Modelling of environmental impacts of 140 years of open pit lignite mining and chemical industry on groundwater contaminants in the Bitterfeld area (Germany)

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Abstract The open pit lignite mining in the period 1850 to 1990 in the Bitterfeld area (Germany) led to a drawdown of groundwater and changing watersheds. The contaminations of the chemical industry, established since 1890, were spread by these changing flow conditions over a wide area according to the influence of the mining activities. The recent contaminant distribution can be described only insufficiently by the measurements. The processes had to be simulated by a groundwater flow and transport model to estimate the complete contamination. The parameterization of this model was widely based on a high resolution geological model of the central model area.

Key Words Groundwater flow modelling, groundwater contamination, mining impacts

Introduction and geological settings

In 1850 the open pit lignite mining started in the area of Bitterfeld (Germany, s. fig. 1). Based on the lignite mining a chemical industry was developed since 1890. The groundwater contamination induced by the chemical industry has effects on the urban area and the surrounding nature reserves that have to be lined out clearly.

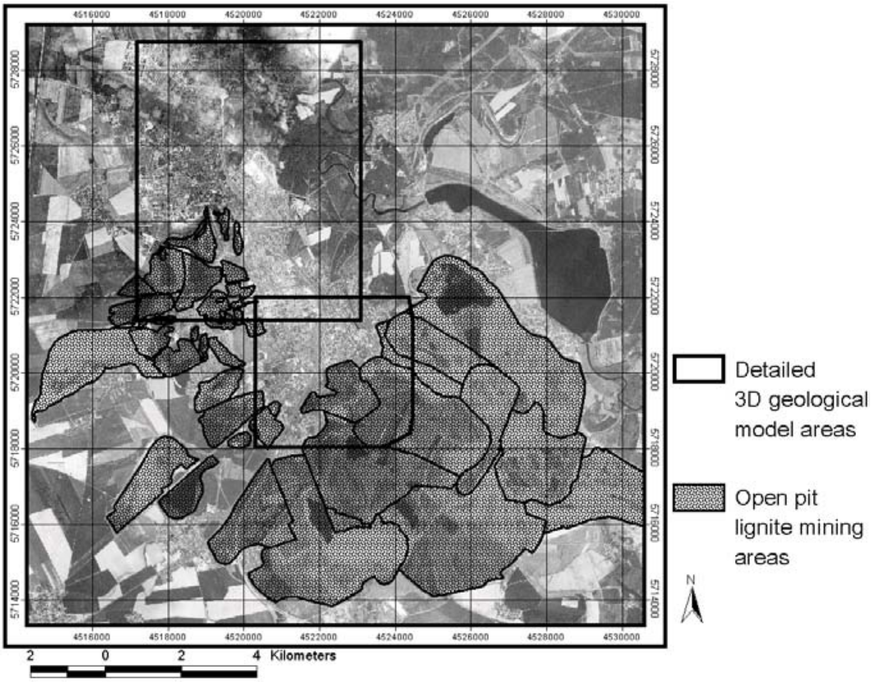

Figure 1 Overview of the different model areas of geological models and hydrogeological model. The background satellite image of 1988 (Topware 1997) shows the extent of the open pits and was database for the digitalization

Geological description	Lithology	Hydrostratigraphical description	Hydraulic conductivity [m/s]
Lignite mining deposits, waste disposals	Sands, clay and waste diposal	1. Layer: Horizontally distributed aquifers and aquitards	1e-6 to 1e-3
Holocene fluvial deposits	Loam, clay		
Weichselian aeolian sediments	Loess		
Weichselian fluvial sediments, upper series	Gravels and coarse sands	2. Layer: Aquifer	1e-4 to 1e-3
Periglacial sediments	Clay	3. Layer: Aquifuge	1e-6 to 5e-6
Weichselian fluvial sediments, lower series	Gravels and coarse sands	4. Layer: Aquifer	1e-4 to 1e-3
Saalenian till	Loam, clay, sands	5. Layer: Aquitard	1e-6 to 5e-6
Saalenian and Elsterian fluvial deposits	Gravels and coarse sands	6. Layer: Aquifer	1e-6 to 1.7e-3
Elsterian till	Loam, clay, sands	7. Layer: Aquitard	1e-7 to 5e-6
Tertiary: Miocene cover of lignites	Clay and sands	8. Layer: Aquifuge	1e-8 to 1e-7
Miocene lignites	Lignites	9. Layer: Aquitard	const. 2e-7
Miocene sands, upper series	Sands	10. Layer: Aquifer	const. 1e-4
Miocene clay	Clay	11. Layer: Aquifuge	const. 1e-8
Miocene sands, lower series	Sands	12. Layer: Aquifer	const. 1e-5
Miocene silt	Silt	13. Layer: Aquitard	const. 1e-8
Rupelian	Clay	Bottom of the Model	const. 1e-10

