Management of water collection and treatment in the remediation of an uranium mill tailings site

Thomas Metschies, Jan Laubrich, Jürgen Müller, Michael Paul, Ulf Barnekow

WISMUT GmbH, Jagdschänkenstraße 29, 09117 Chemnitz, Germany

Abstract As of the-Mid 1990s remediation of former uranium mining and milling sites is under way including the geotechnical stabilisation of tailings storage facilities at Seelingstädt (Germany). With advancing remediation water management requirements evolve facing new challenges: changing chemical water composition, more restrictive concentration limits and shrinking water storage space while the treated water volume just slowly decreases. The paper outlines ways to adapt water collection and treatment strategies to the new challenges and points out the influence of water management on the physical remediation works. Lessons learned for similar remediation projects are presented to allow considering relevant aspects at an early stage of a mining legacy remediation planning.

Keywords Mine water management, mill tailings, remediation, case study

Introduction

Uranium mining and milling in Eastern Germany took place between 1946 and 1990. A significant portion of the mined ore was processed at the Seelingstädt milling site leaving behind the two major tailings storage facilities (TSF) of Trünzig and Culmitzsch with a total volume of about 105 Mm^3 of stored tailings material. Each of the TSF consists of two individual ponds separated by a dividing dam and store the residuals of the alkaline and the acidic leaching process respectively. The storage facilities were developed in mined out open cast uranium mines operated between 1949 and 1967. Additional rock-fill dams were erected to contain the deposited tailings material. These dams were sealed by discharging fine slimes (auto-stable dams). Tailings material was disposed into the Trünzig TSF from 1960 until 1967 and the Culmitzsch TSF between 1967 and 1990. According to the historic discharge pattern, sandy tailings settled out near the discharge points while fine tailings more distantly below the water table usually in the centre of the ponds (Barnekow *et al.* 2012).

By the end of uranium production in 1990 only the Culmitzsch TSF was in use while the Trünzig TSF was already inoperative and remained in a managed but unremediated condition with supernatant pond water covering most of the deposited material.

A dry *in situ* stabilisation technology was selected as the most appropriate general remediation option under the given local conditions requiring the removal of supernatant pond water as a first step. Concurrently with this, the exposed tailings surfaces were immediately covered with an interim cover layer of 1 m thickness to reduce radiological impacts. Before covering and contouring the tailings material had to be geotechnically stabilised using various technologies. During this process highly contaminated pore waters were released from the tailings material which had to be treated. For the covering of the tailings preference was given to locally available materials from adjacent mine dumps.

Site characterization

The conditions at the four separate ponds of the Trünzig and Culmitzsch TSF are summarised in Table 1. In terms of area covered and stored material volume the Culmitzsch TSF clearly exceeds the Trünzig TSF. Because of the earlier end of deposition and the consequently more advanced process of consolidation, contouring and final covering of the Trünzig TSF started already in 1992 and is nearly complete now.

Remediation of the Culmitzsch TSF will last until 2022. The present status with contouring work in progress on pond B is shown in Fig. 1. Pond A still contains supernatant water on top of the fine slimes.

Pore and seepage water composition is strongly determined by the chemical processing applied (Table 1). While pore water from the acidic process deposited in the A ponds contains very high concentrations of iron and magnesia thus resulting in elevated hardness, the main characteristics of the pore waters at the B ponds are high uranium concentrations. Sulphate and chloride concentrations are generally high in both ponds. Table 2 shows the average as well as a representative range of the concentrations of major water constituents based on samples from sampling wells in the sandy and transition zones. Pore water of the fine slime tailings stored in major parts of the TSF contains even higher concentrations (Table 3).

In 2001 a treatment plant was put into operation close to the TSF with a design capacity of 300 m^3/h, replacing the water treatment unit of the former mill. The main treatment of collected water is done by lime addition thus reducing the concentration of metals and semi-metals as well as of uranium below the discharge limits but not decreasing the salt and hardness content. Uranium complexes have to be removed prior to the lime treatment. Therefore the water is acidified and fed into stripping columns where free CO_2 is removed by an air stream to reduce the carbonate content of the water as a first step.

