Use of mine water for filling and remediation of pit lakes

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Abstract Water from dewatering operations of operating mines was used for the filling and management of pit lakes successfully in Germany. The mine water contributed considerably to the filling of pit lakes in Germany in the last 20 years. Its use allowed for fast filling of the pit lakes, stabilising the side walls of the mine voids and avoiding acidification of the pit lakes. This paper reports on the experiences from the southern part of the Central German lignite mining district where mine water was the main source for the filling of pit lakes in the last 20 years.

Key Words acidification, neutralisation, pit lake, flooding, water quality management

Introduction

Many new pit lakes had to be filled in eastern Germany since 1990 because of the closure of the majority of the lignite mines in the Lusatian and in the Central German lignite mining districts (Krüger *et al.* 2002). Fast filling of the mine voids was the preferred filling strategy to stabilise the side walls of the mine voids, to avoid acidification of the forming pit lakes and to allow for new developments in the post-mining landscape as fast as possible. Diversion of river water was the main way of fast filling. However, the use of water from dewatering operations of active mines (referred to as mine water in the following) also contributed substantially to the filling of the pit lakes in the last 20 years (763×10^6 m^3, corresponding to 21.2% of the pit lake volume filled in that period).

Mainly four aspects stimulated the consideration of mine water as a source of water for filling pit lakes in the Central German lignite mining district in the first half of the 1990s: (a) The quality of river water was poor, with high concentrations of biological and chemical oxygen demand, of phosphorus, nitrogen and, at least in some cases, heavy metals and other trace contaminants. Adequate waste water treatment was in an early stage of implementation. The experience from a well monitored filling of a pit lake with river water was not available yet. Therefore, treatment of the river water was discussed to ensure an adequate water quality of the new pit lakes suiting the requirements of the planned use, mainly recreation. (b) Treatment facilities for the mine water of the still operating mines were required by the regional authorities in order to improve the water quality of the rivers. In particular, the iron load of the mine water (on average <10 mg/L) affected the rivers by oxygen consumption and turbidity. (c) The iron concentration of the mine water of the operating mines was low compared to the acid waters occurring in abandoned mine voids (>200 mg/L of iron). The water from the operating mines was net-alkaline, mainly natural groundwater originating from areas which were not influenced by mining before. Estimates indicated that the bicarbonate of the mine water would be enough to neutralise the majority of the pit lakes to be filled. (d) The use of the mine water provided an economic benefit for the ones responsible for the filling of the pit lakes (Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft, LMBV) as well as for the operators of the active mines (Mitteldeutsche Braunkohlengesellschaft, MIBRAG). Costs for construction and operation of treatment facilities could be saved by both parties.

The southern part of the Central German lignite mining district (fig.1) is an excellent example for the use of mine water for filling pit lakes since the majority of pit lakes filled there in the last 20 years were filled with mine water. No river water was used and only few pit lakes were filled exclusively by groundwater rebound.

Data source and study area

All chemical data used in this paper originate from the monitoring program of the LMBV which is responsible for the remediation of lignite mines closed after 1990 in eastern Germany. The chemical analyses were done by contractors of the LMBV according to German standard methods for water analysis (DEV 2009). In this paper, only results from the lake surface are presented. Regular sampling at further depths indicated that the presented results from the lake surface were representative.

Fig. 1 shows the southern part of the Central German lignite mining district. Tab. 1 summarises details of the pit lakes numbered in fig. 1. The lig-

