MINING LAKES IN EAST GERMANY. THE PROBLEM OF ACIDIFICATION AND CHANCES FOR ECOSYSTEM DEVELOPMENT

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ABSTRACT

Several hundred geogenically acidified mining lakes of different age and maturity have formed in the lignite mining areas in East Germany during the last hundred years. The water deficit in the Lusatian region is 13 billions m^3, the volume of all German reservoirs. Although almost all of the mines have shut down, pumping continues, draining groundwater from about 2500 km^3. To overcome the water deficit in the region and to fill the holes quickly, they are filled with rising, highly acidic groundwater and also with eutrophic river water. One problem not only because of the further use of the lake for recreation is: What do you get when you mix acidic groundwater with polluted surface water? A limnological approach to answer this question is to estimate and evaluate the development of water quality with different flooding regimes as well as the ecological potential of these lakes.

These newly formed lakes offer a remarkable opportunity for limnologists to investigate and to influence primary successions in lakes. They are diverse in morphometry, mixing regime and hydrochemistry. They are among the largest and most acidic lakes in Germany. The pH and total acidity (base capacity $K_{B4.3}$) range from 2.6 - 4 and 0-35 mmol l^{-1}, respectively. The extremely high acidity is from both iron and hydrogen ions.

The lake chemistry is the main determinant for the planktonic composition of the water bodies whereas the trophic state mainly determines the level of algal biomass. The dissolved phosphate-P concentrations are < 10 $\mu g\ l^{-1}$ and lake productivity is limited by phosphorus and -this is a paradox in coal mining lakes- by carbon. At pH 3 the maximum concentration of CO_2 is approximately 0.1 mg l^{-1} . Nevertheless, almost all lakes are colonised by planktonic organisms at an oligotrophic or mesotrophic level. Dominant algal taxa belong to Chrysophyceae, Chlorophyceae and Dinophyceae. These taxa are sometimes found in considerable quantities and untypical vertical patterns indicating remarkable potential for primary production. The extremely acidic limnetic ecosystems (pH < 3) are very sensitive and may respond to changes in abiotic conditions with algal mass developments often in hypolimnion or near the sediment comparable with eutrophic conditions in neutral hardwater lakes.

INTRODUCTION

Brown coal was the most important inland energy resource in the German Democratic Republic with a production peak of 200 million tons in 1989. The main coal deposits were found in Lower Lusatia. After German reunification, the extraction of lignite was greatly reduced and a major effort is being directed towards the recovery of the disturbed landscape. In Table 1 the development of mining activities in east Germany is shown.

Year	Mitteldeutschland		Lusatia	
	Lignite mining in 10^6 tons per year	Number of mines	Lignite mining in 10^6 tons per year	Number of mines
1963	145.5		108.7	17
1985	115.4	20	196.8	17
1988	109.8	20	200.5	17
1989	105.6	20	195.2	17
1990	80.9	19	168.0	16
1991	50.9	11	116.8	12
1992	36.3	9	93.1	9
1993	28.5	5	87.5	9
2000[1]	< 20	3	70	5

[1]expected

Table 1. Number of coal mines in Lusatia and around Halle/Leipzig (Mitteldeutschland, East Germany) from 1963 to 2001 (after Möbs and Maul, 1994).

Many artificial mining lakes (more than 400, expected final area of several thousand ha) have been created in the Lusatian coal mining region as a consequence of the infilling of pits from open-cast lignite mining with groundwater and/or river water (Figure 1).

The main problem of the mining lakes is extreme acidification resulting from pyrite oxidation (pH < 3.5, $K_{B4.3}$ up to 15-30 mmol/l). The lakes are rich in iron and sulphate. Whereas phosphorus and CO_2 concentrations are very low, inorganic nitrogen is available in excess due to a high ammonium-N content.