Seepage water collecting drains and pumping wells are installed downstream of the TSF to contain the flow of contaminated waters. These actively collected waters and any other surface water or contaminated seepage

Fig. 1 *Aerial photograph of the Culmitzsch TSF with pond A (left, with supernatant water) and pond B (right) and the Lokhalde waste rock dump (centre foreground) during remediation (2012).*

Tailings Impoundment	Culmitzsch Pond A	Culmitzsch Pond B	Trünzig Pond A	Trünzig Pond B
Residues of processing type	Acidic	alkaline	acidic	alkaline
Tailings surface area (ha)	159	84	67	48
Tailings volume (Mm^3)	61	24	11	6
Solid mass (Mt)	64	27	13	6
Max. tailings thickness (m)	72	63	30	28
U_{nat} in solids (t)	4,800	2,200	1,500	7,00
U_{nat} in pore water (mg/L)	0.3 ... 3.9	1.0 ... 16.5	1...19	1...20

Table 1 *General characterization of the TSF at the Seelingstädt site.*

2000 – 2013	pH	U mg/L	Mg mg/L	Ca mg/L	SO_4 mg/L	Cl mg/L	Fe mg/L	Ni µg/L
Pond A								
Median	8.0	0.9	1,300	380	12,000	1,500	0.67	28
10^{th} percentile	7.2	0.2	590	340	7,200	860	<0.08	<15
90^{th} percentile	8.3	2.2	2,300	420	15,000	2,200	104	470
Pond B								
Median	8.3	6.2	110	27	8,200	1,100	0.18	<20
10^{th} percentile	7.8	0.9	66	11	6,200	750	<0.04	<10
90^{th} percentile	8.7	11.2	650	380	9,500	1,500	1.15	40

Table 2 *Concentration levels in sampling wells at the beach and transition zones of the Culmitzsch TSF.*

2000 – 2013	pH	U mg/L	Mg mg/L	Ca mg/L	SO_4 mg/L	Cl mg/L	Fe mg/L	Ni µg/L
Median	6.7	0.3	1,400	380	11,000	1,300	75	410
10^{th} percentile	5.9	0.1	700	360	6,600	770	14	68
90^{th} percentile	8.0	1.9	2,800	460	15,000	2,400	220	1400

Table 3 *Concentration levels in pore water of fine slime tailings of the Culmitzsch TSF pond A (sampling points CA 90A, CA91A, CA 93A).*

and pore waters pumped from the TSF are treated. Standards for waste water discharge into the receiving streams were set by the regulatory authorities of Thuringia for metals, semi-metals and uranium. Limits for the salt concentrations and water hardness are given for a sampling point in the receiving Culmitzsch creek downstream of the tailings site as well as further downstream in the Weiße Elster river. At least temporarily these limits restrict the discharge volume of treated waters and therefore curtail the water management operations at the Seelingstädt site (Metschies *et al.* 2012). As a result the full technical capacity of the water treatment plant might not be available throughout the year depending on the discharge conditions in the respective water bodies as well as additional sources of salts and hardness in the watershed.

During the ongoing remediation of the Culmitzsch TSF additional major challenges for the water management are (1) the treatment and release of supernatant waters from the pond A in order to allow sufficient work to progress on the surface areas, (2) the collection and treatment of the released, pumped or expelled pore waters and as a consequence (3) the continuous adaptation of the water treatment to the changing water composition to ensure the full treatment capacity is available throughout the year.

