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Hydrogeochemistry of groundwater seepage into an acidic mining lake

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Introduction

In the Lusatian Lignite Mining District 259 mining lakes (ML) originate from abandoned mines. They significantly differ in their morphometry and most are strongly acidic (HEMM et al. 2002). The oxidation of sedimentary pyrite in aerated dump sediments (tertiary sands) forms acid mine drainage rich in iron and sulphate, which has decisive influence on matter flux, biocoenotic development and possible water uses (e.g. for recreation or municipal water supply; UHLMANN et al. 2001).

Hydrological processes in mining lakes are dominated by groundwater (HOFMANN et al. 2004). During the last three decades seepage meters were mainly installed in shelf regions of oceans, estuaries or lakes to quantify groundwater flux (LEE 1977, BOYLE 1994, BURNETT et al. 2002), but only in a few acid-mining lakes the ground water flux has been measured using this technique (BOZAU et al. 2000, WEBER 2000).

The main purpose of this study was to investigate the interaction of acid mine drainage with the sediment by using seepage meters. Therefore, ML Plessa 117 was chosen as a typical example of mining lakes in areas devastated by geological, hydrogeological and hydrological changes.

Key words: mining lake, acidification, total phosphorus, groundwater seepage, sediment-water interface

Study site

ML Plessa 117 is located in the former mining pit Plessa of the Lusatian Lignite Mining District, Germany (51°30′57.14″N, 13°39′45.80″E). It formed after mining activity stopped in 1968 and has been filled by groundwater inflow since 1972. Since 1976, the lake has been used for recreation purposes locally. Nevertheless, acid mine drainage led to an increase in conductivity values up to 900 µS cm^{-1}. pH values decreased to 3.1. The lake has a surface area of 0.95 km^2. Its maximum depth is 14.4 m in the northeastern part and total water volume amounts to $5.6 \times 10^6 m^3$ at a surface water level of 92.3 m a.s.l., which varies by ± 0.5 m, seasonally depending on precipitation.

ML Plessa 117 is the biggest lake in the region and is linked to other lakes by ditches, which drain in a north-south direction into the River Schwarze Elster. In the West the lake has a surface water inflow from ML 118 and in the South an outlet into ML 116 (Fig. 1).

The groundwater table in the bordering aquifer is 1–2 m above the surface water level. The main groundwater flow is directed from north to south. The lake's shorelines are characterised by unclaimed quaternary aquifers. Only a small groundwater flux is present from southwest and passes through claimed areas mainly composed of tertiary dump material (Fig. 1).

Methods

Since 1995, ML Plessa 117 has been frequently monitored (with regular intervals of 2–8 weeks) for physical and chemical conditions. Vertical profiles of temperature, oxygen, pH and conductivity were taken at the deepest point with a multi-parameter probe (HYDROLAB H20 or YSI 650). During summer stagnation in 2002 a grid of about 50 vertical conductivity profiles was laid over the northern part of the lake. In September 2002, five seepage meters were placed by divers close to the north and west shoreline to measure groundwater flux and to collect water samples suitable for chemical analysis. Groundwater samples from two wells (W 41 and W 46) were analysed in October 2002 and April 2003. Since 2002, water samples have been taken from the surface water inflow of ML 118 (Fig. 1).

Water samples were analysed for major cations and anions (DEV 1976–1998). The carbon content was determined by carbon analyser (DIMATEC Dima-TOC 100) and phosphorus by photometry (DEV 1976–1998).

