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Implications of EU-Water Framework Directive for the East German Postmining Landscape Lausitz: Coping with a sparse knowledge of the underground

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Abstract

Mining dumps are major sources of pollutants within the mining area of Lausitz, especially sulphate and iron. Their existence in catchment areas comprising groundwater bodies or lakes often imposes negative effects on the water quality. The European Union Water Framework Directive [EU-WFD, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. The European Parliament and Council, L327/1, p. 72] aims to achieve ‘good quality’ status for all water bodies across Europe by 2015. Consequently, predicting the development of ground and lake water quality is necessary and must be based on the geochemical composition of the mining dumps. Therefore, the dumps need to be quantified as pollutant sources.

A method to calculate the amount of sulphate in mine dumps is presented. It is based on historic geological and geochemical data characterising the pre-mining situation. Additional information on the dump body, derived from the vertical extension of mining activities and the current Digital Elevation Model (DEM), allows the composition of the dump to be determined. This procedure is demonstrated for the Bärwalde site. An average total sulphur content of 0.62% (5.9 million tonnes) was calculated for the Bärwalde dump. About 40% of it is estimated to be pyrite sulphur. Applying an average pyrite oxidation rate for the whole dump body of 7% led to an additional water-soluble mass of 0.18 million tonnes of sulphate sulphur.

Applying this technique to all mine dumps managed by the postmining administration company LMBV, will improve our knowledge of the catchment area for the different lakes of Lausitz and will form an essential basis for reactive transport calculations.

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Keywords: Mine dump; Composition; Sulphate content; EU-Water Framework Directive; Pollutant source; Lausitz; Germany

Introduction

The Lausitz (Lusatia) is situated in the eastern part of Germany south of Berlin and near the border with Poland. Regional geology is characterised by tertiary

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depositions that were partly eroded and disturbed during quaternary glaciation. Coal mining started as early as the 19th century (Nowel, 1981) and reached a maximum in the 1980s. After the reunification of Germany, most of the mines were closed and the postmining administration company LMBV was founded to develop the former mine areas. The extensive mining activities during the last two centuries led to many mine dumps covering approximately 15% of the area of Lausitz. The spatial dimension of these dump areas and associated acid mine drainage problems create the demand for a geochemical and hydrochemical budget of the region. The release of pollutants such as sulphur and iron (leading to acidification) dominates the development of downstream situated ground- and surface water bodies.

Lakes form in the voids left by the open cast mines, as groundwater returns to natural levels. An interconnected cone of depression in the groundwater covers over 1000 km². In many cases acidified lakes with high concentrations of sulphur and iron are created. The filling process is accelerated using additional surface water from rivers in order to improve the quality and the future development of the lake water. Most lakes still receive surface water after the filling.

The European Union Water Framework Directive (EU-WFD, 2000) aspires a good chemical status and a good ecological potential for artificial lakes like mine lakes. Monitoring programs within management plans at the river basin level need to be implemented to determine the chemical and ecological status of each lake. Conditions observed at the site of interest may be compared to pristine conditions of a reference. Furthermore, a prediction of the future development and long-term changes in mine lake quality are necessary. A pathway to good conditions must be outlined if deviations from the reference state occur.

In order to predict the future development of mining lakes, all inflows with their current and future hydrochemical conditions need to be considered. Important influencing variables include the fractions of surface water and groundwater inflow and the location of mining dumps in the catchment areas. A sketch with different influges to the lake Bärwalde is shown in Fig. 1. The data were published in Müller (2004). Very different developments of lakes are probable due to the wide range of individual conditions. Furthermore, it must be recognised that groundwater catchment areas depend on the regional groundwater flow conditions, which may change with the groundwater rise. Therefore, only individual predictions for different lakes are possible.

