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PREDICTIVE MODELING OF WATER QUALITY IN POST MINING ENVIRONMENTS

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ABSTRACT

Extensive open pit lignite mining has created a vast water deficit in two districts in south-east Germany. Abandoned mines will form lakes with a volume of approximately 20 billion qm. The process of flooding the mines is well on its way. A case study on a partly filled post mining lake is presented that includes measured data, a model based prediction of the future development, and the evaluation and quantification of a planned treatment action.

Existing data for the site include a time series of ground water and surface water quality. Bank sediments have been mapped and investigated in the laboratory by means of acid/base titrations. Geochemical budget calculations were performed based on measured values for water quality, the inflow of surface waters, estimated mass fluxes from erosion, and a 3D groundwater model.

A mass budget algorithm was coded into a program to perform a balance calculation for lake fragments. The combination of water and mass balance allows to calculate dissolved and solid mass concentrations that are used in a reactive modeling step. A geochemical speciation model is invoked in this step. The exchange of atmospheric gases and the precipitation of metals is simulated. Mineral precipitation within the lake is calculated based on a partial and local equilibrium assumption for Iron oxyhydrates (Ferrihydrite). Gas-exchange between the lake water and the atmosphere is calculated on the assumption of effective partial pressures that reflect steady state conditions. The code has been successfully tested for a number of similar objects.

Due to the future development in the flow system, seepage water and groundwater from a still drained overburden dump area will discharge into the lake. Effects of ground- and surface water recharge and erosion on the water quality of the lake is modeled. A sodium carbonate treatment was modelled with respect to its long time behaviour.

PROBLEM DEFINITION

In the two East German lignite mining districts about 40 lignite mines were closed during the past years. A government owned agency is in charge of the rehabilitation of the post mining landscape. The flooding of these mines follows a master plan for the region. A mayor part of the planning was to optimise the distribution of surface waters. Most mines are flooded using surface waters to avoid geotechnical problems as well as water quality problems. High concentrations of dissolved metals, sulphate and acidity are the major water quality problems. Desired lake water qualities were defined according to the legal regulations and the planned use of the post mining lakes. As divergence of the measured water quality from expected values occurs, process based predictions are needed to evaluate alternative strategies of action. These predictions are based on models. Water and mass balances are calculated from expected mean values to predict future hydrogeological conditions as a base for complex ecosystems to establish.

MODELING TOOLS

The hydrogeological conditions of the forming lakes are modeled using different simulation codes for different local scales and different physical processes. A regional groundwater flow model was developed in a first step. A model of the hydrogeological structure is available from the mining period. Boundary conditions are used according to the planned flooding regime. Uncertainties are introduced by the simplification of the rewetting process and the lack of a possibility to calibrate for the flooded state. Flow parameters are used as investigated in the period of drainage. The hierarchy of the used models is shown in Figure 1.

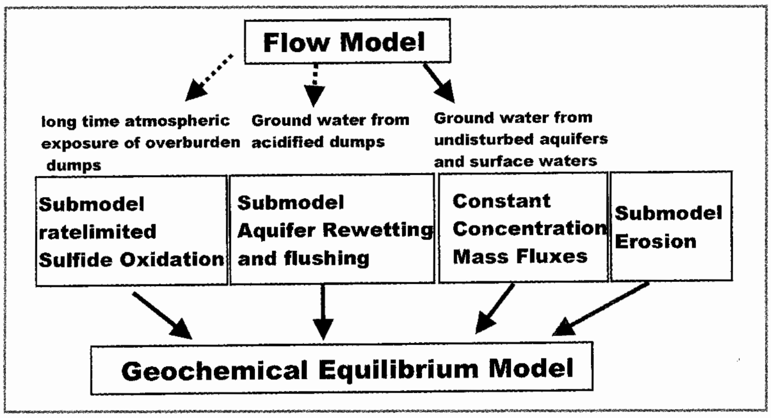

Figure 1. Overview showing used models and their hierarchy.