Figure 2 *Hydrostratigraphical units in the Bitterfeld area with ranges of the hydraulic conductivity implemented in the numerical groundwater model*

The mining was enabled by groundwater extraction because the lignite is found in most parts of the area in a depth of 40 m to 50 m below ground whereas the groundwater reaches levels of 2 m to 10 m below ground. The Quaternary and Tertiary sediments have completely different geneses: The Pleistocene sediments consist of glacial sands, gravels and tills intercalated by clay and humous layers from the interglacial periods. These Pleistocene sediments with a thickness of ca. 30 m are covered by aeolian fine sands and silts in the higher parts and by fluvial silts and clays in the valley of the river Mulde. The Tertiary sediments are of marine, mostly lacustrine, genesis. They consist of fine sands, silts, the lignite and clay of Eocene, Oligocene and Miocene age. An overview of the geological layers is given in fig. 2.

The geological situation is very complex due to Pleistocene channels and gullies, especially of Saalenian age. The mining activities additionally led to highly disturbed (or destroyed) geological structures, which complicated the modelling approach additionally. The geological model, which is described in Wycisk et al. (2002), shows already the important features of hydraulic connections between aquifers and the distribution of sorption horizons.

In the 1890s parallel to the increasing mining activities the chemical industry was built up in this area and led to contaminations of soil and groundwater. The production started with some inorganic chemicals and developed to mainly pesticide and organic solvent synthetization. The contamination spread in the groundwater according to the changing flow conditions due to the mining activities. The distribution of this contamination was observed by frequent measurements since the beginning 1990s.

Methods

Two high resolution geological models of the area of interest were developed based on a constructive approach with connected cross sections as described in Wycisk et al. (2002). The areas of the two models are shown in fig. 1. The main contributing data for these models were boreholes and maps that covered a total area of 60 km^2.

For the numerical groundwater model the area had to be enlarged to get reliable boundary

Figure 3 *Spreading of an ideal tracer based on the numerical groundwater flow and transport modelling 1970, 1980, 1990 and 2000 of one deposit in the Quaternary aquifer*

conditions. The area of the numerical groundwater model amounts to 330 km^2. The numerical model was set up based on a GIS database with the tool Feflow (Diersch 2009). This tool was chosen because of its capability to reflect the different levels of information: For the detailed model areas with a high need for information a high discretization was elaborated and for the outer area with low level information and of less interest a reduced discretization was chosen. For the groundwater flow model not only the hydrogeological structures and parameters but also the time dependent groundwater recharge and boundary conditions had to be set. The transport model was created by setting the parameters for dispersivity and diffusivity. Only ideal tracers were modelled without sorption and degradation parameters. The calibration of the groundwater model in this historical time frame is a challenging task and could only be realized by a wide use of proxy data, e.g. the levels of the lignite layers that were mined. Most important for the transient modelling approach was the coupling to additional modelling systems, e.g. for groundwater recharge, the unsaturated zone and the connection to surface water.

Results

The model results show clearly the successive spreading of the contamination in the last 100 years. Additionally the influence of the geology, the mining activities and the locations of contamination zones that lead to the observed distribution becomes obvious. Most important was the pumping of groundwater in different directions of the contaminating chemical industry. Thus, a complex contamination spreading was outlined by the model and the recently observed contaminant distribution which was inexplicable without the numerical groundwater model became more understandable. As shown in fig. 3 some of the contamination sources are spreading in different directions according to the hydrogeological and hydrological conditions. Additionally, the groundwater model allows the determination of time frames for the occurrence of contaminants at sensitive locations. The planning of remediation techniques, locations and time frames is much more reliable based on these widely calibrated modelling results. The elaboration of future scenarios is now possible. Since 1998 the flooding of the remaining open pits started and it was forced by a regional flooding event of the adjacent river Mulde in August 2002. Due to that event, the regional groundwater flow patterns changed once again completely and the model indicates that the contamination will extend to nature reserve zones in the next decades.

Conclusions

The complex situation of geological settings, anthropogenic impacts on hydrogeological structures and flow conditions as well as a complex contaminant input makes a numerical approach for this area necessary. A bare estimation of groundwater flow directions and velocities is not suitable for such a long time frame with changing hydrogeological conditions. The effects of the 3D spatial and transient influences are so complex that they can only be understood a posteriori. The work in this area is going on in terms of implementing sorption and degradation processes so that a profound understanding of all involved processes can be achieved.

References

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