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Impact Assessment of Mine Drainage on the Yield of Groundwater from a Well Field Using a Numerical Model, Case Study, Huaibei, China

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Abstract Very large amounts of groundwater enters the mine workings. The water must be removed if mining is to be continued. This water, coming as it does from a groundwater aquifer, may result in the water level of the aquifer decreasing and this may affect the supply of potable water in the surrounding area. It seems that there is a conflict between water supply and mine drainage. This research takes a mine area, Huaibei, China, as an example and focuses on that conflict. Based on a numerical simulation model of groundwater flow, our research analyzes the mine water drainage effect on groundwater level of a Quaternary porous aquifer and an Ordovician fractured karst aquifer. After three years of mining, the maximum additional drawdown of the fracture karst aquifer caused by the mine drainage is 0.33 m in the center of the mine area. In a well field located 10 km from the mine, the additional drawdown is only 0.03 m, accounting for only 0.5 percent of the allowable groundwater drawdown of 6.0 m. The additional groundwater drawdown of the overlying porous aquifer is no more than 0.012 m. These results demonstrate that the porous aquifer and the well field are not significantly influenced by mine dewatering. In other words, the residential water supply is essentially unaltered.
Key words Huaibei, mine drainage, additional groundwater drawdown, well field

Introduction

During mining at many mines, large volumes of groundwater are pumped out of the mine workings and discharged resulting in environmental problems such as changes in groundwater flow patterns, land subsidence, water pollution, formation of groundwater depression cones, and simple groundwater depletion. Some investigators have studied methods to try to prevent mining activities from affecting the groundwater at the mine itself but this strategy is impractical and not feasible in China. A fruitful approach is to analyze and evaluate the impact of mine drainage. Mine drainage studies can aid decision and policy making, especially in the fields of environmental and water resources management. The effect of mine drainage on groundwater is also an important concern for the mining industry.

Mine drainage has caused massive environmental problems in many countries where mining has taken place such as the catastrophic event at the disused Wheal Jane tin mine, Cornwall, England, in 1992 when a range of contaminants entered the environment (Younger et al. 2005, Neal et al. 2005). There have been many studies attempting to quantify adverse effects such as these. For example, some traditional methods have been used successfully to determine the quantity of the mine water discharged (Guo and Ma 2010, Hua 2009). However, the results of these studies have not provided much information for water resources managers or decision makers. To solve this problem, additional studies are essential.

Huaibei is a typical mining city in China. Presently, plans are underway to further expand the mine to meet domestic demanded. While there is a well field 10 km northeast of the mine that supplies groundwater to supply domestic water to the city of Huaibei. It is an underground iron mine. Its rocks adjacent to the well field are marbles with a fairly direct hydraulic connection with the fractured karst aquifer from which the wells in the well field produce. During mining, a very large volume of groundwater will be pumped out of the mine workings and discharged. Groundwater discharge will inevitably result in a decreasing water table in the fractured karst aquifer and may even affect the viability of the well field. Some questions therefore present themselves: Owing to the direct hydraulic connection between the mine and the well field, how large is the cone of depression that will result from mine dewatering? If the area of influence is larger than 10 km, then the water table in the well field will decrease and the water supply will be jeopardized. How much will the groundwater in the fractured karst aquifer be drawn down?

Study area

The study area is located in eastern China in northern Anhui Province. It extends over a roughly rectangular area of about 167.5 km^2 (fig 1). The climate is temperate continental monsoonal with an annual average water evaporation of about 103 cm and an annual mean precipitation of 84.5 cm, most of which is falls in the months of June through September. Being part of the Huaihe River basin, the study area is drained by several rivers and artificial water diversion canals, the main river being the Xinbian River (fig 1).The study area is quite flat; elevations range from 28.5 m to 29.9 m, and the landscape is an alluvial plain sloping slightly from northwest to southeast.