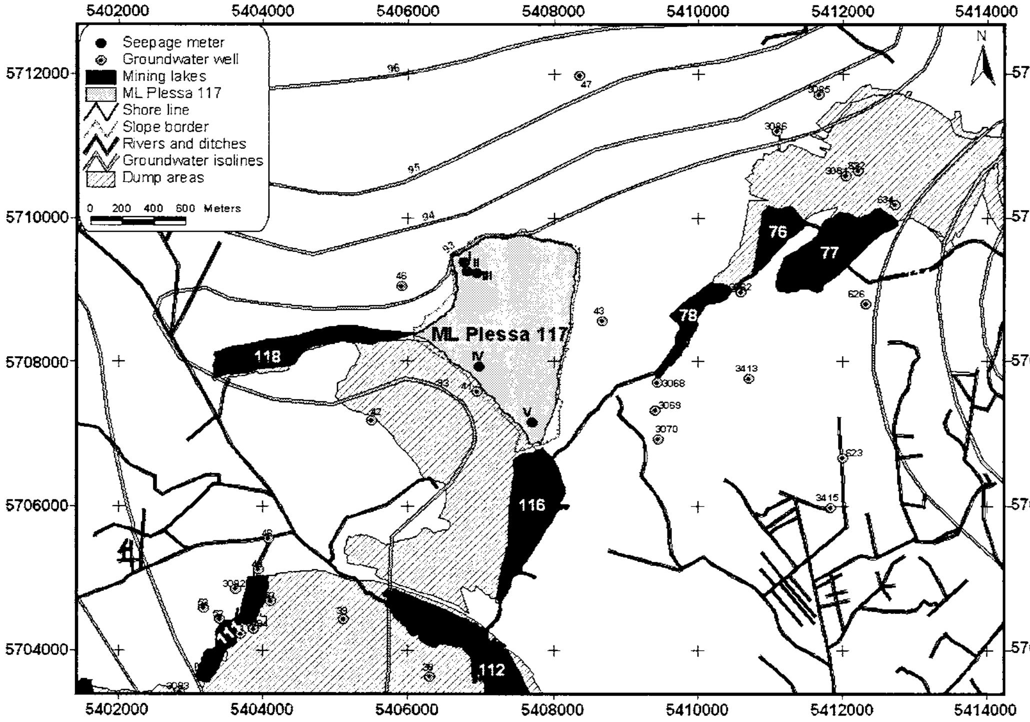

Fig. 1. Study site of ML Plessa 117 with sampling locations, groundwater isolines, dump areas and bordering mining lakes and ditches (coordinates in DHDN, Gauß-Krüger, 5th meridian).

Results and discussion

Hydrological and hydrogeological background

ML Plessa 117 is groundwater-dominated (about 70% of total input into the lake), as are many other mining lakes of the region, based on a groundwater model by WEBER (2000) and isotope water balance investigations with ^{18}O (HOFMANN et al. 2004). More than 85% of the groundwater input is coming from the aerated but unclaimed quaternary aquifers along the lake's northwestern shoreline, corresponding to groundwater well W46. The remaining 15% of groundwater input comes from the southwestern shoreline via claimed areas, mainly composed of tertiary dump materials. This flow is characterised by groundwater well W41. The surface water inflow of ML 118 is 100% fed by groundwater from the northern catchment, which corresponds to W46.

Spatial distribution of conductivity caused by groundwater inflow

The evaluation of vertical conductivity gradients in the northern part of ML Plessa 117 showed significant differences in vertical and horizontal direction, especially close to the lake bottom (Fig. 2). These gradients were caused by groundwater intrusions. Former studies confirm conductivity as indicator for the localisation of groundwater inflows (LEE & BIANCO 1994, HARVEY et al. 1997). Hence, the spatial distribution of conductivity represented preferential groundwater flow. This conclusion could be drawn from the marked conductivity gradient between groundwater (about 300 $\mu S\ cm^{-1}$ at W46) and surface water (about 900 $\mu S\ cm^{-1}$).

Characteristic changes in the chemical features of groundwater seepage

The groundwater inflow of ML Plessa 117 is formed by two different sources. The first, and