The surface water impact on mining lakes is well known in its composition and generally characterised by low concentrations of mining-influenced physico-chemical parameters like sulphur and iron. In future, it is possible that S and Fe concentrations in rivers will

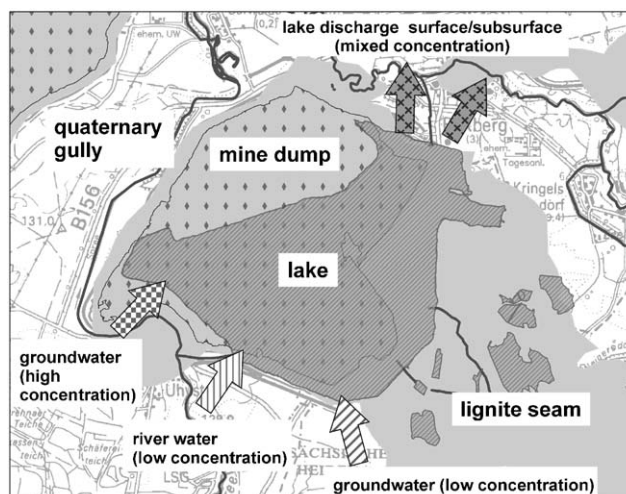


Fig. 1. Sketch of lake influges from different sources indicating concentrations of pollutants.

increase due to outflow from mining lakes. Authorities responsible for managing water bodies set tolerable limit values for the major hydrochemical parameters. The available amount of surface water for flooding the lakes is dependent on the fluxes in the rivers Spree, Schwarze Elster and Neiße. Hydrologic variability and decreasing mean fluxes may cause a lower availability of surface water than expected. During the period 1997–2001, half of the expected supply of surface water could be used for flooding (Grünwald & Uhlmann, 2004).

The amount of groundwater infiltration in mining lakes is identified through modelling of groundwater flow, but little is known about the future composition if dumps are part of the catchment area. While the supply of surface water for lakes may be managed, this remains almost impossible for groundwater inflow (Geller, Luckner, Matthes, Gockel, & Börner, 2004). Furthermore, the acidity of groundwater may significantly exceed the alkalinity of surface water. Due to its importance it will be necessary to close that lack of information by predicting the future groundwater composition upstream of lakes, considering dumps as sources of high sulphur and iron concentration. Describing and quantifying geochemical properties of dumps is an essential first step. Reactive groundwater flow and transport modelling can then be used to calculate groundwater composition upstream of lakes.

A method to quantify mine dumps as pollutant sources of sulphur was developed and applied to the pilot site of Bärwalde and results are presented in this paper.

Methods

Quantifying the amount of potential pollutants in a dump is possible by drilling boreholes and analysing

samples. However, due to the heterogeneity of mine dumps a mesh with a high horizontal and vertical density of samples would be necessary to calculate the average concentrations and total amounts of different parameters. Even though this may be possible for one dump it would become unfeasible for several or even all dumps in the Lausitz, covering an area of about 430 km². That led to a different approach in this study based on work of Hoth (2002).

The most relevant parameters that determine the quality of ground and lake water are the amounts of sulphur and iron released in dumps through pyrite oxidation. The aim was to estimate their level and concentration in a dump at the time of completion by using exclusively existing geological, geochemical and morphological data. Creating a historical, geological model of the pilot site to describe the pre-mining situation was the first step (shown in Fig. 2). In a second step the current geological model was set up. Comparison of both models could be used to determine the volumetric proportions of each geological layer on the dump. Combining the geometrical information with geochemical properties of the different layers enabled the calculation of the dump composition. The concept was applied to the pilot site Bärwalde. It was then to be applied to all other dumps in the Lausitz, to create a regional database.