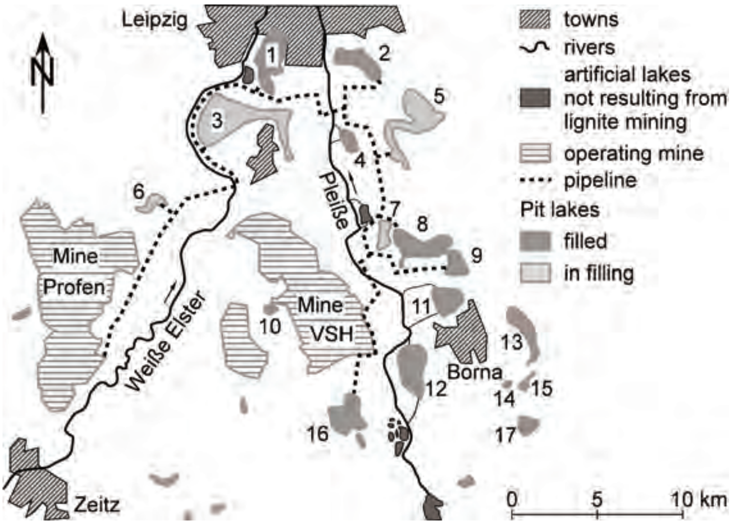

Figure 1 *Map of the southern part of the Central German lignite mining district. Only pit lakes are numbered which were filled after 1990 or which are of special importance for the water management in the region. For details on the numbered pit lakes see tab. 1. VSH – Vereinigtes Schleenhain.*

Table 1 *Morphometric data, kind and state of filling and dominating use of the pit lakes in the south of Leipzig; * - state as per cent of total volume (in March 2011). ** - filled before 1990.*

	Lake	Volume	Area	Maximal depth	Filling kind	Filling state*	Dominating use
		10^6 m³	ha	m		%	
1	Cospuden	109	439	54	mine water	100	recreation
2	Markkleeberg	60	252	62	mine water	100	recreation, nature conservation
3	Zwenkau	176	963	50	mine water	43	recreation, flood protection, nature conservation
4	Stöhna	11	280	10	groundwater	100	flood protection, nature conservation
5	Störmthal	157	733	56	mine water	91	recreation, nature conservation
6	Werben	8.9	80	32	mine water	70	nature conservation
7	Kahnsdorf	22	125	43	mine water	96	nature conservation
8	Hain	73	405	49	mine water	100	recreation, nature conservation
9	Haubitz	25	160	40	mine water	100	nature conservation
10	Großstolpen	0.3	28	5	mine water	100	recreation
11	Witznitz**	53	236	30	groundwater	100	reservoir, flood protection
12	Borna**	97	550	38	groundwater	100	flood protection, recreation
13	Bockwitz	19	170	19	groundwater	100	nature conservation
14	Hauptwasserhaltung	1.1	19	11	groundwater	100	nature conservation
15	Südkippe	1.6	33	6	groundwater	100	nature conservation
16	Haselbach	24	335	31	mine water	100	recreation, nature conservation
17	Harthsee	5.4	88	14	groundwater	100	recreation

nite of the Central German mining district is of Tertiary age. The seams are embedded in unconsolidated rock like gravel, sand, loam and clay. Therefore, the side walls of the mine voids are susceptible for erosion by overland flow and wave action in the filling pit lakes as well as for land slides when groundwater rebound occurs. A general overview on the geological conditions in the Central German lignite mining district can be found in Eissmann (2002a,b) and on the pit lakes in Schultze *et al.* (2010).

Filling and management of pit lakes in the south of Leipzig with mine water

The main sources of mine water for filling pit lakes in the south of Leipzig were the operating mines Profen and Vereinigtes Schleenhain (VSH) which are owned by MIBRAG. Fig. 2 shows the

