result of the remediation activities are aspects to increase the acceptance of an increase of the limit values.

Results and Discussion

The ongoing remediation of two extensive former uranium mining and milling sites in the catchment area of the Weiße Elster River is connected with the collection of contaminated seepage, consolidation and mine waters. After conventional lime treatment used at both sites the discharge waters carry high concentrations of salts and hardness. Depending on the hydrological conditions limit values in the receiving stream are reached requiring a reduction of the water discharge and thus interfering the remediation progress. With advancing remediation the flexibility for shifting of works is more and more limited, therefore the importance of a sound management of the emerging waters is significant.

Various alternatives have been discussed for the remediation of the Thuringian remediation sites. Already at an early stage it was found that only a combination of different measures will ensure the compliance with the limits under reasonable economic conditions. The decision concerning the appropriate measures is also influenced by the limited time period where due to the overlap of remediation activities peak loads will be released in the near future making major investments unrealistic. Furthermore additional treatment measures would resulting in additional residues which are critical to handle.

As a consequence, management of water discharges mainly focuses on the control of the released loads of sulphate, chloride and hardness from both sites depending on the hydrological conditions within the receiving streams. This is supported by an extension of the treatment capacity to gain flexibility for the future and to ensure that all emerging waters are properly treated. To reduce the effect of low flow conditions WISMUT contracted the operators of upstream storage reservoirs to discharge additional water to ensure a higher minimum water flow in the Weiße Elster River at the inflow of waters from the remediation sites. In addition to the implemented technical measures the temporary increase of the limit values allows a continuous progress of the site remediation.

Conclusions and Outlook

A crucial part of the remediation of mining sites is the management of the collection, treatment and discharge of emerging water. It has to be considered that during the remediation process the quantity and the quality of the collected waters might vary requiring to continuously adapt the water management schemes. Limit values in the surface streams impose a significant constraint on the water management and thereby on the remediation progress itself. In this case the loads to be discharged on a daily basis depend on the hydrological conditions in the receiving stream and the general water use in the catchment area while the contaminated waters at the site emerge continuously. To meet the limit values a combination of technical and administrative measures is necessary taking into account economically feasible solutions.

For the two WISMUT sites discussed here the combination of a whole variety of measures is relevant for different time periods. In the period until 2015 all possible technical short-term measures are introduced in combination with an amendment of river water at low flow conditions and an increase of the relevant limit value for hardness. In the following period the releases will further decrease due to the implemented measures, and the existing storage and treatment capacities will be sufficient to manage the load discharge depending on the hydraulic conditions properly with regard to the existing limit values.

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