The most important results from the flow model are water balances for the lake and fluxes in the recharging and discharging aquifers and surface waters over time. Based on this water balance a mass balance is calculated. A mass flux is assigned to each hydraulic flux using the results from groundwater quality monitoring that is conducted to document the efforts of flooding.

Important mass fluxes are transported into the lakes by solid matter caused by the erosion of the banks of the lakes. Two types of erosion are distinguished, erosion driven by waves and erosion driven by rainfall during storms. The first one is taking place right at the water level, the second one affects the banks above the water level. The amount of sediment that is eroded over time is calculated using empirical methods as well as direct measurement.

Water and mass fluxes are combined in a second step to evaluate possible reactions within a lake fragment that is believed to constitute a 0-dimensional mixing reactor on a time averaged basis. Reaction calculations are performed using a speciation code and allowing for reactions of the dissolved matter with the atmospheric gases and the precipitation of oxidised metal oxyhydroxides. The main effort is focused on the simulation of the acid-base system.

CASE STUDY

Lake Bockwitz is located in the Middle German mining district about 30 km south of the city of Leipzig. Its water volume will be about 19 Mio. m^3 in its completely flooded state. A map of lake B, exhibiting the sloped banks of the lake and the location of the groundwater monitoring wells is shown in Figure 2. The wells were installed to sample water from 6 different aquifers of quaternary and tertiary age. The dump was as well classified as a separate aquifer. The porous media of the aquifers is mainly quartz. The location of the wells were designed on the base of the flow model results.

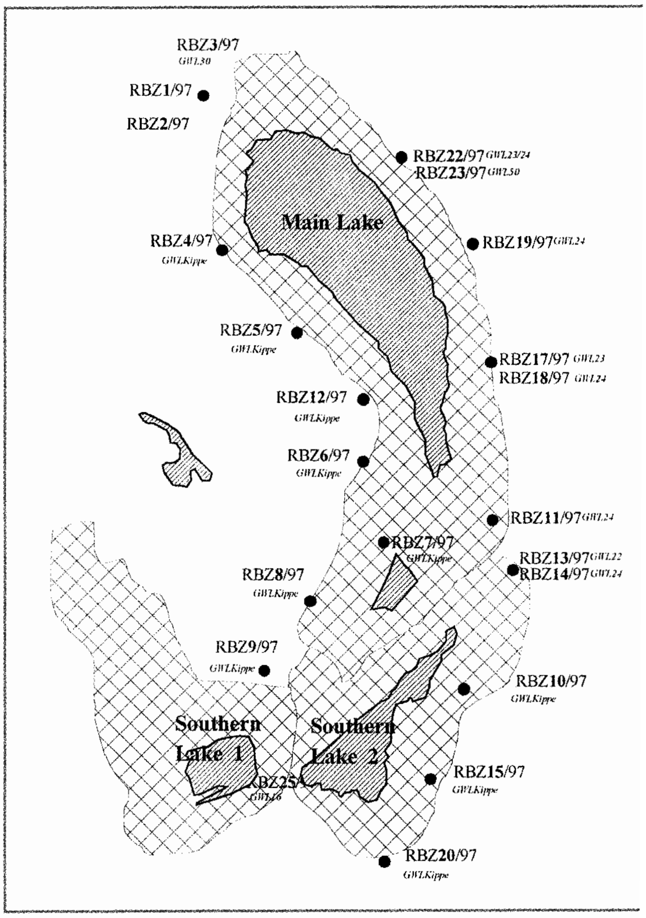

Figure 2. Lake Bockwitz (Main Lake) in today's extension.
Hatched areas represent the sloped banks. Black dots locate ground wate monitoring wells

The results from the flow model are shown in Figure 3. More than half of the ground water flux exfiltrating into the lake is discharged from carbonate containing aquifers of marine origin.