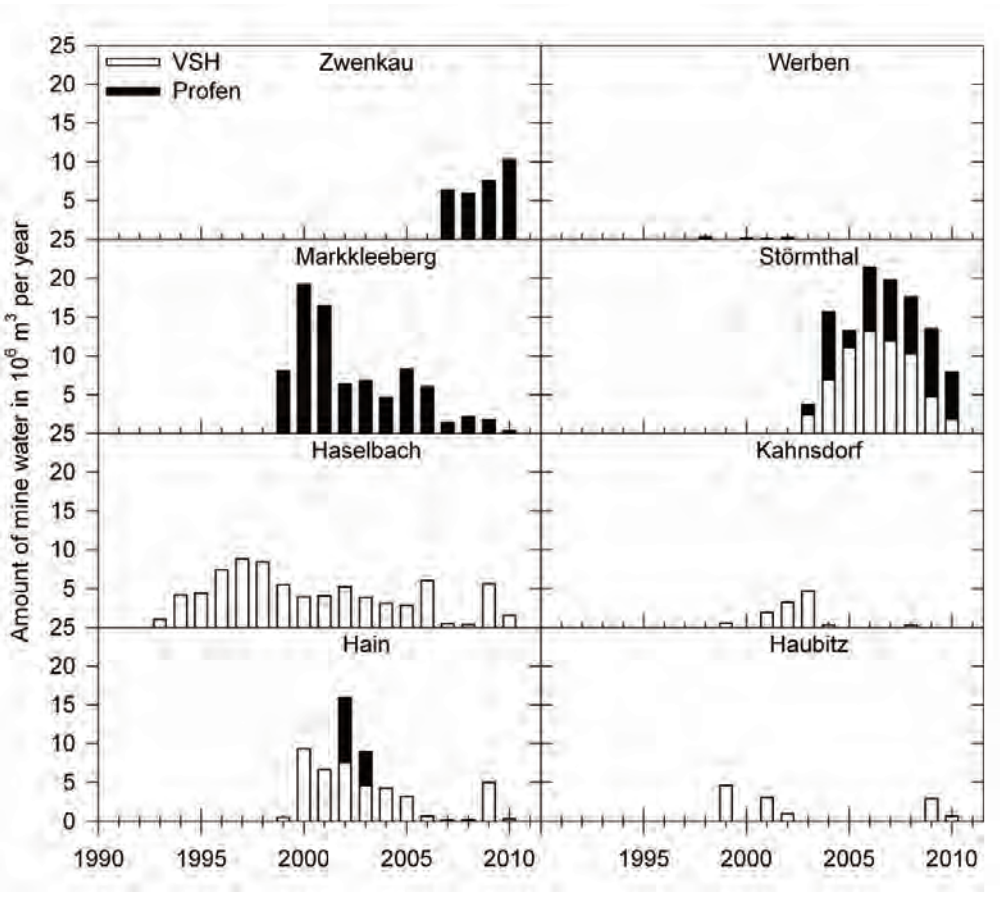

***Figure 2** Amount (per year) and source of mine water used for filling and management of pit lakes in the south of Leipzig (except Lake Cospuden). VSH – Vereinigtes Schleenhain.*

amount of mine water from the two mines diverted into the lakes for filling and management of the lakes over time, except for Lake Cospuden. The development of Lake Cospuden is presented in a separate section of this paper in more detail. The mine water was introduced at the surface of the pit lakes.

In some cases, dewatering operations of the former mines had to be continued into the period of filling of the pit lakes. Such operations were limited to areas where high groundwater levels close to the side walls of the mine voids put the side walls at risk of heavy erosion and land slides. The water resulting from such operations was generally diverted into the filling pit lake. Usually, the contribution of this water to the filling was small compared to other sources of water.

In all pit lakes, groundwater contributed to the filling of the pit lakes. In particular, the aquifers at the bottom of the mine voids which were never fully dewatered provided groundwater for the filling of the pit lakes. At the same time, the upper aquifers which were fully dewatered received water from the filling pit lakes. In this way, the water level of the filling lake could be kept higher than in the aquifers relevant for the stability of the side walls.

The quality of the mine water from the mines Profen and VSH differed due to differences in the local geology and in particular due to the different influence of already mined areas (fig. 3). Compared to mine Profen, a bigger portion of the mine water of mine VSH originated from already mined areas causing a considerably lower acid neutralisation capacity. Since 1998, there was even a tendency of increasing influence of already mined areas on the water quality of the mine water for both mines. In the case of mine VSH, this development resulted in the exclusion of this mine water from filling and management of pit lakes. The

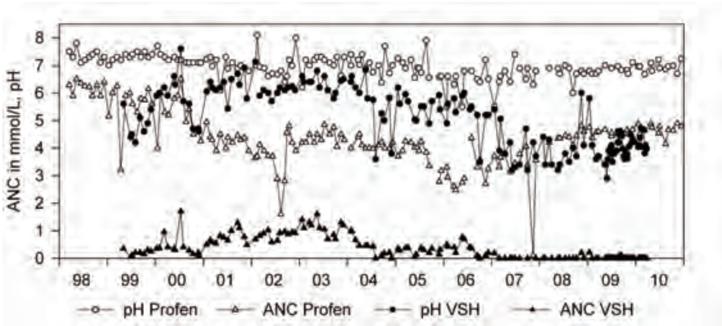

Figure 3 pH and acid neutralisation capacity (ANC, analysed by titration with 0.1N HCl to pH 4.3) of the mine water from the mines Profen and Vereinigtes Schleenhain (VSH).

only exception is Lake Haselbach were this mine water is still used to stabilise the water level. Lake Haselbach is located within the catchment area of the dewatering operations of mine VSH. Fig. 3 shows the pH and the acid neutralisation capacity of the mine water from the mines Profen and VSH.

