

# Development of Two Meromictic Pit Lakes – a Case Study from the Former Lignite Mine Merseburg-Ost, Germany

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## Abstract

Two meromictic pit lakes formed in the former lignite mine Merseburg-Ost between Halle and Leipzig, Germany, since mining ceased in 1991. Fresh and highly saline groundwater as well as diverted river water filled the lakes. The lakes also received acid water from dewatering operations in a neighboring gravel pit. The development of stratification and water quality are presented. Perspectives of future development and general conclusions for meromictic pit lakes are drawn.

**Key words:** pit lake, meromixis, water quality, acidification

## Introduction

Many pit lakes are meromictic (e.g. Boehrer and Schultze 2006, Castendyk and Webster-Brown 2007, Sanchez Espana et al. 2008). Meromictic lakes are permanently chemically stratified. The bottom layer (monimolimnion) of meromictic lakes does not participate in the annual overturn of the upper water body (mixolimnion). Density differences due to dissolved substances keep it stratified at the deepest locations of the lake bed (Boehrer and Schultze 2008). This paper reports the development of two meromictic pit lakes, which have formed in the voids of a lignite mine in Germany. The meromixis of these lakes is a result of the inflow of waters of different densities: highly saline groundwater, relatively fresh groundwater and river water. The temporal changes of water quality are discussed including the consequences of meromixis for development.

## Study site

Lake Wallendorf and Lake Rassnitz developed in the former open cast lignite mine Merseburg-Ost south-east to the city of Halle, Germany, in the floodplain of river Weisse Elster (figure 1). The mine was operated from 1973 to 1991. From 1991 to 1998, the slopes were prepared for filling with water, while dewatering operations were partly continued to regulate the water level. From 1998 to 2000, water was diverted from neighboring river Weisse Elster into both mining voids for rapid filling (figure 1). Destruction of the prepared slopes by erosion and land slides should be prevented in this way. The water level in Lake Rassnitz was fixed by an overflow to Lake Wallendorf. The water level in Lake Wallendorf was regulated. Table 1 shows the morphometric data of both lakes for their recent final state.

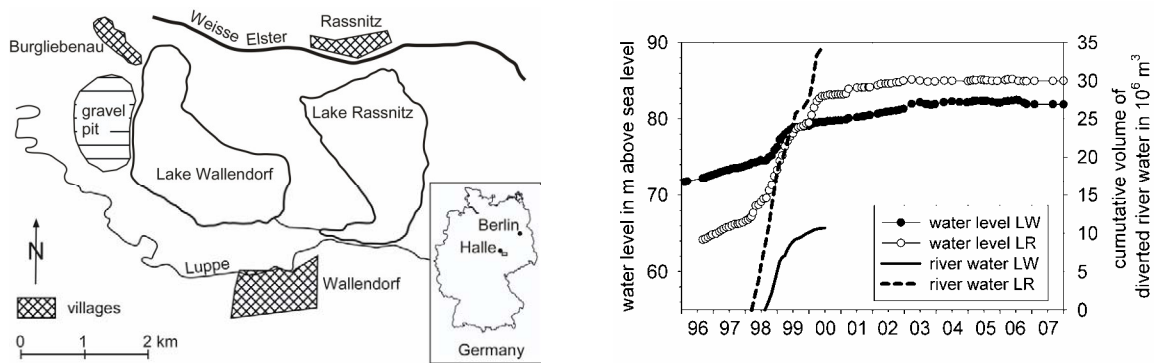
**Table 1** Morphometric data of the lakes

	Lake Wallendorf	Lake Rassnitz
water level in m above sea level	82	85
surface area in $10^6$ m <sup>2</sup>	2,8	2,3
volume in $10^6$ m <sup>3</sup>	30	47
maximal depth in m	27	36
mean depth in m	10,7	20,4

Due to the special conditions of this region, highly saline water from deeper underground had already reached the surface as saline springs before mining had started (Doering 1987). The subsidence of the Permian salt deposits caused fractures in the overlying Triassic sandstone which allowed the rise of some saline water to the surface (Eissmann 2002a,b, Heidenreich et al. 1999, Trettin et al. 1999). As a result of the dewatering operations, the rise of saline water was increased. The second groundwater source connected to the lakes originates from the Tertiary strata which include the lignite deposit. Quaternary strata partly consisting of typical flood plain deposits (loam, gravel) also contribute to the groundwater inflow to the lakes. Groundwater from the Triassic sandstone, from the Tertiary and the

Quaternary are fresh waters of different salinities. The groundwater from the Tertiary strata is partly acidic as a result of pyrite oxidation (Trettin et al. 1999).

