# Can EU-WFD be Applied to Former Lignite Mining Districts? A Case Study for the Lausitz Mining District (Germany)

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## Abstract

For all dumps of closed mining sites within the Lausitz mining district geochemical inventory was determined, considering pyrite oxidation and sulphate reduction. Based on existing groundwater flow models and geochemical inventories, the dissolved mass discharge is calculated using PHT3D. Contaminated area and amount of dissolved sulphate in groundwater is predicted to increase at least until 2025. Therefore good groundwater quality conditions and even trend reversal cannot be expected within the time frame of the EU-Water Framework Directive (EU-WFD). Measures that might significantly improve conditions for the whole region are not at hand. Therefore it might be necessary to define less stringent environmental objectives in terms of the legal framework of the EU-WFD.

**Key words:** Lausitz mining district, lignite mining dumps, dump inventory, pyrite oxidation, mass transport modeling, EU-Water Framework Directive, PHT3D

## Introduction

The Lausitz lignite mining district in Germany covers an area of approximately 2500 km2 and has been mined for a period of more than a century. Five mines are still in operation whereas over 40 mines (19% of the area) have been closed, mostly after the reunification of Germany. Currently former mining sites are under remediation. Rising groundwater level will form 104 open pit lakes over the next decades. Questions about future AMD impacts from mining dumps in the area on groundwater and surface water bodies have arisen. The EU-Water Framework Directive (EU-WFD) demands good chemical conditions for groundwater or at least reversal of upward trends within 15 years. Surface water bodies should achieve good conditions and degradation of surface water quality due to groundwater inflow should be inhibited. Comparing demands of the EU-WFD to expected extent and time frame of mining impacts within the Lausitz district could give an indication of whether the application of the EU-WFD to former lignite mining areas is reasonable.

## Methods

For all dumps of closed mining sites within the Lausitz district the original dump composition was determined especially with respect to sulphur species as sources of acid generation. The method is based on existing geological and geochemical data collected during several exploration campaigns (Graupner et al. 2005). A geological model with 13 model layers was created for the entire area on a grid with a 200 m cell size. Geochemical data were assigned to model layers and interpolation methods were used for transfer of point data to areas. The composition of the dumps was determined via mass balance calculations neglecting changes in sulphur speciation due to oxidation for a start. Technological effects on mass distribution within the dumps, like the dislocation of dump material by a conveyer bridge are neglected. Storage of dump material on offsite dumps during opening of a mine does influence the total mass content of especially small mining dumps. Therefore, material distribution has been considered by means of information about the total amount of material located off site and the quaternary fraction.