For the lakes Zwenkau, Störmthal, Kahnsdorf, Hain and Haubitz, the filling with mine water caused an increase of the pH (tab. 2). The Lakes Markkleeberg and Werben were neutral already at the start of the filling with mine water. In Lake Haselbach, the inflow of mine water from mine VSH caused a decrease in pH. Therefore, a limestone treatment (314 t) was conducted in Lake Haselbach in four campaigns from 2008 to 2010. The limestone slurry was spread from a special boat constructed for the treatment of acidic lakes in Sweden which were impacted by acid rain. Also the neutralisation of the lakes Hain and Haubitz required addition of lime because of the low quality of the mine water from mine VSH. In Lake Hain, the lime (8,614 t) was spread as slurry on the lake surface, using two sprinklers fed by a floating pipeline from 2008 to 2010. The lime for Lake Haubitz (1,390 t) was added to the inflowing mine water in the second half of 2009. The neutralisation of Lake Zwenkau is supported by the addition of 25 t/d of lime to the water from mine Profen since July 2011. The liming will last until 2014 when filling will be completed in Lake Zwenkau.

Example Lake Cospuden

Lake Cospuden was the first pit lake in Germany where neutralisation was a major goal of the use of mine water. Mine water from the mines Zwenkau and Profen was used for its filling and management. Mine Zwenkau was in operation until September 1999. The remediation required continued dewatering to a certain extent until 2006. Fig. 4 shows the contribution of the two mines. The water quality of the water from mine Zwenkau varied widely depending on the location inside mine Zwenkau where the water came from. Fig. 5 shows the pH and the acid neutralisation capacity of the water from mine Zwenkau, separated for the three pipelines from mine Zwenkau to Lake Cospuden.

Before the diversion of water from mine Zwenkau into the former mine Cospuden started, some small water bodies had formed at the bottom of the mine void (referred to as precursor lakes in the following). Their water level was kept stable by dewatering operations as long as necessary for the preparation of the side walls of the mine void for flooding. The pH of the precursor lakes (CO1-CO7 in fig. 6) was different. When the water level raised the precursor lakes merged. The lake water became neutral in 1998, before the final water level was reached in spring 2000 (fig. 6). The further inflow of mine water was necessary to keep the water level of Lake Cospuden stable and

Table 2 Changes of pH in the pit lakes south of Leipzig (except Lake Cospuden) between start of filling with mine water from the mines Profen or Vereinigtes Schleenhain (see fig. 2) and spring 2010.

Lake	pH at the start of filling with mine water	pH in spring 2010
Markkleeberg	7.6	7.8
Zwenkau	2.45	2.9
Störmthal	2.9	5.9
Werben	8.0	7.85
Kahnsdorf	2.8	3.1
Hain	3.0	6.4
Haubitz	3.5	6.7
Haselbach	7.6	6.5

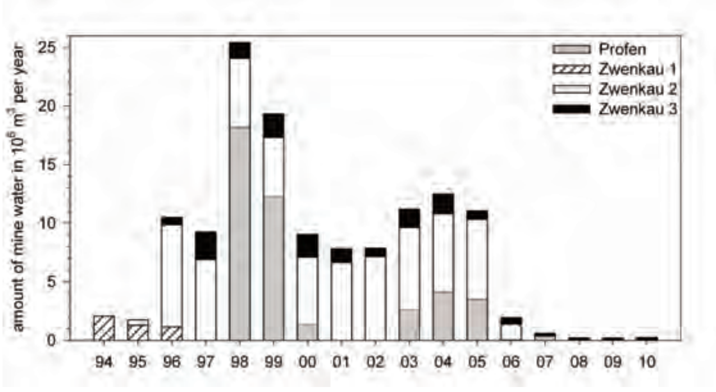

Figure 4 *Amount (per year) and source of mine water used for filling and management of Lake Cospuden. Zwenkau 1, Zwenkau 2 and Zwenkau 3 indicate the three pipelines for the transport of mine water from mine Zwenkau to Lake Cospuden. The pipeline Zwenkau 1 and Zwenkau 2 were decommissioned in 1996 and 2006, respectively.*