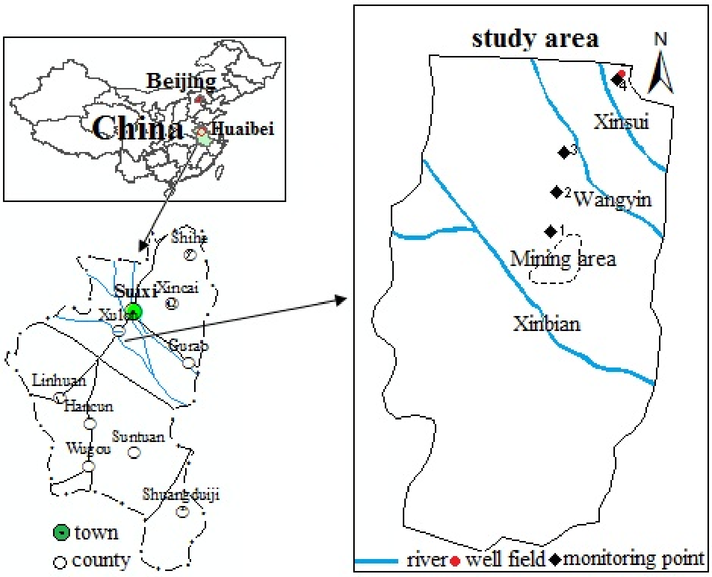

Fig.1 *Map showing the location of the study area*

Hydrogeology

The bedrock consists of Lower Ordovician marbles and overlying Upper Tertiary units overlain by Quaternary deposits. In the study area, the aquifer system consists of an unconfined aquifer 10-42 m thick, an underlying 15-40 m aquitard, and a number of confined layers below the aquitard that are 40-220 m in aggregate thickness. These are all floored by an impermeable bottom layer. fig. 2 shows the intermittent loams and clay lenses in the study area and also shows that the hydraulic connection between the porous aquifer and the fractured karst aquifer is fairly direct in the Huaibei area. However, these two aquifers have no direct hydraulic connection near the well field. Depths to the water table are as little as 3.5 m in the northern part of the study area but are in general over 10 m.

Groundwater well field

Water is in short supply in the vicinity of Huaibei. To meet the domestic water demands of a developing city, a groundwater well field, located northeast of the mining area, was developed and is managed as a water source for the basin (fig. 1). The well field, which taps the fractured karst aquifer at a depth of 70 m, is located about 10 km from the center of the mining area.

There are also many villages surrounding the mining area and these people's household water demands are mainly met by water pumped from wells in the overlying porous aquifer.

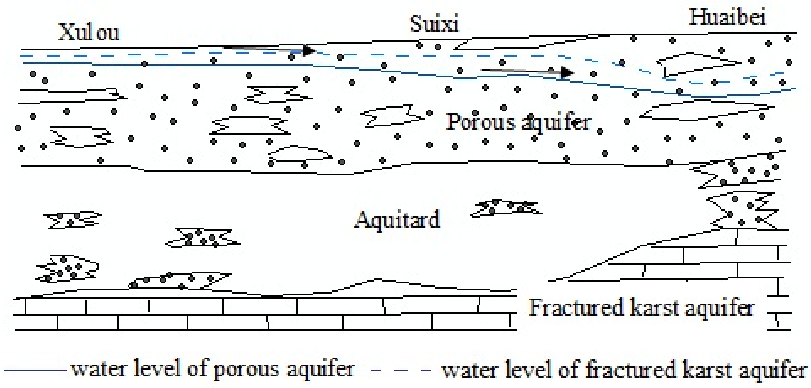

Fig. 2 *Illustrative geological profiles*

Mining area

The mine is an underground mine about 300 m deep. The surrounding rocks are Ordovician marbles. There is a fairly direct hydraulic connection between these marbles and the karst aquifer and therefore much of the water pumped from the mine comes from the fractured karst aquifer, although some of it comes, indirectly, from the Quaternary porous aquifer.