Geological models

The tertiary and quaternary geological layers including the main mined lignite seam were combined to 14 model layers (Fig. 3) that represent different hydraulic and geochemical properties. The geological models were created with a layer approach based on these model layers. Such a proceeding required a continuous system of key numbers for the different geological layers. We chose the system of ascending stratigraphic key numbers

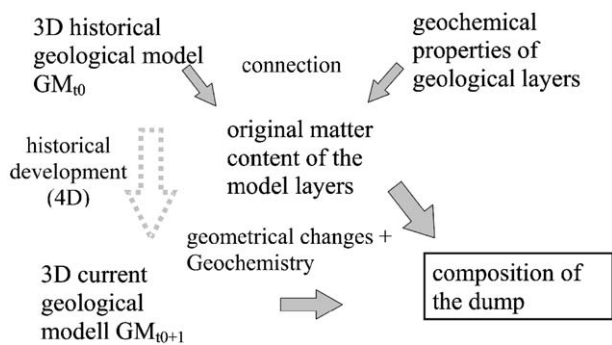


Fig. 2. Delineation of concept for estimating the composition of the dump from existing data.

Period	Epoch	Geological units	ID numbers (EMB 1985)	Model layer	
Quaternary	Holocene	Mine dump		1	
			1010-1050	2	
	Pleistocene	Weichsel cold period	Obere Talsande (sand)		1910-1990
			Lausitzer Interstadial (silt)		2000
		Saale cold period	Saale-III		2040-2090
			Saale-II Nachschüttungsande (sand)		2140-2150
			Saale-II ground moraine		2160-2180
			Saale-II Vorschüttungsande (sand)		2190
	Elster cold period	Saale-I Nachschüttungsande (sand)	2360		
		Saale-I ground moraine and Vorschüttungsande (sand)	2370-2430		
	Tertiary	Miocene	Raunower layers	Flaschenton (clay), aquifer 200 (sand)	3410 – 3620
			1. Lausitz seam complex	brown coal	3650 – 3890
				upper Briesker layers	Liegendschluff (silt)
			aquifer 300 (sand)		3920 – 4020
Oberbegleiterkomplex (silt and coal)			4030 – 4070		
aquifer 400 (sand), Hangendschluffkomplex (silt)			4110 – 4270		
2. Lausitz seam complex			brown coal	4300 – 4380	
			lower Briesker layers	Liegendschluff (silt)	4390
aquifer 500 (sand)				4400	
Unterbegleiterkomplex (silt and coal)				4410 – 4450	
aquifer 600 (sand)				4510 – 4720	

Fig. 3. Geological layers at the research area and their representation in model layers.

with ascending age of geological layers that was developed by the ministry of coal and energy and the ministry of geology in the former German Democratic Republic for this region (EMB, 1985).

Over 3000 borehole datasets from lignite exploration, provided by the LMBV, were used to create the historical geological model of the former mine site Bärwalde as shown in Fig. 4. After transferring the data into the model layers, the geological model was built with the software Groundwater Modelling Software (www.ems-i.com). The dump body was formed by the current Digital Elevation Model (DEM) as the upper surface and the vertical extension of the mining activities as the lower surface. Implementation gave the current geological model of the example site. Comparing the models enabled calculation of the volumetric proportion of the model layers in the dump as shown in Fig. 5. As illustrated in Fig. 6 the dump is made up of quaternary and tertiary material in about equal proportion. Fig. 7 gives an impression of the current geological model of the former mine site Bärwalde.

Geochemical data

During a pre-mining investigation in 1981, geochemical parameters such as sulphur and carbonate content were determined for a number of boreholes and condensed to average values for representative layers. The concentrations of these layers were converted to the 14 model layers. Estimates of the release of sulphur during pyrite oxidation were based on the amount of pyrite in the dump. The geochemical data provide information on total sulphur and sulphate sulphur. Sulfide sulphur is calculated based on an estimate of organic sulphur.