There has been political impetus to improve the water quality of several acidic lakes in Lusatia to make them more attractive for recreation. Concepts for landscape recultivation and lake management include neutralisation of the lakes. Therefore, we have been investigating the biotic and abiotic conditions in a number of mining lakes since 1993. The first step of the complex research program was to determine the chemical, hydrological and biological status quo of the lakes. How does the infilling of the pits with groundwater and surface water influence hydrochemistry, nutrient status and planktonic development of the lakes? How important are morphometry, topography and hydrography to prevent reacidification and to avoid the risk of eutrophication?

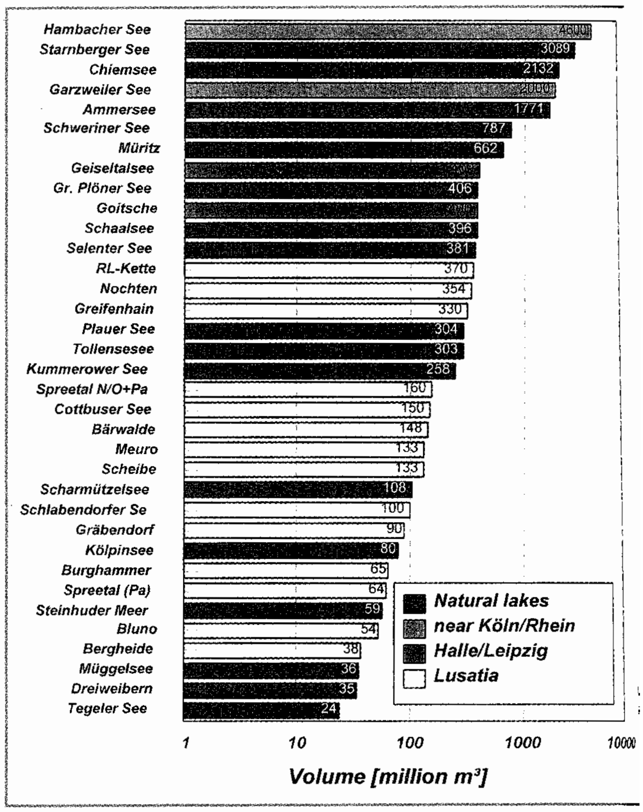

Figure 1. Volume of German natural lakes and mining lakes in three coal mining regions

STUDY SITES

Lusatia comprises the south-eastern part of Brandenburg and the north-eastern part of Saxony in eastern Germany (Figure 2). The standing waters in this region have their origin in open-cast lignite mining activities since the end of the 19th century. As a consequence of the intensive exploitation of brown coal and the dramatic reduction in production since 1990, a number of pits have infilled with water (mainly groundwater and water from rivers).

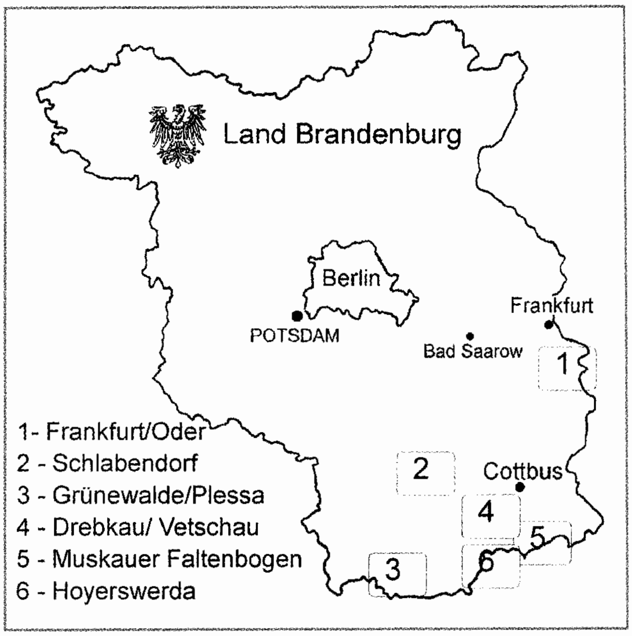

Figure 2. Mining regions in Brandenburg/Germany.