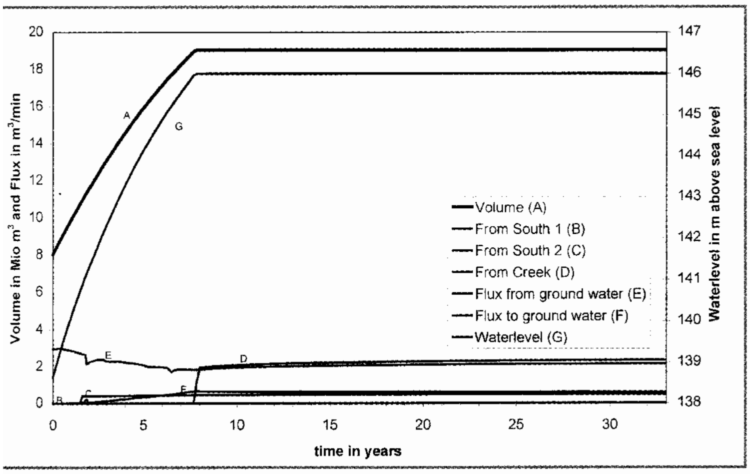

Figure 3. Hydraulic fluxes to and from lake B. As calculated by IBGW, 1998.

The comparision of the water quality of the lake water (Table 1) and the groundwater revealed mayor differences between both waters. The lake water is low in pH and contains significant acidity whereas ground water is near to neutral containing a slight alkalinity. This lead to the assumption that the acidity is carried into the lake by erosion.

Parameter	Unit mol/l	mg/l
base consumption to pH 4.3 and	5.2e-3	-
pH 8.2	8.6e-3	-
Na	0.5e-3	11.5
K	0.1e-3	3.9
Mg	1.5e-3	36.5
Ca	8.8e-3	350
Mn	<0.05e-3	<0.5
Fe II	<0.05e-3	<0.6
Fe III	1.2e-3	67.2
Al	0.8e-3	21.6
TIC	0.2e-3	2.4
Si	0.3e-3	8.4
SO_4	14.4e-3	1370
Cl	0.4e-3	14.4

Table 1. Water quality in Lake Bockwitz, pH=2.7.

Bank sediments where mapped and investigated in the laboratory. Acid-base titrations were preformed on water sediment suspensions. Figure 4 shows experimentally determined titration curves and a model curve that was constructed based on the measured curves. The deviation in the low pH range is a result of the water sediment ratio that was used in the experiments. The calculation considers only solid matter and its effect on the concentrations of aluminium, iron, sulphate and acidity of the lake water.

Acidity influx due to erosion was calculated in two steps. Step (1) calculated the sediment flux. Step (2) derived an acidity flux from the sediment flux by using the above described soil acidity function (Figure 4) and the calculated intermediate lake water quality at the beginning of step (2).

RESULTS

A prediction for the changes in water quality of lake Bockwitz was lumped on a equivalent 0-D reactor. A base case was constructed using measured concentrations in the inflow and measured concentrations within the lake to estimate the acidity flux that is assigned to the two considered types of erosion. A acidity flux of about 6 Mio mol/year was calculated to be necessary to produce the measured conditions. The acidity flux

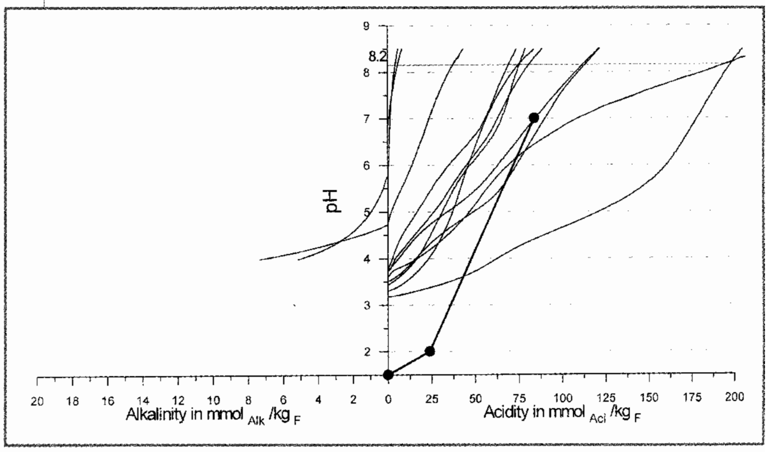

Figure 4. Titration curves (black lines) of water sediment suspensions (wt ratio 10:1) with 1M NaOH and model curve (black dotted line). Initial pH is lower for the model curve as it represents conditions in residual pore water.