**Figure 1** Location of the study sites (left panel) and development of the water level in the lakes and cumulative volume of river water flow into the lakes (LW – Lake Wallendorf, LR – Lake Rassnitz; data from LMBV; right panel)



A gravel pit was mining Quaternary strata nearby directly west of the former lignite mine. The acidic water from the dewatering operations of this gravel pit was diverted into Lake Wallendorf since rising groundwater necessitated dewatering in 2001.

### Quality of the introduced river water

The quality of water from the River Weisse Elster was surveyed at the time of diversion into Lake Wallendorf and Lake Rassnitz (table 2). The relatively high concentrations of nutrients, especially ammonia, result from waste water from the city of Leipzig despite waste water treatment. River Weisse Elster is relatively small (mean flow 25.1 m<sup>3</sup>/s, mean low flow 9.87 m<sup>3</sup>/s, mean high flow 127 m<sup>3</sup>/s for the period 1973-2005, LHW Sachsen-Anhalt 2005) in relation to the number of inhabitants of Leipzig (about 550,000). The impact of operation and cessation of uranium and lignite mining upstream on water quality in river Weisse Elster was insignificant with respect to the filling of Lake Wallendorf and Lake Rassnitz.

**Table 2** Water quality of river Weisse Elster at monitoring site Oberthau about 5 km upstream Lake Rassnitz (data from the regional water authority Staatliches Amt für Umweltschutz Halle; alkalinity was determined by titration with 0.1 N HCl up to pH 4.3; SRP – soluble reactive phosphorus; TP – total phosphorus)

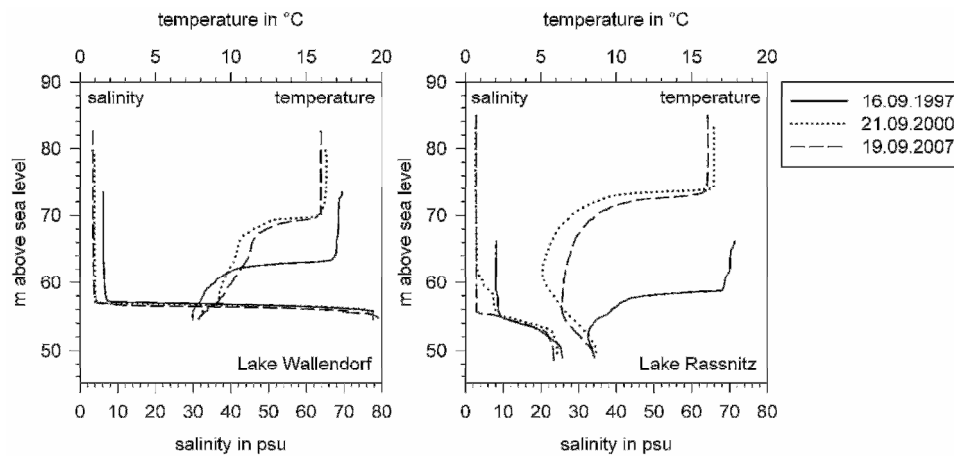
	Minimum 1998-2000	Maximum 1998-2000	Median		
			1998	1999	2000
SRP in mg/l	0.010	0.303	0.057	0.053	0.079
TP in mg/l	0.145	1.58	0.329	0.255	0.305
NH <sub>4</sub> <sup>+</sup> -N in mg/l	0.58	7.78	2.41	2.57	1.87
NO <sub>3</sub> <sup>-</sup> -N in mg/l	1.69	10.14	6.25	6.07	5.18
Cl <sup>-</sup> in mg/l	37.8	119	75.7	82.9	87.3
SO <sub>4</sub> <sup>2-</sup> in mg/l	137	376	250	281	275
alkalinity in mmol/l	1.5	3.3	2.3	2.6	2.6

### Results and discussion

The lakes were already meromictic before filling with river water. The inflow of river water stabilized the meromixis by further dilution of the mixolimnion. This dilution increased the salinity difference and density difference between mixolimnion and monimolimnion. In figure 2, we include selected profiles of salinity and temperature for both lakes from 1997 (before filling with river water), 2000 (immediately after completion) and 2007 (about four years after reaching the final water levels). The

lower salinity of the monimolimnetic water in Lake Wallendorf compared to Lake Rassnitz resulted from locally different groundwater salinities (Reichling and Sengpiel 1995).