Vulpus and Neubert (1982) found a high correlation ($r = 0.95$) between the organic sulphur and the total sulphur for the second coal seam in the Lausitz. The fraction of organic sulphur on total sulphur S_{tot} is decreasing from 80% to 65% with increasing concentration of total sulphur. In the range of 0.5–3 mass percent of S_{tot} , the proportion kept nearly constant at

80%. This correlation could help to overcome the lack of information on organic sulphur. The concept was checked with all available current data on sulphur species in quaternary and tertiary layers of the Lausitz. Data from Berger (2000) and Vulpus (2004) are shown in Fig. 8. Measurements at total sulphur concentration below 0.2% were neglected. The current data show a similar dependency of organic and total sulphur but on a much lower level as it has been found for the lignite seam in Vulpus and Neubert (1982). The fraction of organic sulphur varies mainly between 20% and 40%. This may be due to sulphate from adjacent upper and lower layers migrating into the lignite seam just after deposition (Vulpus & Neubert, 1982). Reductive conditions caused a transformation into organic sulphur and its accumulation. Following these results, an average organic sulphur fraction of 30% was assumed for quaternary and tertiary layers.

The concentration of pyrite sulphur within the geological layers was calculated from the measured

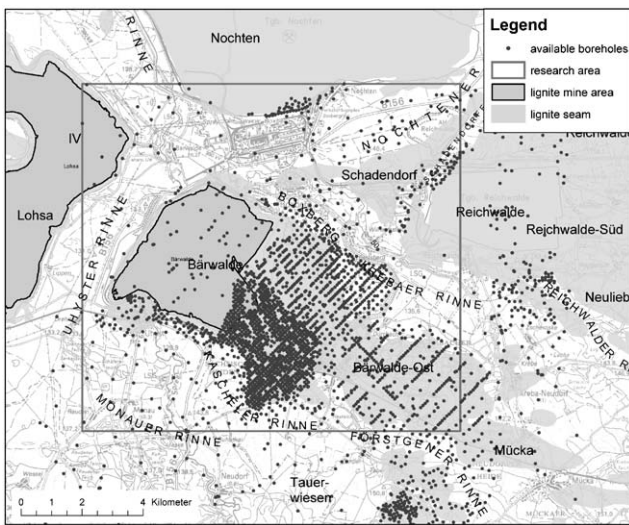


Fig. 4. Available boreholes at the Bärwalde site for creating geological models.

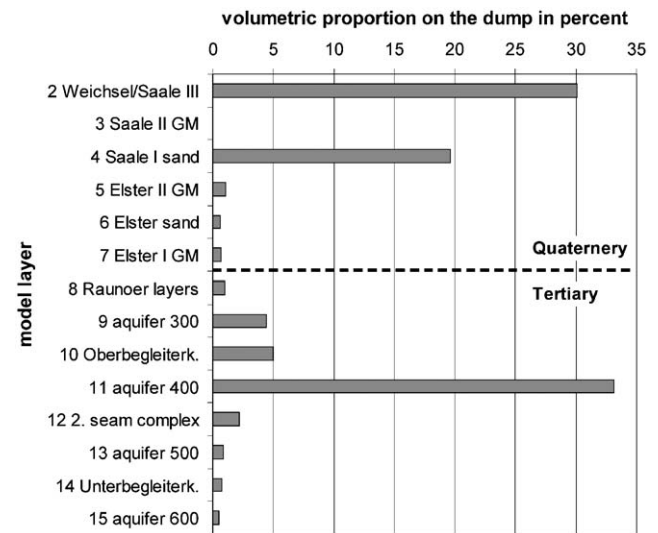


Fig. 6. Volumetric proportion of the model layers on the dump.