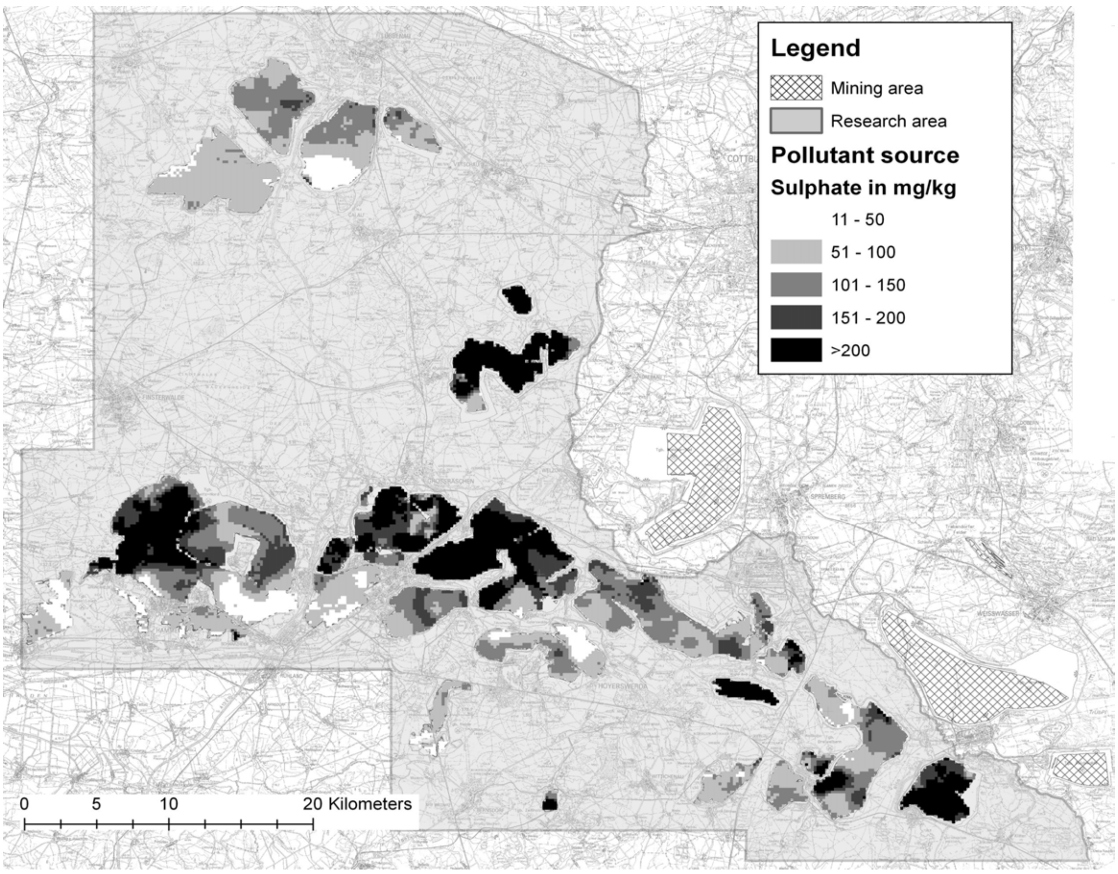
During mining about 7% of pyrite was oxidised according to examinations from Berger (2000). After mining dump composition changes over time. Oxygen diffusion over the surface into the dump body keeps pyrite oxidation going within the unsaturated zone. Below the oxidised zone sulphate reduction decreases the amount of matter available for dissolution in groundwater. Pyrite oxidation, depending on pyrite concentration, groundwater level, porosity and water saturation was calculated with PYROX (Wunderly 1994). Sulphate reduction was considered with a zero order rate of 0.02 $mmol/l^{-1}a^{-1}$. PYROX calculates pyrite oxidation based on a shrinking core concept for a column (1D). Therefore a software module was developed in Visual Basic that runs PYROX for each grid cell and each year until 2000.

Based on existing groundwater flow models, dissolved matter discharge over time is calculated for the whole area using PHT3D. The Modflow/MT3DMS and PHREEQC-based reactive transport program PHT3D was developed by Prommer et al. (2003). Groundwater flow models were built with PCGEOFIM (Sames and Boy 1997), a mining site specialised software. With the LMT6-package of MODFLOW (Zheng et al. 2001) groundwater flow results can be passed to MT3DMS in ASCII format. Grid transformation operations were necessary because MT3DMS cannot use local grid refinements. Furthermore the developed software module allows aggregation of several groundwater flow layers to one transport layer and it is possible to produce a transport model for a section of the flow model area. The amount of oxidised pyrite defines the pollutant source. Release of pollutants is considered as a kinetically-controlled, double-porosity process where the exchange coefficient has been calibrated from column experiments. Sulphate reduction is included within the source as well as during transport. A rate of 0.02 mmol $L^{-1}$ $a^{-1}$ was considered as representative for the region. Additionally a Michaelis-Menten limitation was used for low sulphate concentration with a $K_S$ of 0.2 mmol $L^{-1}$.

## Results and Discussion

All considered mining dumps within the research area contained about 100 million tonnes (Mt) of sulphur at the time of their creation. About 66% of the sulphur is present as sulphide sulphur. Approximately 4.6 Mt of sulphur were oxidised during active mining. The 12 largest mining dumps stored 85% of the total amount of sulphide sulphur. Sulphur concentrations in samples from mining dumps were measured by different authors. Comparison of measured values to calculations showed good agreement over the whole area. Secondary pyrite oxidation (occurring after dump construction) produced another 5.8 Mt of sulphate sulphur. Sulphate reduction within the saturated zone of mining dumps cannot reduce the pollutant source significantly. Figure 1 shows spatial distribution of sulphate concentration within the mining dumps of the research area as effect of primary and secondary pyrite oxidation.