During mining, mine water will be pumped out of the workings and discharged. This will inevitably result in decreasing the water level in the fractured karst aquifer and possibly affect the water level of the overlying porous aquifer. Either or both of these eventualities may affect the viability of the well field.

Numerical simulation approach

Conceptual models

Concerning the aquifers, the confined or fractured karst aquifer is most important because the well field pumps from the fractured karst aquifer. In this aquifer, the fractures are developed discontinuously and are separated by clastic rocks in some areas. The aquifer was treated as isotropic with $Kx = Ky = 10$ kz. Under pumping conditions, the main recharge sources include precipitation and lateral recharge. Groundwater extraction is the main sources of discharge.

Mathematical model

The general, three-dimensional, partial, finite differential equation for constant density transient groundwater flow in a heterogeneous and isotropic medium for a confined or unconfined aquifer is, as expressed by Bear (1979) and Todd and Larry (2005):

$$\frac{\partial}{\partial x}\left(K\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K\frac{\partial h}{\partial z}\right)+N\left(x,y,z,t\right)=S_s\frac{\partial h}{\partial t} \quad (1)$$

where K is the hydraulic conductivities [L/T], h is the hydraulic head [L], $S_s$is the specific storage of the porous medium; N is the volumetric flux per unit volume representing sources and/or sinks of water; and t is time.

Aquifer properties

The aquifer hydraulic conductivities, specific yields, storage coefficients, effective porosity, and the initial conditions were estimated from the pumping well test records and other sources. These parameters were assigned to the different layers in the aquifer-modeled area based on zonal techniques. In the first layer two, zones of hydraulic conductivity were identified with values of 0.95 and 2.61 m/day, in the second layer, the aquitard, the hydraulic conductivity was assigned a value of 0.005 m/day, and, in the third layer, the value of hydraulic conductivities are 0.2, 3, and 20 m/day. Likewise, the specific yields and storage coefficients also differ in the different aquifer model regions. In layer one, the specific yield has a range of 0.045-0.15; in layer two, the specific yield is 0.01. The third layer specific storage is 2×10^{-5}. In general, the total porosity has a range of 0.2-0.3 in the three layers.

Boundaries

The constraints for the modeled area considered here are recharge and the area's hydrologic boundaries. Precipitation was the only recharge considered and precipitation was presumed to take place on the top surface of the modeled area. From the four meteorological stations present within the area, three precipitation recharge zones were identified using 3 years of precipitation data. For this time period, the spatial precipitation infiltration coefficients had a range of 0.12-0.25. Evapotranspiration was assumed to be from the top of the saturated zone at an extinction depth of 3.5 m.

The study area is hydrogeologically unbounded on all sides. Its extent as defined for this study is such that long-term hydraulic gradients at the area's geographic boundaries are negligible and any groundwater fluxes computed using reasonable permeability values are small compared with the total changes in storage owing to any vertical stresses applied. Hence, the entire modeled area domain boundary was assigned a general head boundary condition, which is a Detrichlet boundary condition.

Results and discussion

Mine water influx

For mining to take place, it is necessary to discharge the water flowing into the mine. This volume of water is what causes changes in the groundwater conditions in the surrounding area, so determining the volume of mine drainage is the first step in creating a model.

According to observational data obtained during mine construction, water influx into the mine is about 4000 m^3/day.

Representative monitoring points

As discussed in section 2.3, water from the fractured karst aquifer of the Ordovician carbonate rocks is the direct source of water infiltrating the iron mine whereas water from the porous Quaternary aquifer is an indirect source. Therefore, mine dewatering will affect the fractured karst aquifer first and may also eventually affect the porous aquifer in the vicinity of the mine. It is also important to determine whether the groundwater in the well field, 10 km from the mine, will be affected. To assess these possible influences, four monitoring points were selected located 1, 3, 5, and 10 km from the mine center (fig. 1).