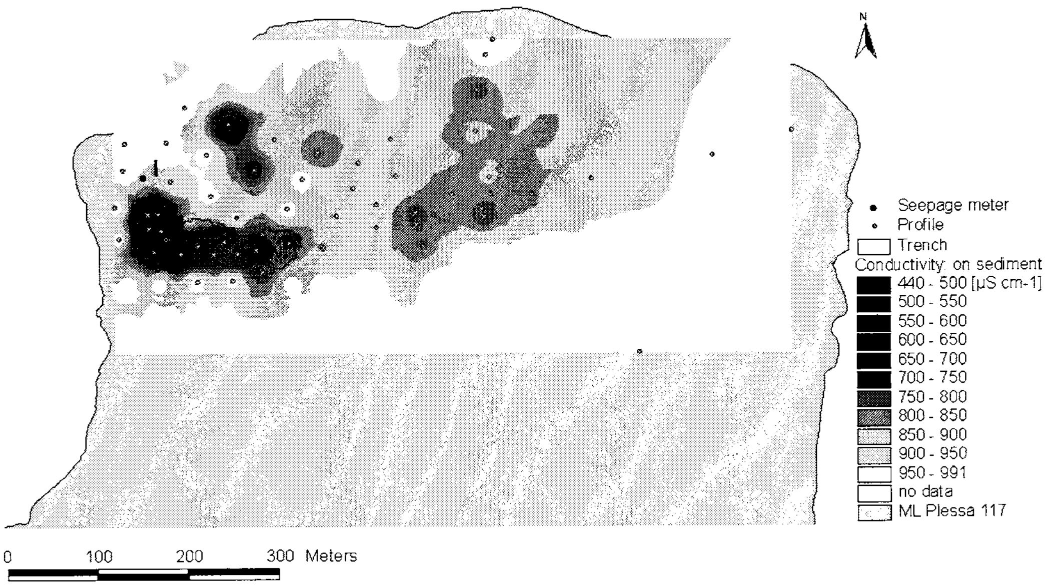

Fig. 2. Conductivity allocation in the North of ML Plessa 117 at lake bottom.

quantitatively most important, enters from the northwest shoreline into the lake and is characterised by low conductivity (250 µS cm^{-1}), low sulphate (150 mg L^{-1}), low calcium (31 mg L^{-1}) and high total phosphorus (TP; 105 µg L^{-1}) concentrations. The second inflow is highly influenced by acid mine drainage, with typical properties of high conductivity (2,500 µS cm^{-1}), high sulphate (1,720 mg L^{-1}), high calcium (370 mg L^{-1}) and high total phosphorus (240 µg L^{-1}) concentrations. The first corresponds to groundwater well W 46 and the second to W 41 (Fig. 3).

The five seepage meters showed high heterogeneities, which were related to their positions. High correlation could be found between groundwater well W 41 and the seepage meter SM IV, especially in conductivity and the concentrations of chloride, sulphate and calcium. Comparable correlations were found between groundwater well W 46 and the seepage meters SM I, II, III and V (Fig. 3).

The concentrations of several variables in the surface water of ML Plessa 117 and in the inflow of ML 118 differed considerably from those in the groundwater wells W 41 and W 46 (Fig. 3). This led to the conclusion that relevant qualitative changes took place in the sediment by chemical equilibrium reactions, for example phosphorus precipitation and its adsorption to iron and aluminium.

The concentration of total phosphorus (TP) as one of the most important growth-limiting nutrients for primary production was significantly reduced at the sediment-water interface. The concentrations at W 41 (240 µg TP L^{-1}) and W 46 (105 µg TP L^{-1}) decreased significantly in the seepage meters (although high heterogeneities occurred) and reached values of about 5 µg TP L^{-1} in the surface water, which are typical for oligotrophic lakes (Fig. 3).

Conclusions

This paper presents the change of groundwater influenced by acid-mine drainage of several variables and elements after passing the sediment-water interface of the groundwater dominated ML Plessa 117.

