Research Article **SRR (2022) 15:126**

Scientific Research and Reviews
(ISSN:2638-3500)

Simulation prediction of mine water surges based on Visual MODFLOW

Pang Yu[1*], Li SiYu[1]

[1]School of Earth Science and engineering, Hebei University of Engineering, Handan, Hebei 056038, China.

ABSTRACT

Mine water damage is a major threat to the safe production of coal mines in China, and how to predict mine water surges scientifically and effectively is an important basis for mine water damage accident prevention and protection of groundwater resources. This paper takes a mine field in northwest China as the research object, comprehensively grasps the geological and hydrogeological conditions of the mine and analyses the causes of coal seam water filling; applies Visual MODFLOW to establish a numerical model of groundwater flow in the study area, and carries out dynamic prediction of mine water influx under natural and artificial boundary conditions respectively based on the method of water conservation and coal mining. The results show that the water influx is significantly reduced under the modified boundary conditions, providing a strong basis for the selection of water-preserving coal mining methods and valuable experience for the mining of coal seams in areas with similar conditions.

Keywords: Numerical simulation, Visual MODFLOW, Surge prediction, Water retention coal mining

***Correspondence to Author:**
Pang Yu
School of Earth Science and engineering, Hebei University of Engineering, Handan, Hebei 056038, China.

How to cite this article:
Pang Yu, Li SiYu. Simulation prediction of mine water surges based on Visual MODFLOW. Scientific Research and Reviews, 2022, 15:126

eSciPub LLC, Houston, TX USA.
Website: http://escipub.com/

Introduction

As a major country in the utilization of coal resources, coal resources have always provided raw material energy for various industries in China and played a vital role in promoting the development of the national economy. However, due to the complex and variable hydrogeological conditions and formations in China's coal mines, the problem of water damage in mines is very prominent [1-2], which has seriously threatened the safe production of mines and sustainable development of the environment. The long-term drainage of groundwater resources in mining activities and the lack of integrated planning and scientific management and other unreasonable development and utilization have caused regional mining imbalance, ecological and environmental damage, and increasing shortage of groundwater resources [3-4]. Therefore, how to predict and reduce mine water surges scientifically and effectively is of great importance to prevent the occurrence of mine accidents such as mine water surges and to ensure the safe mining of coal resources and the harmonization of ecological and environmental protection [5].

Since the last century, a large number of domestic and foreign research scholars began to mine water surge prediction methods to carry out research, has obtained many results [6-9]. At present, the main methods of predicting mine water surges are: (1) deterministic mathematical model method, which has the representative method of water balance method, analytical method, numerical method; (2) statistical analysis methods, such as hydrogeological comparison method, water surges - depth reduction curve method, correlation analysis method, etc. [10-12]. Among them, the numerical method can fully understand and portray the complex hydrogeological conditions of the mine area, considering the non-homogeneous anisotropy of the hydrogeological parameters of the aquifer, and can calculate the dynamic change process of water level at different moments at any point. At the same time numerical simulation method has the characteristics of convenience, efficiency and flexibility [13], so in the simulation of water influx prediction is widely used [14-20].

In decades of concentrated mining of coal resources, the treatment of groundwater resources is mainly based on sparse drop, high discharge and low utilization, and some coal bases or provinces and cities have successively experienced ecological and environmental geological problems, among which the more significant ones are the drop of groundwater level, water resources pollution, subsidence and collapse of mining areas and ecological environment deterioration, which have already caused great impact on the groundwater environment. In response to the problems, Chinese research scholars have proposed a variety of theories, technologies and methods for coal mining based on water conservation [21-24], and have reached a world-leading level. In recent years, the focus of coal mining in China has gradually shifted to the central and western parts of the country. Coal mining in the central and western regions with fragile ecological environment should pay particular attention to the protection of the groundwater environment [25-26], and should not follow the old path of pollution before treatment and destruction before restoration. In terms of the current domestic energy share, coal resource development and ecological environmental protection have formed a sharp contradiction, and there is an urgent need to combine coal mining with ecological environmental protection to achieve coordinated and sustainable development of the energy economy and ecological environment [27-28]. Therefore the core issue of coal resource development in the west lies in how to effectively protect and reduce groundwater resources in the process of coal mining.