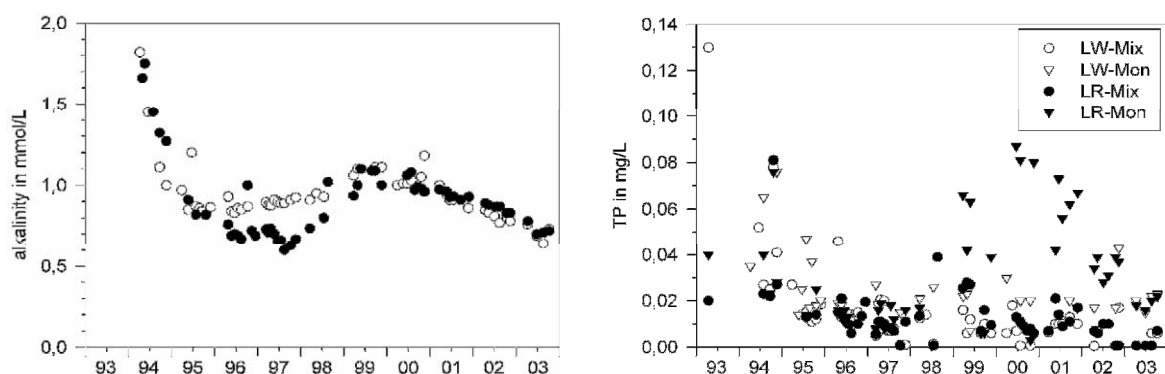
**Figure 2** Development of chemical stratification level in both lakes (psu – practical salinity unit)



In Lake Wallendorf, the depth of the chemocline increased at a very slow rate (von Rohden 2002). In Lake Rassnitz, filling with river water produced a secondary halocline, which persisted from 1999 until 2006. The observations confirmed the predicted stability of the meromixis and the evolution of the salinity profiles by Böhler et al. (1998) made prior to river water introduction. They also supported von Rohden and Ilmberger (2001), who used the tracer SF6 and concluded that the transport of dissolved substances from the initial monimolimnion into the mixolimnion was very small.

As mentioned above, both lakes have received acid groundwater. Additionally, acid water from the neighbouring gravel pit has been introduced into Lake Wallendorf. Despite these acidity imports, the pH never fell below 7, but the development of the alkalinity of the mixolimnetic lake water clearly indicate the consumption of buffer capacity (figure 3, left panel). Filling with river water caused a temporal elevation of alkalinity due to the higher alkalinity of the river water compared to lake water. However, the gradual decrease started again after ceasing of river water diversion.

**Figure 3** Development of alkalinity (result of titration with 0.1 N HCl to pH 4.3; left panel) and phosphorus concentration; right panel)



Decay of settling organic material and geochemical dissolution of minerals under anoxic conditions in the monimolimnion and at the sediment surface resulted in an accumulation of dissolved substances in monimolimnetic waters. Turbulent diffusive transport into the mixolimnion was small. As shown in figure 3 (right panel), dissolved phosphorus accumulated in the monimolimnion of Lake Rassnitz during filling with river water. However, the concentrations detected were still moderate. After filling ceased, monimolimnetic phosphorus concentration decreased. In Lake Wallendorf, no accumulation of phosphorus was observed. The availability of dissolved or freshly precipitated iron was higher in Lake Wallendorf due to the introduction of iron-rich acid water from the gravel mine. Phosphorus was

adsorbed by iron precipitates and settled to the sediment together with the iron particles. Only a small portion was re-dissolved in the monimolimnion or directly liberated from decay of organic material at the sediment surface. Results from sediment investigations by Rusche (2003) confirmed this interpretation.

### Conclusions

The development of Lake Wallendorf and Lake Rassnitz showed that the filling of pit lakes with river water in parallel with inflow of saline ground water resulted in a stable chemical stratification. However, high density gradients at the chemocline were required to sustain meromixis under the particular conditions of these lakes: good exposure to wind action and relatively small depth compared to surface area. For long term stability, permanent recharge of the monimolimnia with saline groundwater was necessary.

The inflow of iron-rich acid waters into the lakes did not result in low pH but in limited eutrophication by removing phosphorus previously imported with diverted river water. In addition, the very small mixing rate between monimolimnion and mixolimnion prevented eutrophication by recycling phosphorus from the monimolimnion of Lake Rassnitz. The monimolimnia served as temporal disposal sites for undesired substances.

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