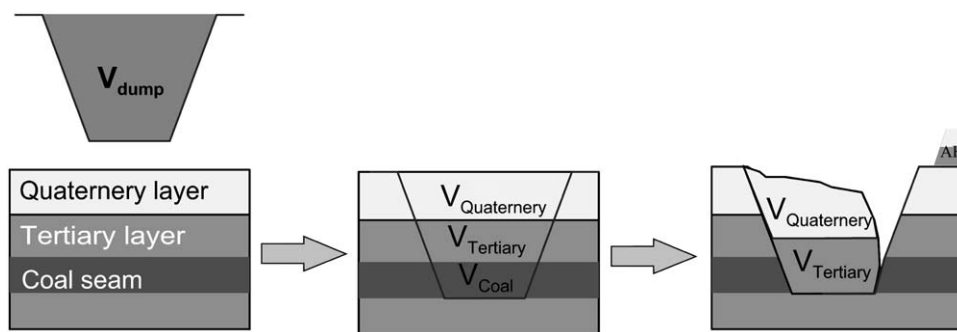


Fig. 5. Implementation of the dump into the historical geological model (left) to get the current geological model (right) and the proportion of the model layers on the dump.

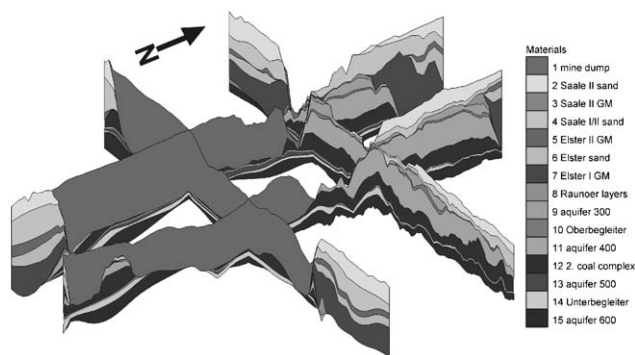


Fig. 7. Cross-sections through the current geological model of the former mine site Bärwalde (of the area shown in Fig. 1).

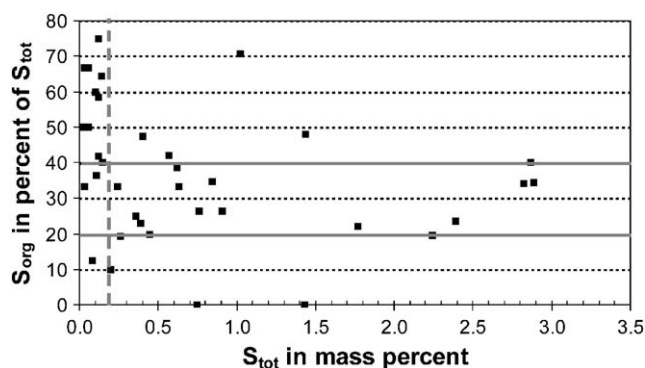


Fig. 8. Fraction of organic sulphur on total sulphur in current analyses of quaternary and tertiary layers in the Lausitz (Berger, 2000; Vulpius, 2004). The fraction of organic sulphur varies mainly between 20% and 40% (solid horizontal lines) if data left of the dashed vertical line are neglected.

total and sulphate sulphur based on this assumption. In Fig. 9, resulting average values for organic carbon and the sulphur species are displayed.

Mine dump composition

The mine dump composition was calculated with mass balancing after deriving necessary geological and geochemical information. The amount of matter m_j (kg) in the model layers j was calculated with an assumed average density ρ_j of 1700 kg/m^3 , the volume V_j (m^3) of each layer and the average concentration of each parameter c_j (%). The volume considered in Eq. (1) was, as shown in Fig. 5 (middle), the volume of each layer above the vertical extension of mining activities and within the horizontal extension of the mine area

$$m_{i,j} = \frac{c_{i,j}}{100} V_j \rho_j. \quad (1)$$

The lignite seam was almost completely removed during mining. Only 10% of this layer, generally accompanying silts, has been left in the dump. Summing

the amount of matter for all layers and subtracting 90% of the lignite seam leads to the total amount deposited in the mine dump. The amount of matter brought to an offsite dump was additionally taken into account. Considering the volume of the dump and an assumed dump density of 1500 kg/m^3 (referring to Berger, 2000), one may calculate average concentrations for each parameter in the mine dump.