Water quantity aspects

On average about 40 to 50 % of the treated waters are seepage and contaminated groundwaters which continuously emerge. The Trünzig and Culmitzsch TSF, as well as the adjacent operational areas such as waste rock dumps and the former milling and processing site, cover a total area of about 650 ha. The collected surface run-off from this area requiring treatment strongly depends on the climatic conditions. The annual average precipitation varied between 450 and 800 mm during the past 10 years dramatically influencing the collected water volumes. Even with the existing water treatment plant running close to the design capacity (Fig. 2, left diagram) such variations of the collected water quantities are not easily to cope with. Therefore especially during past wet years the storage of surplus waters in pond A (Fig. 2, right diagram) was necessary to ensure the safe operation of the treatment facility and as consequence to meet the limit values for the discharge.

With the progress of geotechnical stabilisation and covering of the Culmitzsch TSF the large water storage potential of pond A will not be available for water storage in the future. Consequently the need for additional storage volumes at the site or alternative management measures arises. Construction of a water storage facility to accommodate the surplus water of up to 1 Mm^3 (Fig. 2) in case of extended periods of precipitation is not feasible. Apart from the cost aspect and a lengthy permitting process any reservoir of such size within the TSF would interfere with the remediation goal while due to the contamination of the collected waters (*e.g.* U) a storage pond outside of the existing radiation protection area will not be permitted.

Therefore the further water management at the site requires a combination of (1) reduction of contaminant water formation and (2) the installation of a reasonable storage volume for the time till the end of physical remediation works.

Separate collection of uncontaminated surface waters from already remediated areas and their direct discharge into the receiving creeks is pursued. This however requires agreements with the permitting authorities regarding additional discharge points and quality criteria for waters to be discharged. Therefore, priority is given to selecting such discharge points where surface waters will be permanently discharged due to the final contour of the facilities. Nevertheless it has to be proven that the discharge limits are met and that no additional risks for floods are generated by these discharges in case of high waters. Following this concept it was possible to already reduce the surface water inflow to the treatment system from a total area of nearly 150 ha till now decreasing the total drained area by about 20 %.

The storage capacity in engineered basins at the site is presently extended to about 100,000 m^3 which in combination with other management measures will allow to cope with most of the expected rainfall scenarios (compare Fig. 2) based on the conditions of previous years. Nevertheless the contaminated overflow of these storage reservoirs is directed into the pond A and thereby remaining safely contained within the existing depression of the pond surface. Therefore the technical planning and implementation of the stabilisation and contouring work on pond A have to make sure that in case of such extreme precipitation events only separated areas of the pond are reflooded and that work could safely proceed without disruption on the remaining un-

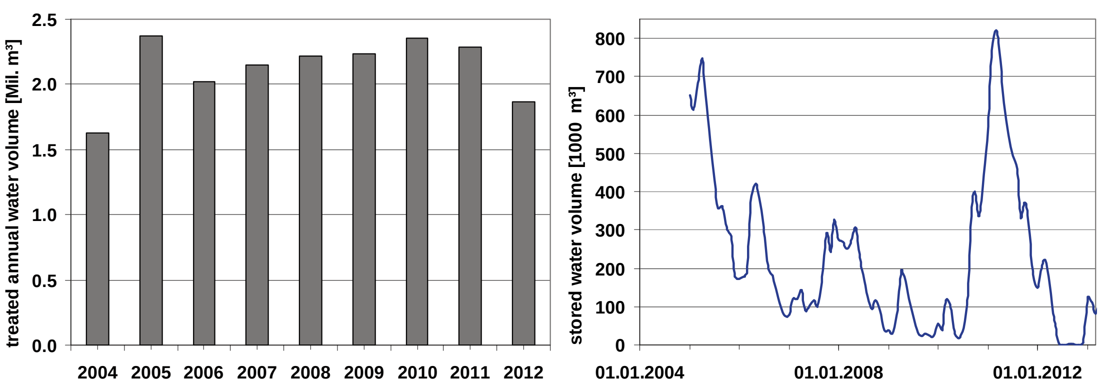

Fig. 2 *Treated annual water volumes (left) and water volume of the supernatant water body stored on top of pond A of the Culmitzsch TSF.*

flooded part. This requires adapting continuously the contour of the pond surface during remediation to account for the temporary storage of the surplus water. On the other hand it has to be ensured that in such cases the water is removed from the re-flooded areas as soon as possible and sufficient storage volume is generated again in the available reservoirs to minimise the impact on the already stabilised, contoured and covered areas.