over time that is driven by erosion is considered to be strongly dependent on the type of erosion. Erosion driven by waves is highly important during the flooding and for some time thereafter. Stationary water levels will create a steady state bank profile [2] and thus decrease the erosive sediment flux to insignificant values. Erosion driven by rainfall during storms as well decreases in time. Nevertheless Lake B will show a bank slope area of 76 ha even after complete flooding. High soil acidity often hinders vegetation to create an effective barrier against erosion. Typical erosion rills and gullies can be observed. The results from the base case scenario are shown in Figure 5. A natural neutralisation within the next century is predicted on the basis of the hydrogeologic data.

Successive scenarios were modeled to vary the development of the sediment mass fluxes over time. The base case was constructed using expected mean values.

A water treatment of the lake water with Soda (Na_2CO_3) was discussed to enhance neutralisation. A simulation of this treatment is shown in Figure 6.

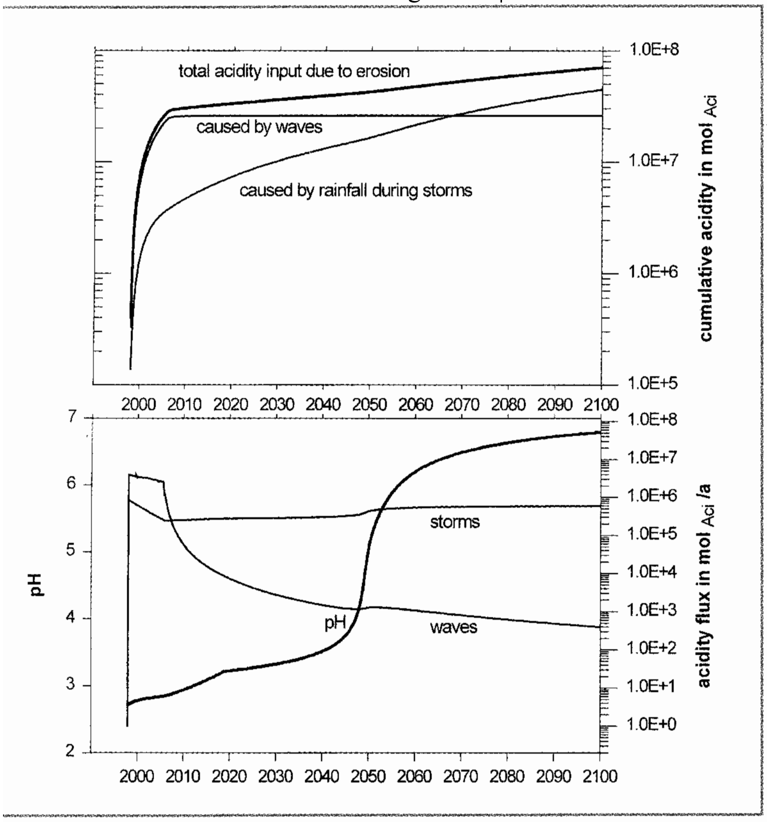

Figure 5. Base case scenario for the development of pH in Lake Bockwitz.

are lumped on a balance point that represents a lake fragment. These lake fragments are on a time averaged basis believed to be fully mixed systems. Thus seasonal variations cannot be modeled with the presented reduction in space. A one dimensional system of balance points is planned to be used to reflect stratification within the lake in a future model. Observations on numerous post mining lakes have shown, that oxygen is regularly found in the hypolimnion during times of stagnation and is not fully depleted. This implies, that the hydrochemical boundary conditions in the layers of the stratified system can be substituted by equivalent lumped conditions within one oxidising reactor. This simplification seems to be valid for the described highly acidic, carbon limited system. As pH approaches neutral conditions the uncertainties that are introduced by neglecting alkalinity input due to biological activity increase. The presented predictive model is in our opinion suitable for the simulation of the hydrogeological conditions that are most effective during flooding. To take into account biological processes and a more complex spatial system the model could be modified without a change in the general approach.