Results

Calculated average concentrations for the dump Bärwalde are shown in Fig. 9 in the topmost bar. Compared to the original concentration of the model layers, the dump concentrations are a weighted average of the quaternary and tertiary layers. The average concentration of total sulphur was estimated to 0.62% which is equal to a total of 5.9 million tonnes. Original pyrite sulphur was about 40%. Furthermore, it was possible to show the original distribution of areas with high and low amounts of sulphur depending on the pre-mining geometry of the model layers (Fig. 10). Technological effects such as the displacement of material with an overburden conveyor bridge for 200 m were neglected.

After describing the dump as matter pool, it was necessary to describe it as pollutant source by considering pyrite oxidation processes. Several authors have suggested average turnover rates for whole dump bodies. Berger (2000) calculated an oxidation rate of 7% for the mine Welzow (Lausitz), Hoth (2002) used an average of 5% and Wisotzky (1994) estimated 14% for the mine Garzweiler (Rhenish mining area).

An average turnover rate of 7% was assumed. Using the dump volume of 640 million m^3 , this would correspond to a transformation of about 0.18 million tonnes of pyrite sulphur into sulphate sulphur or about 9 mol/m^3 sulphate sulphur. According to Appelo and Postma (1994), oxidation of 1 mol pyrite sulphur releases 2 mol of potential acidity (1 mol as H^+ and 1 mol as Fe^{2+}). The acidity of iron takes effect if it is oxidised. Therefore, the release of sulphate is going along with a release of 18 mol/m^3 of potential acidity. Considering a complete dissolution in a pore volume of 30%, a concentration of about 2800 mg/l sulphate and about 840 mg/l iron would be expected.

The illustrated composition of the mine dump describes the situation immediately after building the dump. Effects of ongoing geochemical reactions since this date were not considered.

A simple 1D reactive transport model was applied to a small part of the catchment area in the south-west of the lake that consists of mine dumps (Fig. 1). The time of discharge was found to be several tens of years for a 1400 m long pathway.