METHODS

Water samples for chemical and biological analyses (planktonic composition, chlorophyll) were taken monthly or irregularly as vertically integrated samples from the epi- and hypolimnion with a 2 l - LIMNOS-sampler. Depth profiles of temperature, oxygen concentration, pH, redox potential, conductivity and chlorophyll fluorescence were measured at 0.5 m intervals by means of a HYDROLAB H20 and a fluorescence probe.

The concentrations of anions (among them the nutrients as phosphate, nitrate, silicate) cations, DIC, DOC and metals (Al, Fe, Mn, Cu, Cd, Ni, Zn) were determined according to the recommendations given in the "Limnological method for investigation of mining lakes" (Schultze et al., 1994) and to standard methods (Deutsche Einheitsverfahren, 1986-1998). For the estimation of the base capacity ($K_{B4.3}$) samples were titrated with 0.02 mol NaOH up to pH 4.3. Chlorophyll a was determined by standard methods with some modifications relating to the peculiarities of acidic water samples (Nixdorf et al., 1995).

RESULTS AND DISCUSSION

Morphometry, mixis and mining lake chemistry

In general, the infilling lakes in Lusatia belong to a type which does not occur naturally in this region. The ultimate depth of most of these new lakes will be at least 20 m with half of them greater than 40 m. Today, the lakes differ greatly in size and shape. Some are well stratified and others are polymictic (Mischke et al., 1994, Nixdorf et al., 1998 a, b). After filling, most of the lakes will be dimictic. Prediction of trophic state from lake morphometry (TGL 27885/01, 1982) which uses the ratio between hypo- and epilimnion volume is very effective for the large, deep lakes (e.g. Gräbendorf, Bärwalde, Scheibe, Burghammer). From the morphometric point of view, most lakes will become potentially oligotrophic or mesotrophic.

The extremely high proton (low pH) and iron concentrations are the main characteristics of mining lakes which influence all other chemical parameters. Since conventional trophic classification is not readily applicable to these lakes, a classification is carried out, based on acidity (Nixdorf et al., 1997, Leßmann and Nixdorf, 1997):

- weak or not acidic, pH > 6, = N,
- moderate acidic, pH = 4.5 - 6, = MS, not common in Lusatia,
- very acidic, pH = 3.5 - 4.5, = SS,
- extremly acidic with three subgroups, pH = 2.6 - 3.5, = ES I-III.

Nearly all lakes exhibit high conductivities due mainly to the high concentrations of calcium and sulphate.

The low pH and high concentrations of Fe and Al reduce the concentration of phosphorus to the level of detection due to chemical fixation (iron- and aluminium phosphate) in the sediment. As a result, algae growth can be P-limited in pelagic waters.

The concentration of TIC in the epilimnion of extremely acidic lakes (pH < 3.5) is very low and has generally been below the level of detection (< 0.5 mg l^{-1}, Nixdorf & Kapfer, 1998). Therefore, a limitation of primary production by inorganic carbon in most of the extremely acidic lakes is assumed (Goldman et al., 1974, Schindler and Holmgren, 1971, Mischke et al., 1996). This applies for the euphotic zone. However, in deeper layers, TIC-concentration may be locally higher due to respiration, decomposition at the sediment surface, or allochthonous carbon input from groundwater inflow (Herzsprung et al., 1998). Microbial decomposition of organic matter may be considered as one source of CO_2-input into the lakes or to the sediment water interface. It is clear that there is an enrichment of CO_2 in the upper layer of the sediment. In contrast to the pelagic water, the concentration of inorganic carbon in the groundwater in some regions of Lusatia is high (Schlabendorf, near lake F-Loch between 60 and 80 mg l^{-1}).

The lake water chemistry can be influenced by mixing the rising groundwater in the lake with alkaline water from rivers in the catchment. A model for this mixing process is shown in Figure 3.