***Figure 1*** *Released sulphate concentration in mg/kg due to pyrite oxidation*



All mining dumps contain a total amount of about 10 Mt sulphate sulphur. About 85% of this sulphate sulphur is stored in the 12 largest mining dumps of the Lausitz mining region.

The implications of mining dumps on surrounding groundwater quality were investigated with transport modelling starting in 2000 over 100 years. Spatial distribution of sulphate concentration after 50 years can be found in Figure 2. Figure 3 shows the development of the size of pollutant source as well as the development of dissolved amount of sulphate in groundwater over time. By the year 2050 the pollutant source is expected to be reduced to one-fifth of the original value. Polluted groundwater affects rivers that are hydraulically connected with the groundwater. In total about 7900 tons of sulphate sulphur is expected to discharge into the river system within the research area.

***Figure 2*** *Spatial distribution of sulphate concentration in groundwater in the year 2050*

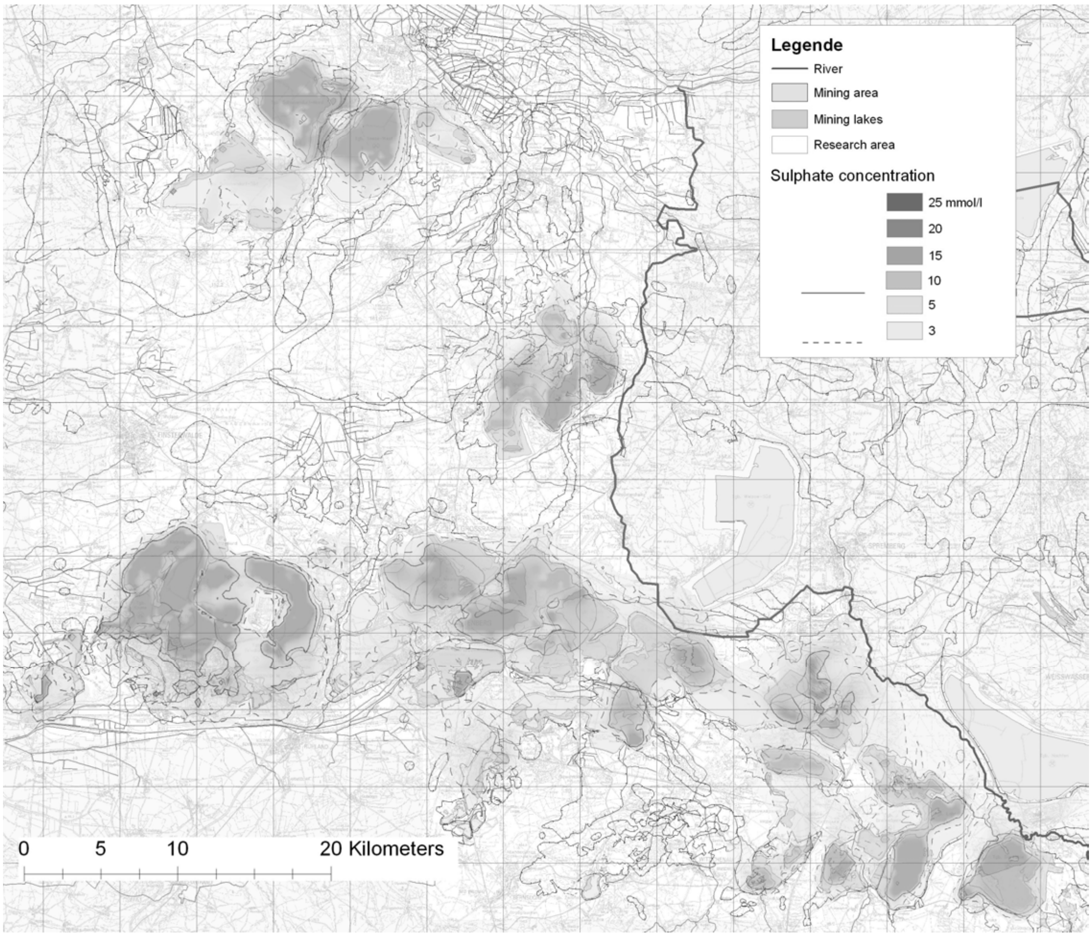
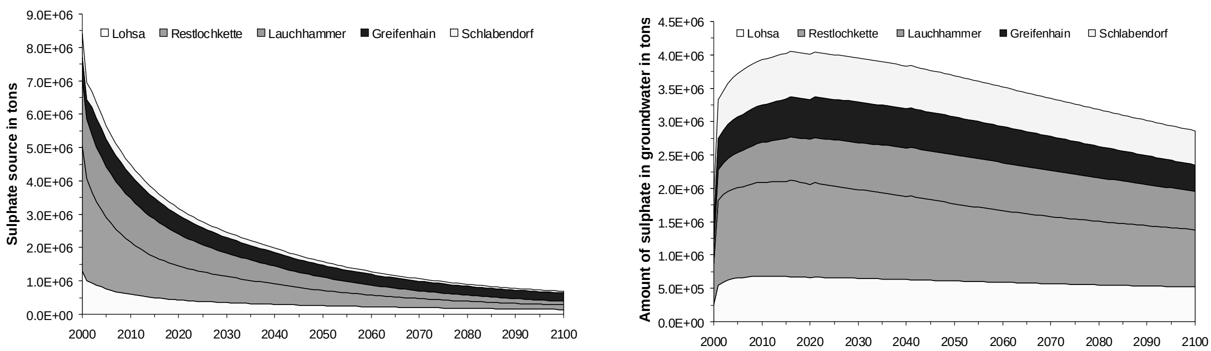