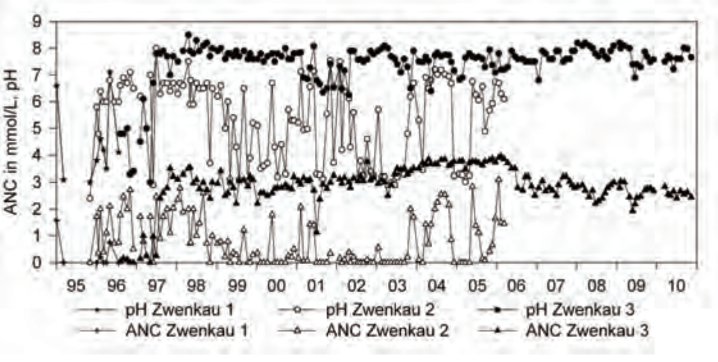

Figure 5 *pH and acid neutralisation capacity (ANC, analysed by titration with 0.1N HCl to pH 4.3) of the mine water from the three pipelines connecting mine Zwenkau and Lake Cospuden.*

to feed a system of creeks downstream of Lake Cospuden. The water from mine Profen diverted into Lake Cospuden after 2000 stabilised the buffering capacity of the lake water.

Outside of Germany, the use of mine water for the management of a pit lake is known to the authors only from Lake Stockton in the Collie region in Western Australia (McCullough *et al.* 2010). Lake Stockton was flushed with mine water from mine Ewington. The pH of the lake water increased temporarily from about 4 to 5.5 (McCullough *et al.* 2010). This Australian example confirms the good German experiences.

Conclusions

The results presented above indicate that mine water can be considered as a valuable source of water for filling and management of pit lakes. A good water quality of the mine water is a prerequisite for such use of mine water. Otherwise the

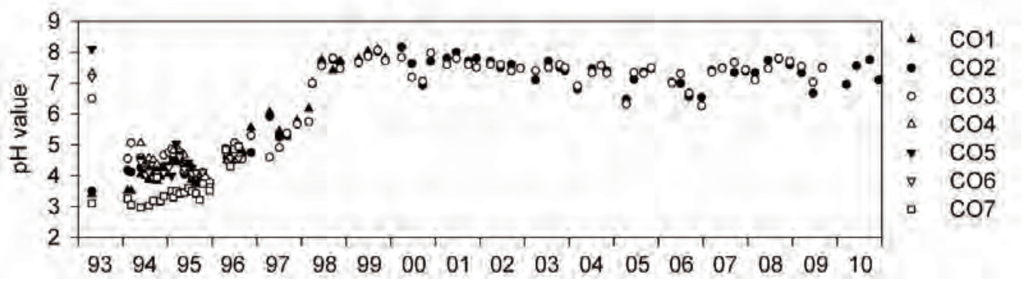

Figure 6 *pH of Lake Cospuden. CO1–CO7 are sampling sites within Lake Cospuden originally located in the separated precursor lakes. They were sampled for some time also after the precursor lakes merged in order to monitor lateral differences in water quality. Only results from the lake surface are shown.*

water quality of a pit lake may be affected or treatment of the mine water or of the pit lake is necessary. Treatment of mine water for its use for filling of pit lakes is a common practice in the Lusatian lignite mining district (Germany). The limited availability of water in that region requires the use of all water resources (Schultze *et al.* 2011).

In many aspects, the advantages and disadvantages of the use of mine water and of river water for the filling of pit lakes are very similar. The processes relevant when using river water for filling and management of pit lakes are the same ones which are relevant for the use of mine water (Schultze *et al.* 2011). The main difference is that the use of mine water requires the presence of operating mines. Therefore, the use of mine water is possible only temporarily.

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