Research and Application of Groundwater Numerical Simulation

A Case Study in Balasu Water Source

Song Yanxun
School of Geology Engineering and Geomatics
Chang’an University
Xi’an China
songchdcn@163.com

Fang Yuan, Qian Hui and Zhang Xuedi
College of Environmental Science and Engineering,
Chang’an University
Xi’an China
aspassiafang@163.com

Abstract—In the paper Visual MODFLOW, the international standard visualization software, is applied to set up the mathematical model which is used for groundwater flow numerical simulation in Balasu water source. The calibration and validation results of the numerical model indicate that the model can reflect the actual hydrogeological conditions, and can be applied in predicting the future groundwater flow conditions. The prediction results show that scheme 4 is optional which is necessary for ensuring the safety and the normal operation of Balasu water source.

Keywords—Visual MODFLOW; numerical simulation; predict; Balasu water source

I. INTRODUCTION

Groundwater numerical simulation is the mathematical model that is based on the generalization of the conceptual model of groundwater system, and supposed to describe the quantitative relation of groundwater system parameters and metric. According to the mathematical model identification and verification, the further validation of adaptability of groundwater system behavior and function can be made and deepening understanding of groundwater system characteristics can be reached [1]. Due to the high similarity, not only the groundwater flow problem but also the groundwater quality problem and other model can be solved efficiently [2]. The three-dimensional numerical simulation model of Balasu water source is built by Visual MODFLOW that is international standard visualization software [3]. Through the recognition and validation of the mathematical model, the mining scheme will be confirmed reasonably in order to ensure the safety and the normal operation of Balasu water source.

Balasu water source is about 45 km northwest of Yuyang district, west to Bulanghe, located on the southern fringe of the Maowusu Desert, and has a continental monsoon semi-arid grassy climate. It is dry in spring and wet in autumn and rainfall usually concentrates in July, August and September [4]. The groundwater in Balasu water source can be classified into two types: Quaternary unconsolidated rock pore phreatic water and Cretaceous elastic rock fissure-pore water. Quaternary unconsolidated rock pore phreatic water spread throughout the entire study area, including alluvial-lacustrine deposits rock pore phreatic water, alluvium pore water, and Quaternary fissure-pore water. The occurrence regularity of Cretaceous fissure-pore water in Luohe aquifer system shows a weaker trend from west to east and from north to south. And so is the enriched water regularity in Luohe aquifer system. In Balasu the aquifer is thick with coarse sediments grain, the storage conditions are good. The distribution of aquifer is stable, the water supply conditions are good, and the discharge of stream is plentiful. The precipitation recharge and the agricultural irrigation regression supplies dominate the sources of the water supplies. The main discharge is phreatic water evaporation, artificial mining, and drain to the river [5].

II. HYDROGEOLOGICAL CONCEPTUAL MODEL

In the simulation zone, the east, west and north boundaries are the phreatic water watershed. So they are conceptualized as confining boundaries, the south boundary is conceptualize as the constant head boundary. Water exchanges occur in top interface which is in contact with atmosphere, such as precipitation recharge, agricultural irrigation regression supplies, phreatic water evaporation and so on. The lower interface that constitutes the impervious base is the boundary layer of Cretaceous and Jurassic, it is generalized as impervious boundary.

III. GROUNDWATER FLOW MATHEMATICAL MODEL

The following three-dimensional transient flow numerical model is set up based on the above hydrogeological conceptual model [6]:
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 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, two groups of orthogonal grid by 200m x 200m which are parallel to x axis and y axis divide the study area into 23810 active cells which represent the actual planar area of 849.56km$^2$. According to the aquifer structural features the vertical dissections were dissected into two layers, in this case, the simulation zone is dissected into 42478 active cells.

In time, the simulation time lasted 12 months, from October 2005 to September 2006. Because of the feature that the groundwater system is conditioned by the external conditions, the simulation time was divided into 12 stress periods corresponding to the months of the year. Each stress period was further divided into 10 time steps, and the time of the two adjacent time steps is binding subject to the fulfillment of the following conditions.

$$t_{k+1} = 1.2 t_k$$

Where, $t_k$ represents the $k^{th}$ time step.

B. The Determination of Initial Conditions

The initial flow field was drawn based on the materials of the water level in October 2005, so as to perfect the experimental material, the professional knowledge of hydrogeological conditions were eeked out at the same time. The two aquifer groups had the same initial flow field because of the minor difference between them and the minor groundwater exploitation quantity.

C. Selection of Parameters

Based on geology, physiognomy, lithology and the water yield property characteristic, Quaternary aquifer can be divided into 7 parameter regions in horizontal direction, and Luohe Formation aquifer can be divided into 3 parameter regions in vertical direction. The water-bearing media in the simulation zone can be compartmentalized into two layers. All the aquifers are generalized as non-homogeneous isotropic medium except the loess layer in the south which is generalized as heterogeneous anisotropic media and its vertical hydraulic conductivity is as twice as its longitudinal hydraulic conductivity.