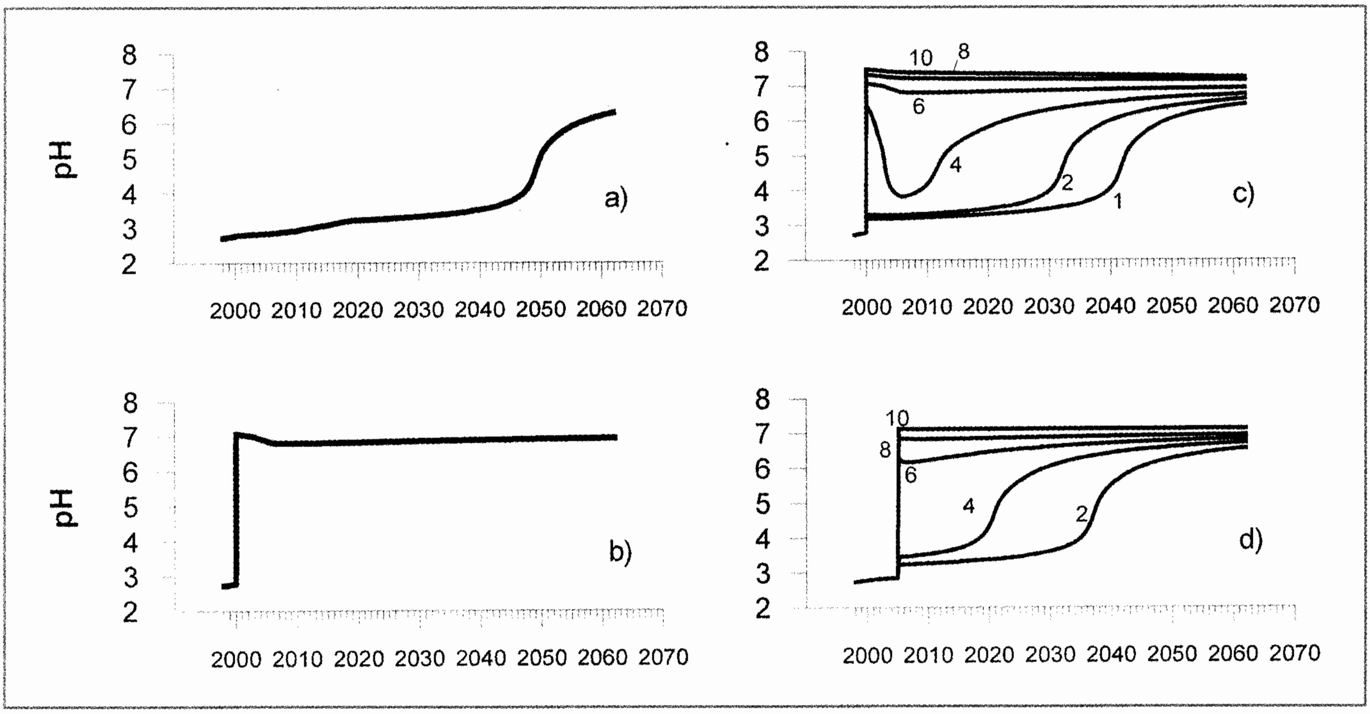

Figure 6. Simulated development of pH for different water treatment scenarios.

a) Base case,
b) Input of 6000 t soda at the 01.01.2000,
c) Input of 1000 t (1), 2000 t (2), 4000 t (4), 6000 t (6), 8000 t (8) and 10000 t (10) at the 01.01.2000,
d) Input of the same masses as in c) at the 01.01.2005

DISCUSSION

The presented modeling approach combines mass balance calculations and reaction calculations. The balances

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Wagner, H., 1998. Dynamik der Windwellenerosion an Uferböschungen verbun-den mit dem Wasserspiegelanstieg bei der Restlochflutung. 6. DGW-Foschungs-tage, Proceedings des Dresdner Grundwasserforschungszentrums e.V., Heft 13, p209-210.