Investigation Methods for Water Exchange Processes between Mining Lakes and Aquifers

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Abstract

In acidic mining lakes a main part of lake acidity can be due to groundwater inflow from oxidised dump sediments. For the assessment of restoration possibilities of sulphate rich, acid mining lakes, the interaction between the lake water and the groundwater from all hydraulic coupled aquifers must be known in detail. Several methods to measure groundwater infiltration into a lake were compared. Modelling, isotope and hydrochemical data as well as ^{222}Rn as an environmental tracer, and additionally temperature mapping and profiling in the shallow shore zones were used to estimate the groundwater inflow and outflow at mining lake ML 111.

Key words: acid mining lake, flux estimation, isotopes, radon concentration, groundwater recharge, seepage-meter, temperature measurement

Introduction and study site

The mining lake ML 111 (pH <3) is located in the Lusatian lignite mining district in Eastern Germany. Mining activities were closed there in 1957. The lake covers an area of 110,000 m^2 and has a mean depth of 6.5 m. The eastern, northern, and southern shore is flanked by dump sediments (Figure 1). The tertiary aquifers and the dump massif connected to the lake body are semi-confined. A hydrogeological characterisation of the investigation area started in 1996 with a chemical and isotopic study related to groundwater from adjacent gauge wells and from the lake water (Knöller and Strauch 2002). The maximum observed concentrations of Fe^{2+} and sulfur in the tertiary groundwater were about 100 mg l^{-1} and 800 mg l^{-1}, respectively. The dump water contained sulfur up to 3,700 mg l^{-1} and Fe^{2+} up to 1,200 mg l^{-1}. The estimated annual input into the lake caused by groundwater inflow for sulfur and iron is 37,800 kg and 7,000 kg, respectively.

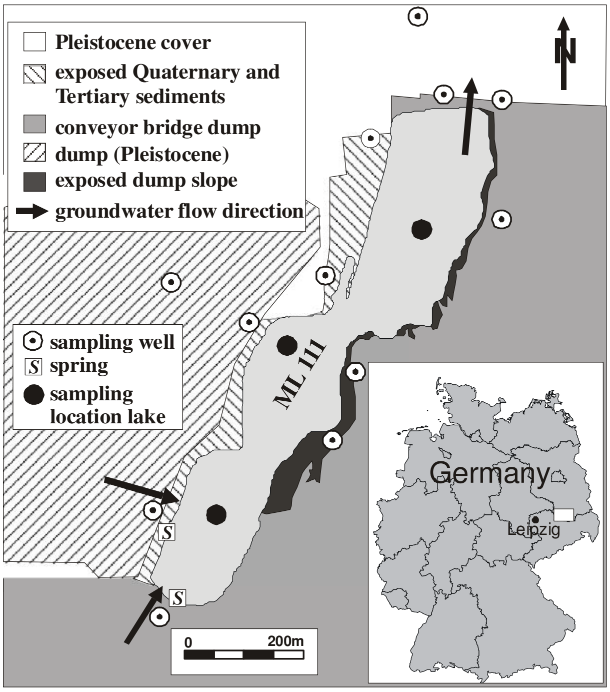
In the lake a biotechnological remediation strategy has been tested for several years (Koschorreck et al. 2007).

Investigation methods

Stable isotope (δ^{18}O and δ^{2}H of water, δ^{34}S of sulfate) and hydrochemical data (SO_4^{2-}-, Fe-concentrations) have been used to estimate the annual groundwater inflow and outflow of mining lake ML111 and to calculate the total amount of dissolved sulfate and iron that is carried into the lake by groundwater. The oxygen isotope measurements revealed that groundwater outflow takes place only on the northern shore. Additionally seepage-meter measurements were carried out. The flow rates of the single seepage measurement points ranged from <1 to 30 l m^{-2} d^{-1} due to the heterogeneous structure of the aquifers and the lake bed. However, these single point measurements are difficult to regionalise (Bozau and Strauch 2002a).