Whether from a strategic level or from the current production reality, there is an urgent need to carry out research on the prediction of water surges in coal mining situations. In this paper, we mainly use Visual MODFLOW software to establish the numerical model of groundwater flow in the well field, based on the method of water conservation and coal mining to transform the boundary of the study area with curtain grouting, set different boundary condition schemes and carry out dynamic prediction of mine water gushing respectively. It will effectively guide the mining of coal resources and ecological environmental protection in ecologically fragile mining areas and provide valuable experience.

1. Overview of the study area

The mine is located in the northeastern part of Shaanxi Province, bounded by a fault to the south, the Yellow River to the north and east, and the man-made boundary to the west, with a length of about 19km from north to south, a width of about 2.8 to 5.6km from east to west, and a mine area of 78.42km^2. The area is an earth and rocky hilly and gully landscape, with fragmented terrain, gullies, complex topography and large undulations. The overall west is high and east is low, with elevations mostly between 700 and 950m. It has a warm temperate continental monsoon climate, with an average annual precipitation of 277.1-625.3mm, mostly concentrated in July, August and September; annual evaporation of 1674.4-2320.3mm.

According to the geological mapping results and the borehole exposures in and around the mine, the stratigraphy from old to new is as follows: Middle Ordovician Majiagou Formation, Middle Carboniferous Benxi Formation, Upper Taiyuan Formation, Lower Permian Shanxi Formation, Lower Permian-Superior Shi Box Formation, Upper Permian-Lower Triassic Sunjiagou Formation, Lower Triassic Liujiagou Formation The Permian-Sub-Triassic Sunjiagou Formation, the Lower Triassic Liujiagou Formation, the Lower Triassic He Shanggou Formation and the Fourth Series. The groundwater types are basically the same as those in the region, i.e. pore and fissure diving in the Quaternary loose rock type, bedrock weathering fissure diving, fissure bearing water in the Permian and Triassic clastic rocks, fissure lacustrine bearing water in the Carboniferous carbonate clastic rocks and karst water in the Ordovician carbonate rocks. The mudstone section of the Lower Permian Shanxi Formation and the mudstone of the Middle Carboniferous Benxi Formation are the main water traps.

2. Numerical model of water inflow

2.1 Hydrogeological conceptual model

The boundary conditions are dealt with according to the characteristics of the groundwater aquifer system in the study area, the characteristics of the hydraulic connection between the aquifers and the characteristics of the drainage of the coal mine. The numerical groundwater model should adopt natural boundaries as far as possible. Through the regional geological information already available, the mine boundary conditions are initially generalised to the northern and eastern boundaries as general head boundaries, which can be automatically calculated by water level changes to adjust the boundary flow magnitude, and the western and southern boundaries as water separation boundaries, as shown in Figure 3-1(a).