Analysis of the fractured Karst aquifer water level

As noted previously, mine operations pump 4000 m^3/day of drainage from the mine. We used our numerical model to analyze how this pumping affects the groundwater levels in the two aquifers and the results are shown in table 1 and fig. 3.

Table 1 *Mine-related fractured karst and porous water level drawdown around the iron mine after 3 years of mine operations*

Monitoring points	Mining center	Point one	Point two	Point three	Point four
Distance from the mining center (m)	0	1000	3000	5000	10000
Fractured karst water level drawdown (m)	0.33	0.20	0.14	0.08	0.03
Porous water level drawdown (m)	0.012	0.011	0.01	0.008	0.003

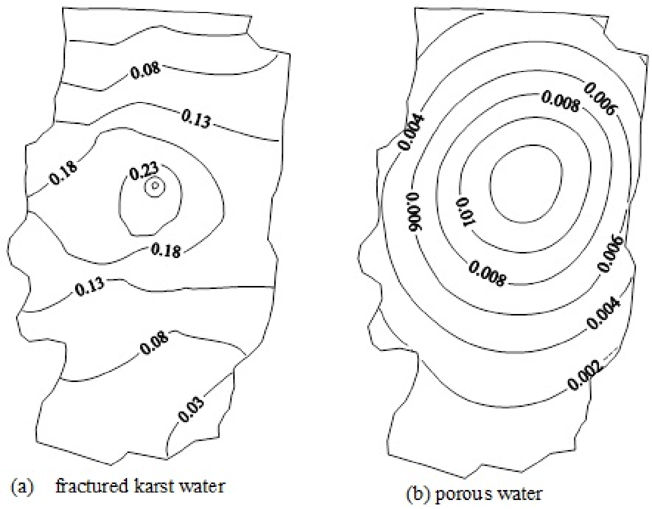

Fig.3 *Contour map showing the spatial distribution of the additional drawdown in the Quaternary porous aquifer and the Ordovician fractured karst aquifer at day 1095*

Table 1 shows that the maximum drawdown of the water in the fractured karst aquifer caused by the mine pumping is 0.33 m after 1095 days (exactly 3 years) of mining. In the well field, 10 km from the mine, the additional drawdown is only 0.03 m; this is only 0.5 percent of the allowable groundwater drawdown of 6.0 m. The spatial distribution of the additional groundwater drawdown in the fractured karst aquifer is shown in fig. 6. The contours show that the additional groundwater drawdown is greater than 0.2 m within a radius of about 1.5 km from the mining center.

Analysis of the porous aquifer water level

The additional groundwater drawdown in the porous aquifer is small, and the maximum value is only 0.012 m. The main reason is that there is a rather stable aquitard between the porous aquifer and the fractured karst aquifer. The model confirms that the porous aquifer is hardly influenced. In other words, the Quaternary porous aquifer, the source for residential water for the numerous villages in the area, is essentially unaffected.

Conclusions

We evaluated the effect of the discharge of 4000 m^3/day from the iron mine on the groundwater aquifers in the general vicinity of the mine area using a Visual MODFLOW numerical model. According to our hydrogeological analysis, water from a fractured karst aquifer in Ordovician carbonate rocks and the overlying Quaternary porous aquifer are the direct and indirect sources for the water pumped from the mine. We used the Visual MODFLOW model to simulate the hydraulic head distributions and analyze the impact of the mine drainage in detail. After exactly 3 years of mining, the maximum mine-related groundwater drawdown in the porous aquifer is only 0.012 m. In the well field that produces water from the fractured karst aquifer 10 km from the mine, the additional drawdown is only 0.03 m, which is only 0.5 percent of the allowable groundwater drawdown of 6.0 m. These results demonstrate that the effect of mine water discharge on the porous water and on the well field are inconsequential. In other words, the residential water supplies for the city and villages in the Huaibei area are essentially uninfluenced.

This project successfully built a numerical model for the quantitative impact assessment of mine drainage. This model can be used effectively for water resource management and environmental decision making at a number of different administrative levels.

Acknowledgment

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