V. MODEL CALIBRATION AND VERIFICATION

In the model calibration and verification, not only the flow field and the water level of the observation well but also the flow of the main river dynamic change need be fitted in the simulation zone. According to the duration of materials of the water level, the model calibration time is from October 2005 to May 2006, and the verification time is from June 2006 to September 2006. The measured flow field in May 2006 was applied to calibrate the calculation flow field. The water level of the observation well fitted the actual flow nicely; the water level warp is no more than 2 m and less than 1 m mostly, see in Figure 1. At the same time, the change trend between computed flow field and actual flow field was in substantial agreement in Figure 2. The calculation flow field responded the groundwater seepage state and its boundary conditions nicely. The computed flow of the six rivers in the simulation zone was 85433.63m$^3$/d, and the actual flow was 85546.40 m$^3$/d, the difference value between he computed flow and the actual flow of the Hailiutu River in calibration and verification time was 112.77 m$^3$/d, they fitted well. To sum up, the practical hydrogeological situation can be shown by the hydrogeological parameters in the model, and the future groundwater flow can be simulated by the groundwater flow mathematical model.

![Figure 1](image1.png)

**Figure 1.** Curving fitting of the observation well

![Figure 2](image2.png)

**Figure 2.** The contrast diagram of calculation and actual flow field
VI. MODEL APPLICATION

A. Design of the Forecasting Schemes

The mathematical model can be used for predicting the groundwater system conditions under the future conditions. The main source of runoff is precipitation recharge, but there is no positive means to predict the future precipitation, and two schemes are given here to predict the future precipitation. One mean is to calculate the average precipitation and evaporation month by month from January 1978 to December 2006; another is according to the cyclical variation of 12 years’ precipitation in the simulation zone that is alternative precipitation scheme. A combination between the two precipitation schemes and the two mining means is applied to design 8 mining schemes in Tab.1. And the initial level is the actual level in September 2006, and the prediction time is 20 years.

| Precipitation Scheme | Exploitation Methods | Exploitation Schemes | Exploitation Quantity (m³/d) |
|----------------------|----------------------|----------------------|-------------------------------|
| Average rainfall scheme (I) | Centralized mining (A) | Large flow-scheme 1 | 1000 |
|  | Distributed mining (B) | Small flow-scheme 2 | 500 |
| Alternative rainfall scheme (II) | Centralized mining (A) | Large flow-scheme 3 | 355.37 |
|  | Distributed mining (B) | Small flow-scheme 4 | 177.69 |

B. Analysis of Forecasting Result

The calculation result of Scheme 5 to Scheme 8 is similar to that of Scheme 1 to Scheme 4, so the discussion is focus on Scheme 1 to Scheme 4.

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

Figure 4. Groundwater drawdown counter (Left for 5 year and right for 20 years)

Figure 5. Curves of Sha River flow changing with time

Figure 6. Curves of evaporation changing with time
By the effects of Scheme 4, contrast the changes of water level, flow field, water balance, flow, and evaporation, the drawdown decreased obviously and the water level has the trend of stability and dynamic stability, the drawdown curving of the observation well is shown in Figure 3. 20 years later, a relatively minor is shown by the changes of the drawdown. The drawdown in hopper center is just 2.5 m. There is little influence in ecological environment, which is shown in Figure 4. What’s more, the curves of Sha River flow and evaporation of the simulation area changing with time in Figure 5 and Figure 6 indicate decreasing tendency of river flow and evaporation, but the range is limit. The Scheme 4 can be considered to be optimal mining scheme with exploitation quantity of 20000 m$^3$/d. However, this is a rational mining scheme which reflects the intercepting water exploitation and the ecological environment indistinctively. To sum up, the scheme that consociates Scheme 4 with igniting spring is recommended to mining the groundwater resource in Balasu water source.

**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 20000 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**

[1] Y. Q. Xue, “the Principle of Groundwater Dynamics” (in Chinese), the Geological Publishing House, Beijing, 1986.

[2] M. G. McDonald and A. W. Modular, “Three-dimensional Finite-difference Groundwater Flow Model”, Techniques of water resources investigation of U. S. Geological Survey, book6 CH. AL, 1988.

[3] Y M Bian, W X Lu, H Y Ma. “Application of Visual Modflow in Groundwater Numerical Simulation in Water Source”, Water Resources and Hadropower of Northeast China, 2006, (3): 31-33.

[4] Y Chen, G H Yang. “The Actual Water Resource Condition and The Analysis of Supply and Demand in Yuyang District in Yulin”, People and Yellow River, China, 2006.8(8):38.

[5] X. M. Zhan, “Three-dimensional Numerical Simulation of Groundwater in Bulang River Water Source, A dissertation for Master’s degree, Xi’an, Chang’an University, 2007.

[6] D. P. Guo, H. Qian, Y. X. Song and X. L. Ran, “Groundwater Dynamics” (in Chinese), Shaanxi Science and Technology Publishing House, Xi’an, 1994.