Another approach for quantifying groundwater discharge into an open pit lignite mining-lake is using the radioactive noble gas radon-222. This gas is produced by the decay of radium-226 within the decay chain of uranium-238. The naturally occurring nuclide ^{222}Rn (half-life = 3.8 d) is emanating by recoil from minerals of soils and sediments into the pore space.

***Figure 1** Site location mining lake ML 111 in the Lusatian lignite mining district*



As a result, ^{222}Rn is significantly enriched in groundwater compared to surface waters. Therefore, if groundwater interacts with surface water it can quickly be identified by their characteristic ^{222}Rn activity concentration. Consequently, ^{222}Rn has been widely employed as a geochemical tracer for groundwater-surface water interactions (Cable et al. 1996, Corbett et al. 1997, Schmidt and Schubert 2007, Schmidt et al. 2008).

The concept of using ^{222}Rn as an environmental tracer for tracing groundwater discharge into lakes is based on the quantitative assessment of all relevant radon flux terms with regard to the lake water body (box model). This allows the estimation of the actual contribution of the infiltrated groundwater to the overall radon input into the lake water body by difference. Given that the studied lake lacks any noteworthy connection to an open watercourse (as given in ML 111) radon input terms are limited to (i) groundwater infiltration, (ii) in situ radon production from decaying radium-226 dissolved in the water column, and (iii) benthic inputs via diffusion or physical mixing (bioturbation, sediment re-suspension) of radon by radium decay in the sediments. The output terms include (i) radon decay and (ii) radon loss to the atmosphere (degassing). A more detailed description and the quantification of the mentioned terms can be found elsewhere (Schmidt and Schubert, 2007).

To apply the radon-method on ML 111 a field survey was conducted in June 2007. All radon activity concentrations were measured using a mobile radon-in-air monitor (RAD7, Durridge Company, Inc). After all radon input and output terms were determined the actual groundwater discharge rate was calculated. The value (18,254 ± 6,334 m^3 a^{-1}) coincides very well with groundwater discharge rates obtained by various independent methods above.

***Table 1** Average data of the annual groundwater flow of the acidic mining lake ML 111*

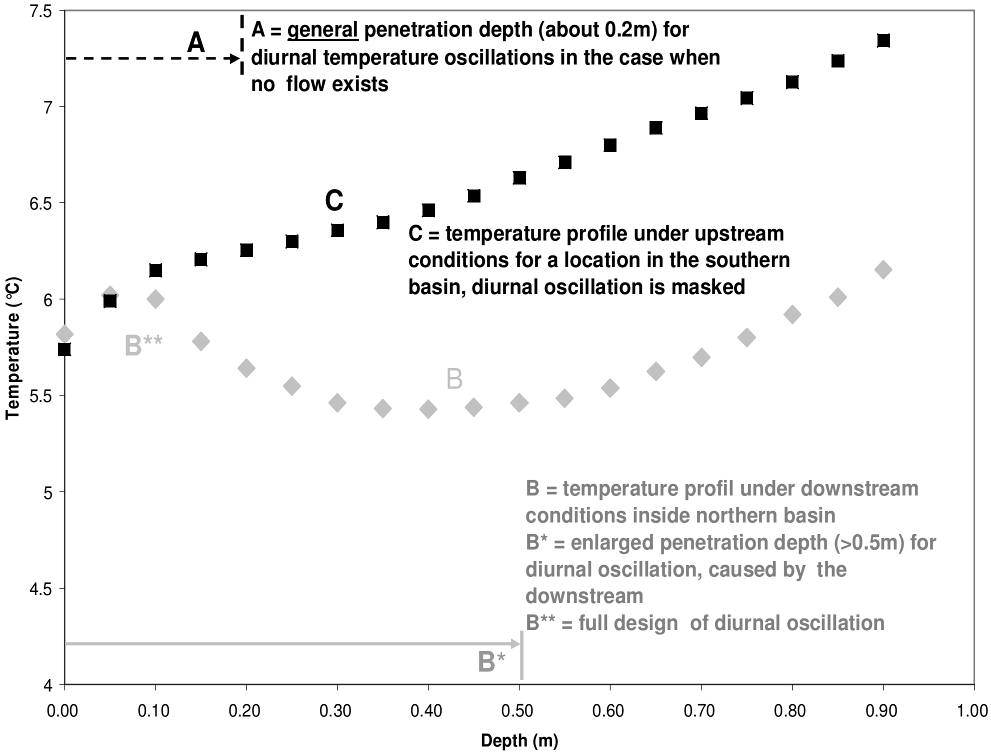
Method	*Isotopic investigations*$^{*)}$	*Seepage measurements*$^{**)}$	*Modelling (MODFLOW)*$^{**)}$	*Radon concentration*
Groundwater inflow	*23,700 m*^{3}	*21,300 m*^{3}	*31,200 m*^{3}	*18,250 m*^{3}
Groundwater outflow	*15,700 m*^{3}	*13,100 m*^{3}	*18,600 m*^{3}	-