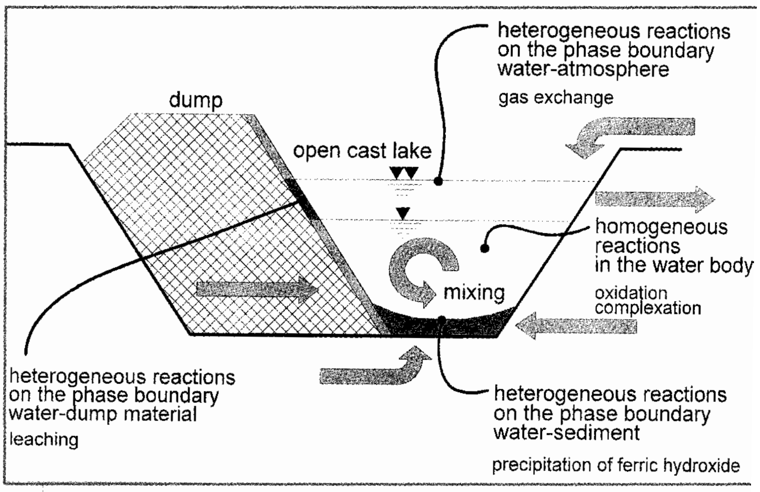

Figure 3. Hydrogeochemical model of ideal mixed open cast lake (after Uhlmann from BTUC, 1999).

PELAGIC LIFE IN MINING LAKES

Lake chemistry is the main determinant of planktonic composition in the water bodies whereas the trophic state mainly determines the algal biomass. In general, species richness, diversity and biomass of pelagic organisms in very and extremely acidic lakes is low (Blouin, 1989; Eriksson et al., 1980; Klapper and Schultze, 1995; Nixdorf et al., 1998 a, b; Wollmann et al., in press). Nevertheless, there is a high potential for primary production even in extremely acidic lakes as is shown in our investigations. Chemical classification is reflected in distinctive phytoplankton composition: in extremely acidic lakes, *Ochromonas* and *Chlamydomonas* dominate the phytoplankton, whereas in very acidic lakes dinoflagellates occur additionally. In the acidic lakes, total phosphorus (TP) is typically around 5 µg l^{-1}. Only temporary increases in TP may occur (e.g. Lake Lichtenau or Felixsee in 1994). Chlorophyll concentration in mining lakes is shown in Figure 4 as median and maximum values. We can distinguish between lakes with episodic chlorophyll maximum (Lake Lichtenau and Felix and epilimnion of Waldsee) and lakes with a seasonal deep chlorophyll maximum (Plessa 111) or permanent maximum in monimolimnion (Waldsee).

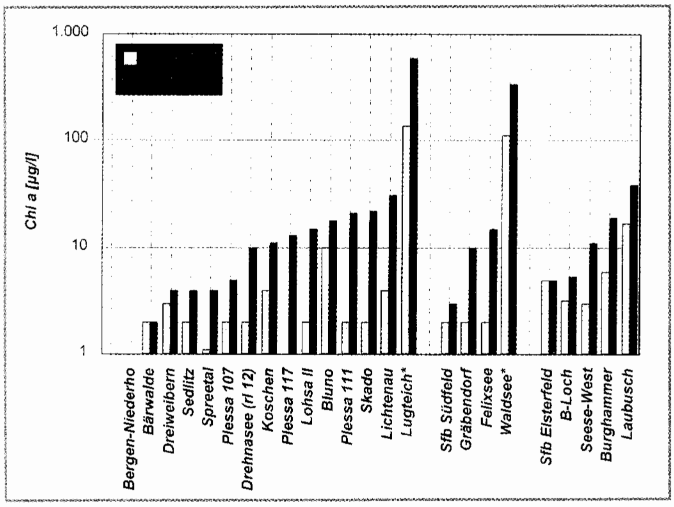

Figure 4. Chl a – concentration in mining lakes in Lusatia (median and maximum). *Lugteich and Waldsee are meromictic lakes.

A further particularity was found in the acidic Lugteiche lakes which are, like Waldsee, also meromictic. In the summer of 1996, we measured chlorophyll concentrations in the upper part (20 - 50 cm) of the acidic epilimnion between 104 and 523 µg Chl a/l. Primary production rate was between 1.52 and 14.4 mg C/(mg Chl a*h) indicating a high production potential even in very acidic waters (pH between 2.7 and 2.8, $K_{B4.3}$ between 12.8 and 15.0 mmol/l). More details to the limnology of these types of mining lakes are given in Fyson and Rücker (1998).