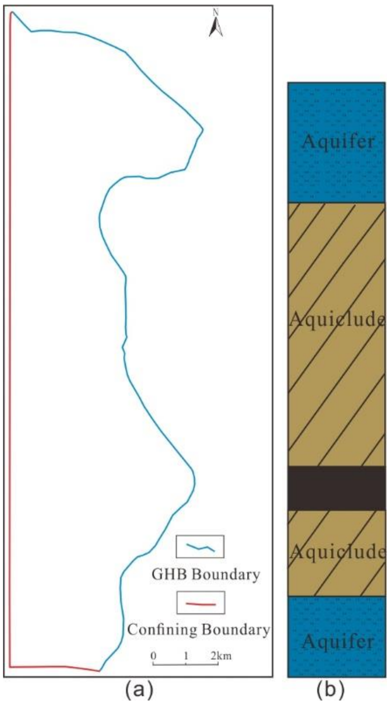

Figure 3-1 Conceptual hydrogeological model of the study area

According to the type of water-bearing medium and its storage space, the groundwater in the area is divided into four major types, namely loose rock-like pore water, clastic rock-like pore fracture water, clastic rock interspersed with carbonate rock-like karst fracture water and carbonate rock-like karst water. Based on the available hydrogeological data, the stratigraphy in the simulation area is vertically generalised into five layers, i.e. micro-compressed sandstone water at the top of the coal seam, upper water barrier, S-group coal seam, lower water barrier and compressed tuff water at the bottom of the coal seam, as shown in (b) in Figure 3-1. Due to the existence of the relative water barrier, the aquifer has no direct hydraulic connection with the overlying diving aquifer and atmospheric precipitation, so the coal seam mining influx of water has no direct relationship with the overlying diving and atmospheric precipitation.

The lithology of the aquifers in the zone is relatively homogeneous and permeability varies with space, with significant changes in each direction, so the water-bearing media are generalised as homogeneous and anisotropic. Although the water-bearing medium in the zone is pore and fracture medium, the hydraulic gradient is small and the aquifer range is large, groundwater movement can still be described by Darcy's law. Both input and output elements of the groundwater system vary with time, and are therefore unsteady flows. After the coal seam is mined, the groundwater is concentrated into the pit and there is a vertical hydraulic connection, and the three-dimensional flow characteristics are obvious, so it is generalised to three-dimensional unsteady flow. In summary, the groundwater system in the study area is generalised as a homogeneous, anisotropic, three-dimensional unsteady groundwater flow system.

2.2 Mathematical models

According to the above conceptual hydrogeological model, the groundwater movement in the study area basically satisfies Darcy's law and can be described by the following differential equations and the corresponding definite solution conditions.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}\cdots\cdots\cdots\cdots(x,y,z)\in\Omega$$

$$K_{xx}\frac{\partial h}{\partial n_x}+K_{yy}\frac{\partial h}{\partial n_y}+K_{zz}\frac{\partial h}{\partial n_z}\bigg|_{S_2}=q(x,y,z,t)\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(x,y,z)\in S_2$$

$$h(x,y,z,t)|_{t=t_0}=h_0(x,y,z)\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(x,y,z)\in\Omega$$

Type in the: K_{xx}, K_{yy} and K_{zz} are the components of the permeability coefficient in the *x*, *y* and *z* directions, respectively (m/d); *h* is the head value (m) at point (*x, y, z*) at time *t*; *W* is the source-sink term, i.e. the volume of water flowing in or out per unit volume (L/d); S_s is the unit water storage coefficient of the pore medium (1/m); *t* is the time (d); *Ω* is the computational domain;S_2 is the type II boundary; *q* is the lateral recharge (m^3/d); n_x is the unit vector along the X-axis of the outer normal line of boundary S_2; n_y is the unit vector along the Y-axis of the outer normal line of boundary S_2; n_z is the unit vector along the Z-axis of the outer normal line of boundary S_2。

2.3 Numerical simulation of groundwater

2.3.1 Spatial and temporal discretization of the calculation area

The groundwater numerical simulation software Visual MODFLOW was applied to the study area using the rectangular finite difference method to dissect the calculation area, the plane was first divided into 40 rows and 20 columns at equal intervals, and the grid was encrypted for the key areas, the whole area was divided into a total of 1550 cells grid, set the grid outside the boundaries to inactive cells, as shown in Figures 3-2 to 3-4. Based on the statistics collected from the geological exploration holes and hydrogeological holes in the mine area, the top and bottom plate elevations of each aquifer were interpolated and the data were imported into the model to generate a 3D structural model of the aquifer in the study area, as shown in Figure 3-5. According to the relevant information collected in this study, combined with the actual needs of the mine area, the simulation prediction time of this numerical model is 2021-2032, the stress period is set to 144 months, the time step is 30 days, and the step factor is taken as 1.2.