$^{*)}$ Knöller and Strauch 2002, $^{**)}$ Bozau and Strauch 2002a, b

A further method for estimating both groundwater discharge and recharge was tested by mapping and profiling temperatures at uniform depths in the shallow shore zones of the mining lake. This method has been carried out successful for calculating groundwater/river water interactions in streambeds (Conant 2004, Schmidt et al. 2007). Basically, temperature measurements should be carried out only in periods of significant contrast between ground- and lake water temperature (winter or summer period).

Long-term temperature measurements (hourly) were conducted using thermistors, which were fixed at a multi-depth constructiondriven into the lake bed sediments up to 0.9 m below bottom. Observations in inflow- and outflow zones show quite different temperature behaviour in the lake bottom. The propagation of the diurnal temperature wave indicates downstream conditions to a depth of about 0.4 m (usually only 0.2 m in case of no flow). Under upstream conditions the diurnal wave is damped and nearly eliminated.

Figure 2 *Thermal response of inflow and outflow through the lake bottom in southern and northern basin of ML 111 during winter period 2008, water depth 1m, aquifer temperature 10°C*



For quick mapping on the shallow lake bottom, a special stainless steel device was used also enabling a multiple depth measurement (investigation depth 0.5 m).

The calculation of upward fluxes, derived from observed temperature data, bases on the analytical steady-state solution of the one-dimensional heat advection equation (Turcotte and Schubert 1982).

However, the method is not applicable to horizontal flow. At the investigated shore zones in ML 111 the lakebed is only less sloped, and therefore, nearly vertically flow can be assumed. Due to diurnal temperature oscillations in the shallow subsurface the calculation of recharge requires another approach (Schmidt et al. 2007). The temperature-derived fluxes reach from 3 to 70 $l\,m^{-2}\,d^{-1}$. However, the calculated fluxes were often overestimated compared to the results obtained from seepage measurements. Preferential flow paths may be created by driving sensors into the lake bed. The investigations were accompanied by long-term observations of the water table and temperature in the lake and in the aquifers (season-depending temperature 9-11°C, 5 m below surface) because the aquifer temperature is one of the boundary conditions for the flux calculation, and the flow conditions depend on hydraulic heads in the aquifers.

Conclusions

Several techniques for assessing the lake water – groundwater interaction were tested with respect to advantages and disadvantages for field scale utilization. Classical investigations and more advanced techniques, like the radon method, were applied for the estimation of the groundwater inflow with a very promising agreement of the obtained results. Temperature measurements allow for exactly distinguishing between active and inactive flow zones at the (shallow) lake bottom. Additionally, the flow direction can be determined. For a fast approximate assessment of the recharge and discharge conditions of a lake, a combination of radon-, temperature- and seepage-meter measurements is indicated.

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