Water quality aspects

Short term fluctuations in concentration levels in the collected waters result from the meteorological conditions showing a clear seasonal variation (Fig. 3), but also from operational conditions such as the emergence of pore waters during the consolidation of the fine slime tailings. These fluctuations were smaller in case of high volumes stored in pond A resulting in a homogenisation of the feed flow to the treatment plant.

Long-term concentration trends as shown for sulphate and uranium in Fig. 3 are influenced by two partly opposing processes: (1) a continuous dilution of the outflow from the contaminant source and (2) the initiated additional water release in the progress of the remediation works. As a consequence of the temporary covering and contouring of the tailings material considerable volumes of highly concentrated pore waters are collected for treatment. On the other hand seepage water flow from the tailings is reduced resulting in a reduction of contaminant release in the mid- and long-term.

The geotechnical stabilisation and contouring of the Culmitzsch TSF pond B commenced already in 2009 contributed 15 to 25 % to the total uranium load in the flow to the water treatment plant in the past years. In addition to other effects uranium concentration of the waters increased making higher demands to the treatment operation to meet the discharge limits. The influence of expelled pore waters from the pond B will decline in the future but reduced dilution will nevertheless lead to higher uranium concentrations in the feed water to the treatment plant. In addition uranium removal from the waters depends on the effectiveness of the stripping process which itself is sensible to air and water temperatures. To adapt the existing treatment technology to this future development an optimisation of the acid dosage and additional air sparging prior to the stripping columns is presently implemented.

Starting in 2014, the geotechnical stabilisation of pond A will again lead to significant changes in the composition of the collected water by the additional release of an expected 3 Mm^3 of pore water as result of the consolida-

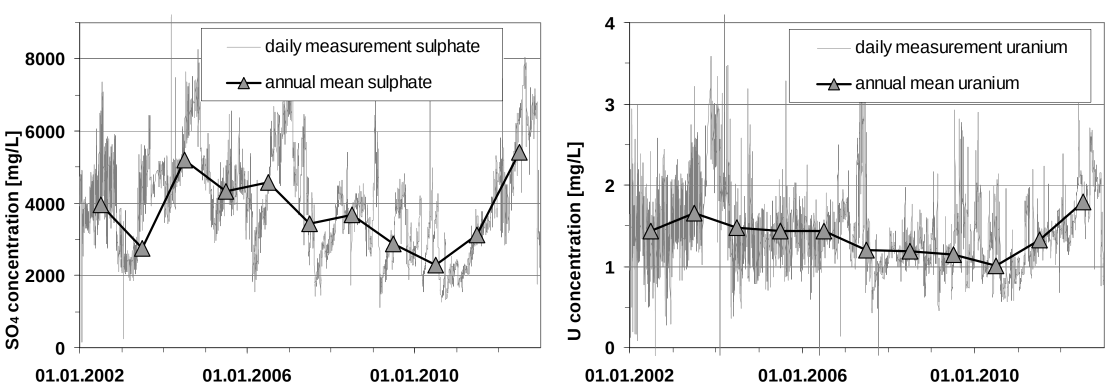

***Fig. 3** Long-term trend of concentrations in the feed water to the treatment facility versus daily fluctuations.*

tion of fine tailings mainly over a period of about 5 years. Based on sampling of pore waters in the fine slime tailings, iron concentrations of up to 250 mg/L (Table 3) are expected in these waters having tremendous influence on the operational stability of the treatment process. Presently technical measures are planned and implemented to cope with these waters to ensure a stable operation of the treatment facility.

