Numerical Simulation of the Groundwater in Bulang River-Red Stone Bridge Water Source

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Abstract—In order to put forward a reasonable mining scheme to ensure the safety of Bulang River-Red Stone Bridge water source, the standard visualization software Visual MODFLOW is adopted to simulate the groundwater flow in the study area. The model identification and verification results indicate that the model can reflect the actual hydrogeology conditions, and can be used to forecast groundwater flow. Based on comparative analysis of the prediction results of mining schemes, a reasonable scheme with exploitation quantity of 35000 m³/d is determined to ensure the normal operation of the water source, under which neither the local ecological environment nor the Haiilitu River flow is influenced.

Keywords—Visual MODFLOW; numerical; simulation; water source

I. INTRODUCTION

As human activities and climate change are becoming more and more intensive, groundwater problems such as groundwater pollution and water shortage are getting worse and worse. Numerical simulation, a useful tool for groundwater management and protection, is always used for solving these problems. In depth understanding of groundwater system characteristics can be reached with the mathematical model [1]. The groundwater flow problems and the groundwater quality problems can be solved efficiently by numerical simulation. In order to quantitatively calculate the available exploitation quantity of groundwater in Bulang River-Red Stone Bridge water source and provide basis for rational development and utilization of water resource, the numerical simulation method is used to establish a three-dimensional numerical simulation model with Visual MODFLOW [2, 3]. An optimal scheme is determined to ensure the normal operation of the water source.

Bulang River-Red Stone Bridge water source is located in the northern bank of Wuding River in the western of Yulin city. The main topographies in the study area are loess-hilly covered sand, sandy land and valley terrace. The groundwater types are mainly Quaternary loose rock phreatic water and Cretaceous clastic rock fissure-pore water. The Quaternary loose rock pore phreatic water spreads all over the study area. The water yield property of Cretaceous clastic rock fissure-pore water is getting weaker from west to east and from north to south. The precipitation infiltration and the agricultural irrigation infiltration are the main sources of the water recharge. And the main discharges are groundwater evaporation, artificial mining and discharge to the river, etc. [4].

II. CONCEPTUAL MODEL

The middle part of the western boundary receives lateral runoff supply and can be conceptualized as flow boundary. Wuding River, located in the south of the study area, can be conceptualized as constant head boundary. Other surrounding boundaries can be seen as confining ones. Water exchanges occurring in the top interface have great contact with atmosphere, such as precipitation, agricultural irrigation infiltration, and phreatic water evaporation and so on. The lower interface is conceptualized as confining boundary.

III. NUMERICAL MODEL

The following three-dimensional transient flow numerical model is set up based on the above hydrogeological conceptual model [5]:

\[
\begin{aligned}
\frac{\partial}{\partial t} \left( K \frac{\partial H}{\partial x} \right) + \frac{\partial}{\partial y} \left( K \frac{\partial H}{\partial y} \right) + \frac{\partial}{\partial z} \left( K \frac{\partial H}{\partial z} \right) - (K_{oz} + W) \frac{\partial H}{\partial z} + W &= 0 \\
\mu \frac{\partial H}{\partial t} &= K_x \frac{\partial H}{\partial x} + K_y \frac{\partial H}{\partial y} + K_z \frac{\partial H}{\partial z} \\
\lim_{\rho \to h_1} 2\pi r K_M \frac{\partial H}{\partial r} &= Q \\
\end{aligned}
\]

Where, \( H \) is the groundwater level, \( K \) is hydraulic conductivity, \( \mu \) is specific yield, \( x, y, z \) is coordinate variables, \( f(x, y, z) \) is the initial water level distribution in the study area, \( h_1 \) is the groundwater level of the First Boundary

Phreatic water surface boundary

Fully penetrating well
which means constant head boundary, \( q \) is the seepage flow of unit width of the Second Boundary, \( Q_i \) is exploitation quantity of the \( i \)th mining well, \( r \) is the polar axis in polar coordinate system, \( W \) is the precipitation recharge intensity, \( n \) is the external normal direction of the Second Boundary, \( \Gamma_1 \) is the First Boundary, \( \Gamma_2 \) is the Second Boundary.

IV. DESIGN OF THE MODEL

A. Discretization

In space, the entire study area is discretized by 200m x 200m grid paralleling to \( x \) and \( y \) into 23810 active cells, based on the aquifer medium characteristic, there are two layers vertically, so the total active cells are 47620.

In time, the simulation time lasts 12 months, from October 2005 to Septembers 2006. Considering the change characteristic of external factors which have effect on groundwater system, the simulation time is divided into 12 stress periods corresponding to the months of the year. To improve the calculation accuracy, every stress period is further subdivided into 10 time steps and adjacent time step must meet the following relation:

\[
I_{k+1} = 1.2 I_k
\]

Where, \( I_k \) represents the \( k \)th time step.

B. Determination of Initial Conditions

The initial flow for groundwater is drawn based on the water level material in October 2005. As the exploitation quantity is small, there is little difference between the water level of two layers, and they have the same initial flow field.