A diverse algal assemblage with diatoms and cryptophytes is found in lakes with low acidity and under alkaline conditions. Simple food chains exist with bacteria, phytoplankton, heliozoans, rotifers and ciliates as zooplankton and corixides as top predators (Wollmann et al., in press). Benthic life is also very common in mining lakes (Kapfer, 1998). An example for food webs in extremely mining acidic lakes is shown in Figure 5.

In contrast to the natural hard water lakes, inorganic carbon in mining lakes is often available at very low concentrations for primary production in the euphotic zone but may be locally higher due to respiration, decomposition at the sediment surface, or allochthonous carbon input by groundwater inflow and under ice cover.

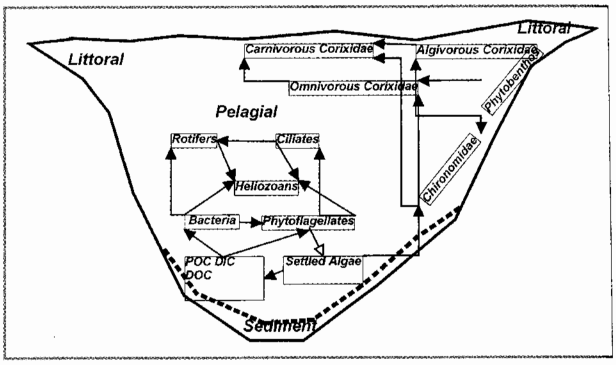

Figure 5. Food web relations in an acidic mining lake (Plessa 111 in Lusatia) which has been investigated since 1995 (from Wollmann et al. in press).

NEUTRALIZATION OF ACIDIFIED LAKES

Neutralisation of acidified lakes is possible through a number of measures including flooding with eutrophic surface water, addition of neutralising chemicals or phosphate (Davison, 1987; Davison et al., 1989, 1995), or establishing anoxic conditions with decomposable organic substrates. Controlled eutrophication by the addition of nutrients and organic substrates may enhance primary production and assist in neutralisation (Fyson et al., 1998 a, b).

The preferred neutralisation measure in Lusatia up to now is filling the pits remaining from open-cast lignite mining with eutrophic river water, mainly from the river systems Spree and Schwarze Elster. It was calculated that the mixing of neutral and eutrophic surface water with acidic groundwater will establish neutral lake water in several mining lakes. In Figure 6, the increase in pH during the infilling of Lake Gräbendorf is illustrated.

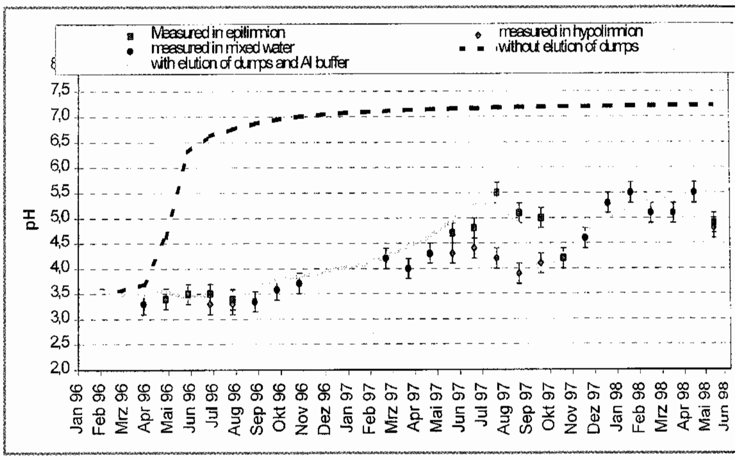

Figure 6. Measured and calculated values of pH in mining lake Gräbendorf during the process of filling with groundwater and river water (after Uhlmann in BTUC – report 1997/98, 1999).

In future, ecotechnological methods will be applied for neutralisation in the acid mining lakes according the approaches of Klapper and Schultze (1995) and Klapper et al. (1998).

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