***Figure 3*** *Development of the amount of sulphur stored in the mining dumps (left) and of the dissolved amount of sulphur in the groundwater (right)*



Even after 100 years the mining dumps are predicted not to be completely flushed. There is still approximately 8 percent of total amount of pollutants left. The maximum load of dissolved sulphate in groundwater is estimated to occur around 2020 with about 4 Mt of sulphate sulphur. Over the next 80 years the load is predicted to decrease slowly to about 2.8 Mt, which is still over the background value. The area of groundwater influenced by mining reaches its maximum between 2020 and 2030, with a plume of about 750 km2, with approximately 30% of the research area affected.

## Conclusions

The results that are presented show the considerable effect of the mining dumps on groundwater within the Lausitz mining region. The amount of dissolved sulphur will increase over time. Trend reversal can be expected at the earliest around 2025 with slowly decreasing loads. The area of groundwater bodies that is affected by mining will slowly decline too. Polluted groundwater affects rivers that are hydraulically connected to groundwater. In total about 7900 tons of sulphate sulphur is expected to discharge into the river system within the research area. Results show no trend reversal until 2100, which is partly caused through their redeveloping function as recipient in the local hydrological system. Mining-related mass input into the river system takes one-third of the total impact.

Under these conditions investigation of the mining dumps indicates a misfit between realistic expectations and the legal framework. A good chemical status for groundwater in the mining area Lausitz is not very probable within the 15 years time frame of the EU-WFD. An extension of this deadline, which is possible for a further 12 years, might not improve the situation significantly. Because on one hand extension is only possible if no "further deterioration occurs in the status of the affected body of water", which is not expected, based on the transport modelling results. On the other hand a trend reversal (improvement in groundwater quality) might be observable within the extended deadline, but achievement of good chemical conditions for groundwater is not probable until 2027. Measures that might significantly improve conditions for the whole region are not at hand. Extent of the mining district allows only protection of certain goods. For example the open pit mining lake Senftenberg shows currently good chemical conditions. But in future mining polluted inflow of groundwater is expected, for which reason currently treatment of upstream groundwater is planned. Taking comparable measures for the whole region with the aim of achieving an extensive decrease in sulphate concentration in groundwater would be disproportionately expensive.

Therefore it might be necessary to define less stringent environmental objectives in terms of the legal framework of the EU-WFD. One possibility would be the definition of an acceptable mining-induced higher sulphate concentration for the Lausitz mining region. It is expected that other European mining areas will yield similar problems.

The work that has been carried out points out the necessity of adopting regional approaches to consider mining related groundwater pollution in former lignite mine districts. Regional based mining effects cannot be predicted without accounting for all existing mining dumps. Otherwise interactions between mining dumps like superposition or extension of discharge are not properly described.

## Acknowledgements

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