C. Selection of Parameters

Quaternary aquifer is divided into 7 parameter areas and Cretaceous aquifer is divided into 3 parameter areas horizontally according to topography, physiognomy, lithology and water yield property. The southern aquifer medium is heterogeneous anisotropy, and its value of vertical hydraulic conductivity is 2 times of the horizontal one, the other parts can be seen as heterogeneous isotropy.

V. MODEL CALIBRATION AND VERIFICATION

During the model calibration, not only the dynamic changes of water levels and observation wells but also the main river flow in the study area should be fit. In accordance with the observation data, the model calibration and verification period is determined respectively from October 2005 to May 2006 and from June 2006 to September 2006. The calculated and the measured groundwater levels in each observation well are well fitted and the difference is usually less than 2 m, most less than 1 m. The fitting curve of the observation well G1-4 and G1-8 is shown in figure 1, meanwhile, the calculation flow field and the actual flow field, shown in figure 2, show a similar variation trend. Comparing the calculated flow with the measured flow, the relative error is only 3.62%, and they reach good fitting. In conclusion, the hydrogeological parameters used in the model can reflect the actual hydrogeological conditions in the study area, and can be applied to simulate and forecast the groundwater flow state under future condition.

VI. MODEL APPLICATION

A. Design of the Forecasting Schemes

The model is used to predict the groundwater flow quantitatively in the study area under future mining conditions. The precipitation infiltration is the main recharge, but there is no reliable way to predict the future rainfall, so two methods are adopted to calculate the precipitation under future conditions. One is average rainfall scheme, which adopts the average monthly precipitation and evaporation from January 1978 to December 2006, the other is alternative precipitation scheme based on the cyclical variation of 12 years’ precipitation. For the above two kinds of precipitation plan, combined two exploitation ways, a total of 8 mining schemes are designed, which are shown in Table 1. The initial water level of each scheme is measured in September 2006 and the forecast time is 20 years.
TABLE I. THE PREVIEW TABLE OF MINING SCHEMES

<table>
<thead>
<tr>
<th>Precipitation Scheme</th>
<th>Exploitation Methods</th>
<th>Exploitation Schemes</th>
<th>Bulang River beach</th>
<th>Xiataohutu-Liyingsha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Centralized (A)</td>
<td>Large flow-scheme 1</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distributed (B)</td>
<td>Small flow-scheme 2</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Average rainfall (I)</td>
<td>Centralized (A)</td>
<td>Large flow-scheme 3</td>
<td>357.14</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Distributed (B)</td>
<td>Small flow-scheme 4</td>
<td>178.57</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Centralized (A)</td>
<td>Large flow-scheme 5</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distributed (B)</td>
<td>Large flow-scheme 6</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Alternative rainfall (II)</td>
<td>Centralized (A)</td>
<td>Small flow-scheme 7</td>
<td>357.14</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Distributed (B)</td>
<td>Small flow-scheme 8</td>
<td>178.57</td>
<td>200</td>
</tr>
</tbody>
</table>

B. Analysis of Forecasting Result

The calculated results of scheme 5-8 are similar respectively to scheme 1-4, so schemes 1-4 are mainly discussed in this article.

Figure 3. Curves of the water level changing with time of the observation well

Figure 4. Groundwater drawdown counter (Left for 1 year and right for 20 years)

Figure 5. Curves of Hailiutu River flow changing with time

Figure 6. Curves of evaporation changing with time
Based on the comparative analysis of the variation of water level, the drawdown, evaporation and water balance, it is found that the drawdown is obviously reduced and the water level tend to be stable and dynamic stable in scheme 4, the drawdown curving of the observation well is shown in Figure. 3. The groundwater drawdown counter in Figure. 4 shows that the drawdown is relatively small and after 20 year’s mining, the drawdown of most areas is less than 1m, the area of drawdown with less than 1m, 1-2m, 2-3m, 3-4m, 4-5m and more than 5m is respectively 728.01km$^2$, 104.04km$^2$, 51.36km$^2$, 31.04km$^2$, 16.28km$^2$ and 24.32 km$^2$. What’s more, the Hailiutu River flow and evaporation of the study area don’t change significantly with time (Figure. 5 and Figure. 6). Hence, the scheme 4 can be considered to be optimal mining scheme with exploitation quantity of 35000 m$^3$/d under which neither the local ecological environment nor the Hailiutu River flow is influenced.

VII. CONCLUSIONS

(1) The Visual MODFLOW software is adopted to simulate the groundwater flow in Bulang River-Red Stone Bridge water source. By model calibration and verification, the simulation results and the measured results are well fitted, and it can be applied to predict the water flow under future mining conditions.

(2) On the basis of simulation prediction, 8 mining schemes are comparative analyzed. Scheme 4 with exploitation quantity of 35000 m$^3$/d is considered to be an optimal scheme in which neither the local ecological environment nor the Hailiutu River flow is influenced.

REFERENCES