- Groundwater, seepage water and surface water differ considerably in their chemical characteristics.
- Seepage meters I, II and III, corresponding to the groundwater well W 46, were highly influenced by the sediment composition, and not as mentioned mainly by the origin of groundwater.
- Although total phosphorus concentrations in the groundwater, especially from W 41, were high, the

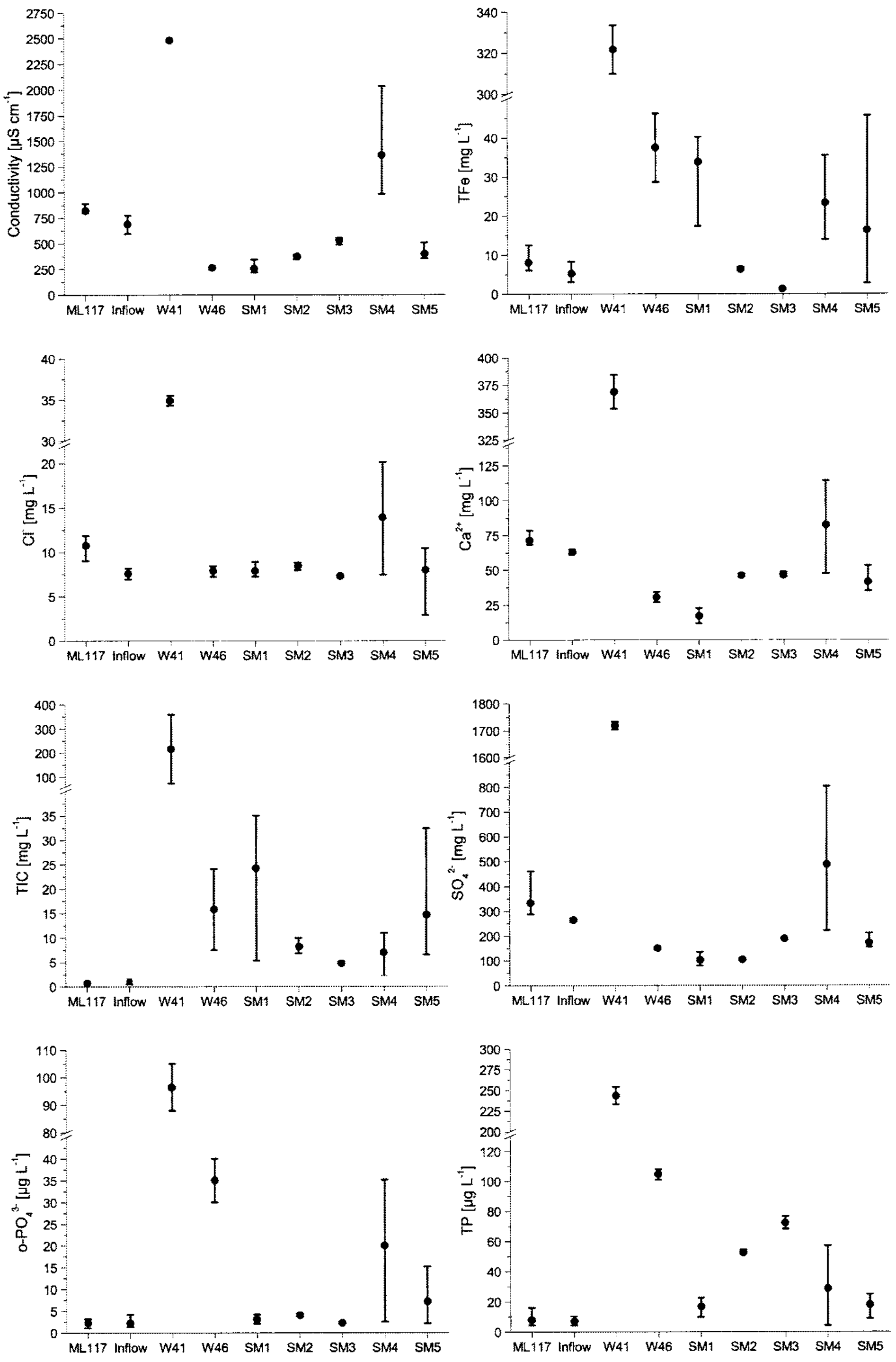

Fig. 3. Chemical features of ML Plessa 117, surface water inflow from ML 118, well water and seepage water into seepage meter SM I to V in 2003.

response in the seepage water was not noticeable and was reduced in the surface water to an oligotrophic level.

- The appearance of large conductivity gradients between groundwater and surface water of the lake verifies conductivity as an indicator to localise groundwater inflow and hence preferential flow.

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