Discharge limits apply to sulphate and chloride as well as hardness given as concentrations in the receiving creek downstream of the tailings site. Especially under low flow conditions this constrains the discharge from the treatment plant requiring to temporarily halt the water treatment as it happened in 2012 when the treated volume was significantly reduced (fig. 2). During that time no significant accumulation of water in the pond A occurred due to the similarly reduced surface run-off. At the same time additional pore water pumping from sandy beaches in order to reduce the mobile contaminant inventory was not possible although sufficient treatment capacity would have been available. To optimise the remediation and allow additional water discharge even under low flow conditions it was agreed with the authorities as a temporary measure to additionally discharge water pumped from the Weiße Elster river via a pipeline formerly used to pump processing water for the milling operation. This increases the flow rate in the Culmitzsch creek and allows to continuously discharge waters from the remediation site.

Conclusions

Management of surface, seepage, pore and groundwaters in terms of water quantity and quality is a crucial part of any tailings remediation project. Progress of physical remediation works and the operation of the water collection and treatment closely depend on each other. These interactions have to be seriously taken into account in planning the remediation works already at an early stage especially in extensive remediation projects.

It is one of the main scopes of the remediation to achieve a reduction of water contamination. Therefore the management of uncontaminated and contaminated waters is a relevant aspect under the remediation project. With remediation in progress the amount of surface waters meeting the discharge limits should continuously increase. A minimisation of the hydraulic load onto the water collection and treatment system could be required to ensure necessary technical resources for the water management. Separation of uncontaminated precipitation and surface runoff and their direct discharge or reuse could be achieved by a continuous management of the respective catchment areas during the ongoing remediation but requires a close coordination between the construction activities and water management on the site. However, separation of clean water should be done at reasonable costs because additional effort might be required in terms of construction work to provide the necessary pipes or channels as well as to contain the respective catchment areas. On the other hand isolation and discharge of clean fractions of water also influence the operation of other parts of the site water management. It could have an effect on the remaining water composition which itself directly influences the treatment operation possibly requiring a necessary revision or even extension of the treatment process.

Changes in the water quantity and quality may occur over the entire project period and have to be monitored thoroughly. A prediction of these changes is necessary to adapt the water collection and treatment in due time. This requires a thorough understanding not only of the remediation object but also of the interaction with the surroundings in terms of hydrogeological and hydrological conditions as well as the relevant sources and sinks for the geochemical components but also the transport pathways of the waters to be handled. In addition the possible effects of the future remediation works on the composition of the collected water have to be taken into account in these predictions.

Providing sufficient water storage capacity on the site is essential to ensure a stable operation of the water treatment unit in terms of cutting peaks of water discharge as well as to ensure a constant rate and composition of flow to the treatment facility. The storage basin or ponds need to be located on the site properly avoiding an interference with the future remediation progress. Planning of these storage facilities should already take into account any relevant needs for the removal of the installations or any contaminated precipitates at the end of the remediation operation.

Release limits for the water discharge into the receiving stream might impose significant constraints on the water management at the site. Especially concentration limits set for the receiving stream which depend on the flow rate within these streams could influence the possible discharges depending on the seasonal variations. The applied treatment technology should therefore assure that the limits are met even under unfavourable conditions with low flow rates in the watercourse and high concentrations of the collected waters to be treated.

In planning such type of remediation projects provisions in terms of costs and effort have to be made for a continuous monitoring, evaluation, optimisation and adaptation of water collection and treatment at the remediation site. As far as possible the choice of treatment technology applied should provide for a safe operation during the entire remediation period taking into account the expected variance of the relevant parameters.

References

Barnekow U, Müller J, Metschies T, Paul M (2012) Experiences gained and major challenges for the remediation of Wismut's Culmitzsch tailings pond. In: Fourie AB and Tibbett M (Eds), Conference Mine Closure 2012, Australian Centre for Geomechanics, p 209 – 222

Metschies T, Paul M (2012) Management of mine and tailings seepage water discharge in an intensively used watershed. In: McCullough CD, Lund MA, Wyse, L (Eds), International Mine Water Association Symposium, Bunbury Australia, p 409 – 416