2.3.2 Source sink item processing

By analysing the recharge, runoff and discharge conditions of the groundwater system in the study area, it is concluded that the main source of recharge of pressurised water in the area is lateral runoff recharge, and infiltration recharge of precipitation is not considered. As the groundwater in the study area is deeper, evaporation is neglected. The discharge term is mainly set to the amount of water gushing from coal seam mining. In the software, the well flow package is used to simulate the water discharge point in the mining area, and the amount of water gushing is replaced by the amount of water pumped from the pumping wells. According to the requirements of the Visual MODFLOW software, the recharge and discharge conditions of the groundwater system are processed accordingly and input into the model. Based on the groundwater level data in the study area, there was little hydrogeological information available due to the limitations of collecting information, so the groundwater flow field at the end of 2020 was determined as the initial flow field for the model, as shown in Figure 3-6.

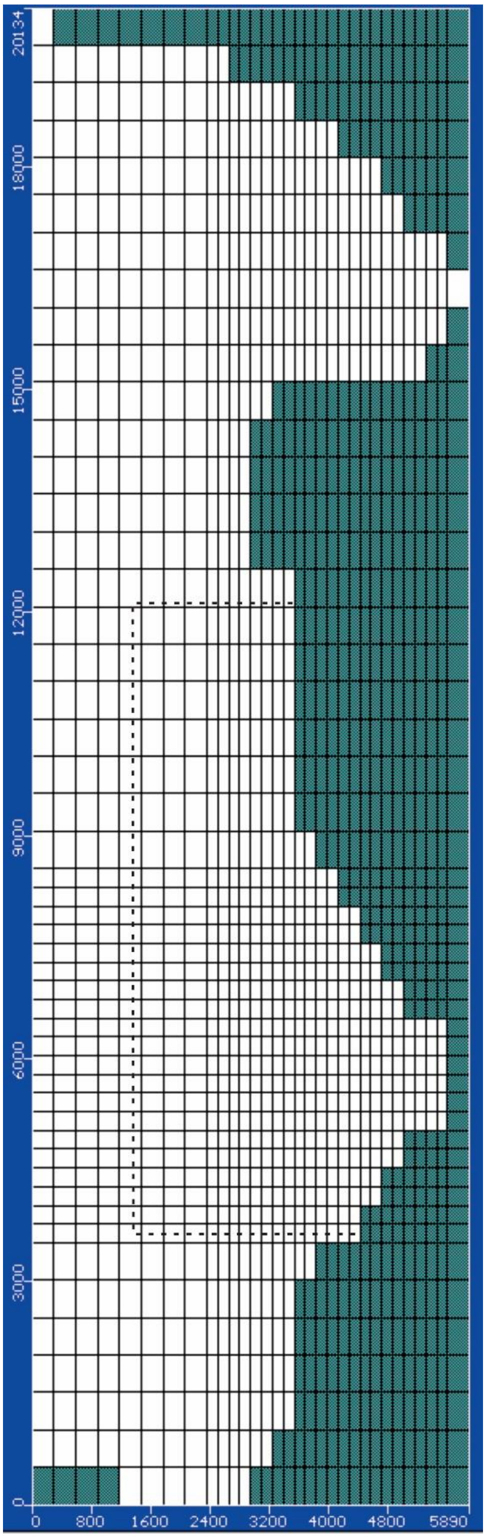

Figure 3-2 Model mesh profile

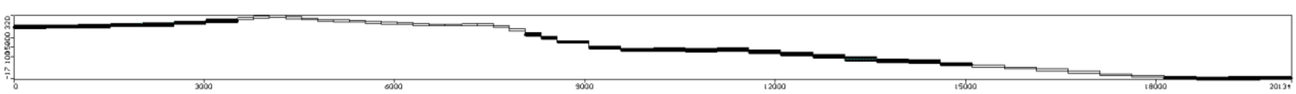

Figure 3-3 Section of model row 25

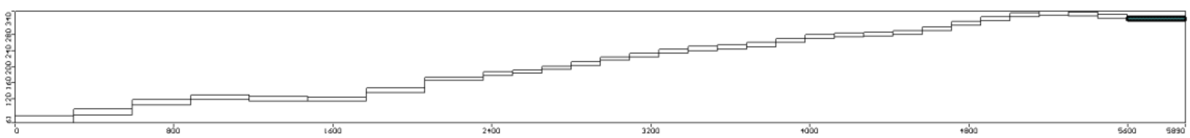

Figure 3-4 Section of model column 15

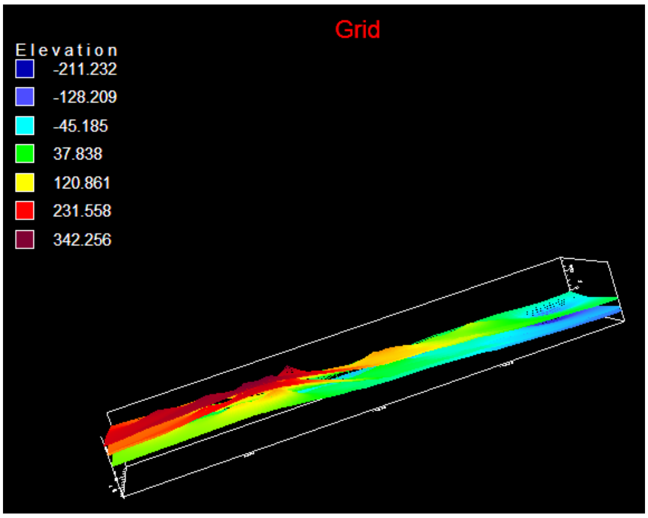

Figure 3-5 Schematic diagram of the three-dimensional model

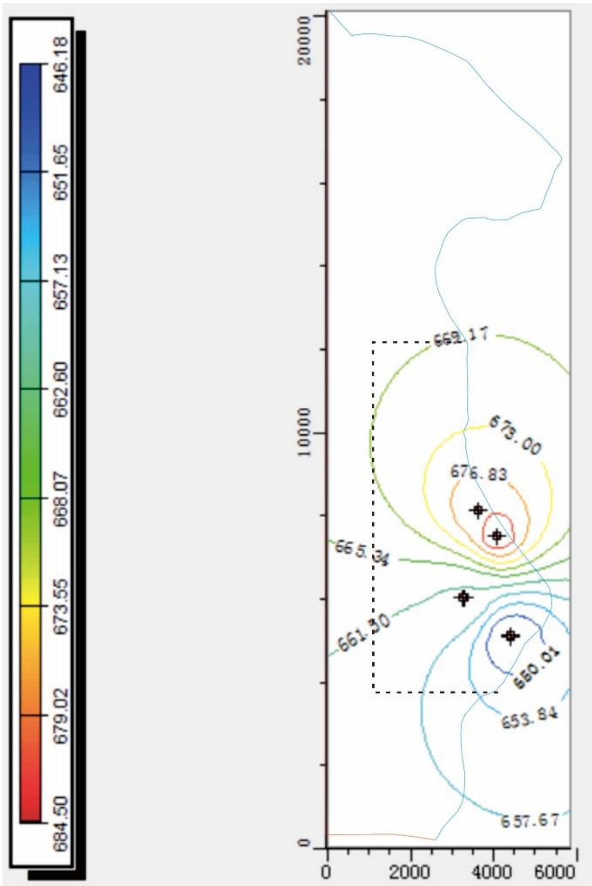

Figure 3.6 Initial flow field diagram of the aquifer

2.3.3 Parametric partitioning

Combining the collected information and the field pumping test data, as shown in Table 3-1, the natural inverse ratio method was used in the software to interpolate and divide the permeability coefficients measured by the pumping tests to determine the initial values of the relevant hydrogeological parameters. After assigning values to the hydrogeological parameters in the study area based on the lithological characteristics of the stratigraphy and geological formations of the well field, as shown in Figure 3-7 and Table 3-2, the hydrogeological parameters were zoned.