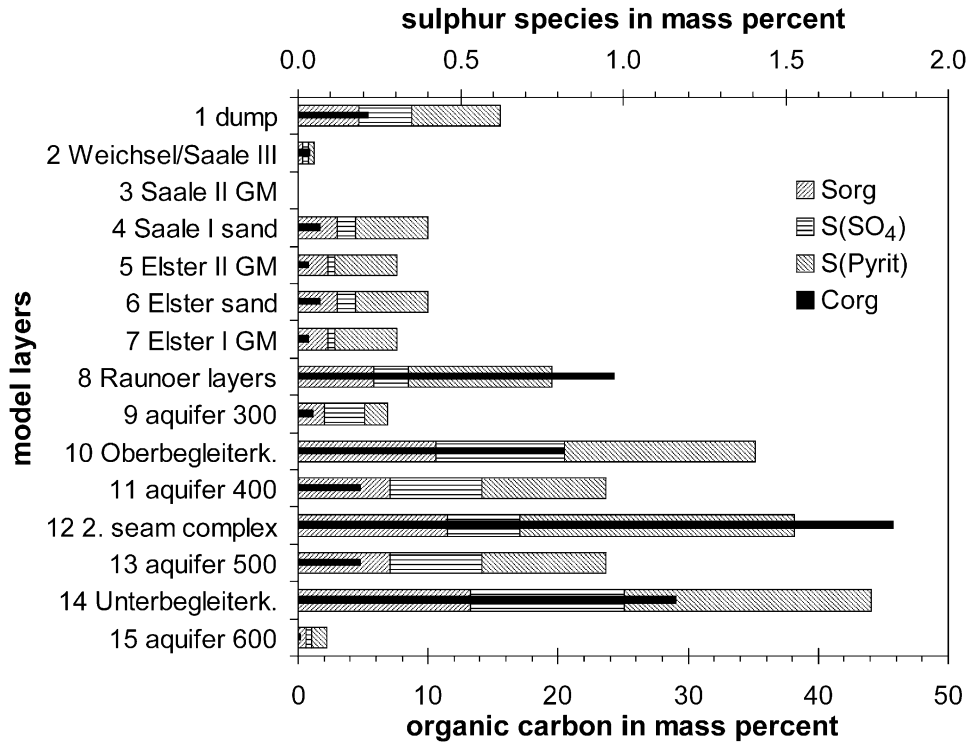


Fig. 9. Average concentration of model layers and calculated concentration for the Bärwalde dump of parameters organic carbon and sulphur species.

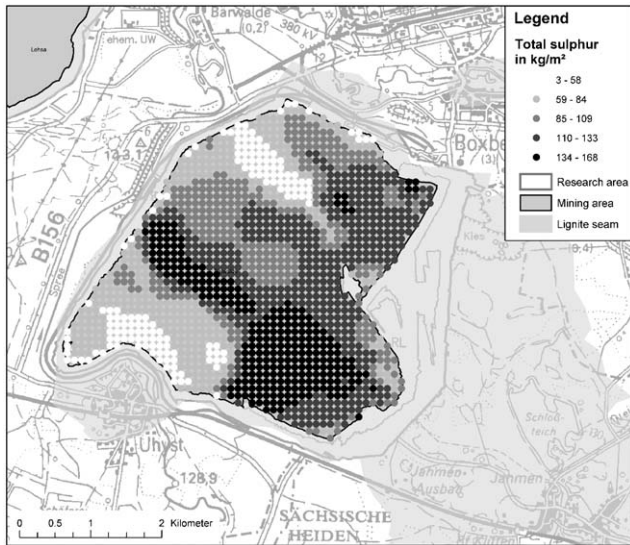


Fig. 10. Distribution of total sulphate sulphur in the historic layers (kg/m²) that form the mine dump.

Conclusions

A method to estimate the amount of sulphate sulphur for the mine dump Bärwalde was successfully developed. The possibility of using mass balance calculations on the base of historic geological and geochemical data is a

feasible alternative to direct geochemical sampling. A direct assessment of the method is difficult. The true composition is unknown and there are no data of an extensive geochemical bore campaign available, which could be used for comparison.

Quantifying the dump as pollutant source provides information on the available amount of sulphate. This is, as mentioned by Geller et al. (2004), fundamental for protecting ground- and surface water against negative influences of mining activities. Characterising the catchment area with respect to potential loads is an important demand of the EU-WFD. Only if all effects on ground- and surface-water are known is it possible to comment on the current and future state of the water bodies and to choose appropriate measures.

Consequently, this work is fundamental for predicting the development of groundwater quality downstream of mine dumps as well as of lakes with dumps in their catchment area. The improved knowledge on the catchment area will give a better understanding of processes and timescales. Of particular concern are the process of dissolving pyrite oxidation products in groundwater and the time it will take to flush all of the products out of the dump. Finally, the results will improve the knowledge of expected quality of groundwater fluxes into lakes. Reactive transport modelling will be an important tool for transferring presented dump composition data into information about composition of groundwater fluxes.

As an example, a 1D modelling was applied to the pilot site. The time of discharge of sulphate from this artificial aquifer with high concentration can extend the time scale of the water framework directive by far. The effects on lakes depend on the proportion of groundwater influxes from different aquifers as well as on the volume of the dump in the catchment area. With described reactive transport calculations it is possible to characterise groundwater in terms of quantity and quality. This offers the possibility of analysing uncertainties within the surface water supply as second major parameter. Calculating different variants with their effects for the lakes would improve the risk analysis by giving a probable range of lake water quality. Decisions about water treatment measures can be based on more reliable information and furthermore related to the expected sustainability of the measures.

Acknowledgment

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