Table 3-1 Summary of permeability coefficients for pumping tests

Drilling	X	Y	Permeability coefficient（m·s^{-1}）
G2	37479336	4161442	8.68E-8
G4	37479791	4160798	3.82E-8
G1	37480115	4158387	1.62E-7
C1	37480099	4158420	8.10E-8
C3	37479018	4159310	7.87E-8
G5	37478983	4159311	9.14E-8

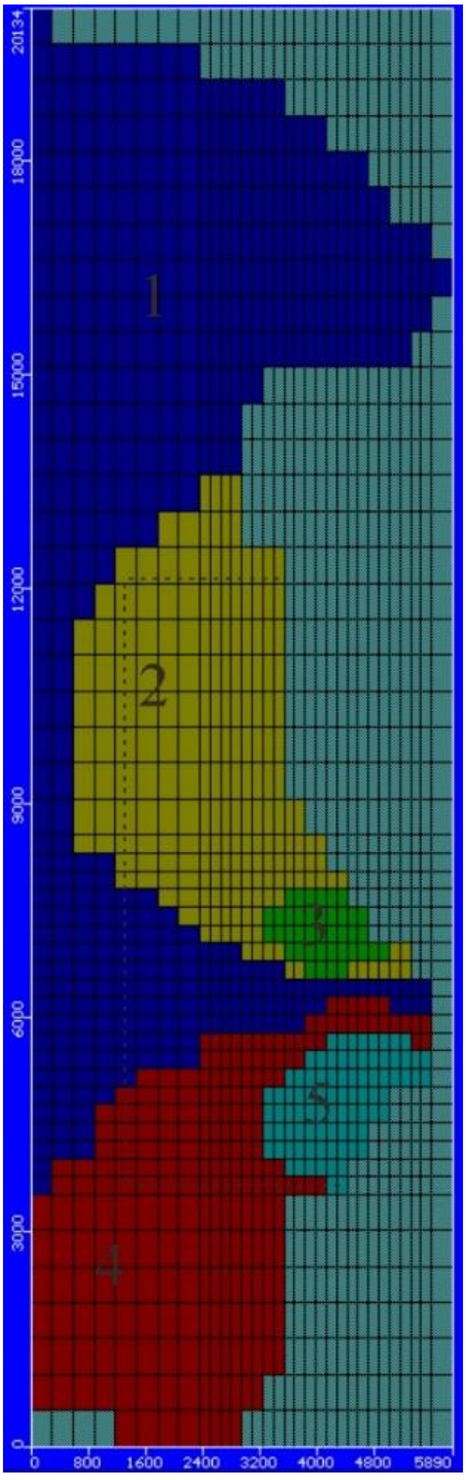

Figure 3-7 Aquifer permeability coefficient zoning map

Table 3-2 Table of zonal assignment of permeability coefficients

Parameters / Regionalization	Permeability coefficient（m·s^-1）		
	K_{xx}	K_{yy}	K_{zz}
1	9.00E-8	9.00E-8	9.00E-9
2	7.00E-7	7.00E-7	7.00E-8
3	4.00E-7	4.00E-7	4.00E-8
4	1.00E-6	1.00E-6	1.00E-7
5	1.30E-6	1.30E-6	1.30E-7

2.3.4 Model identification and validation

This study is based on the water level dynamic observation data of the hydrological observation boreholes in 2020, and adopts the trial estimation-correction method. By analysing the patterns of the calculated water level and the observed water level and their causes, the model boundary conditions, hydrogeological parameters and other contents are continuously adjusted and trial calculated on the basis of the existing model, so that the water level calculated by the model and the actual observed water level curve are basically fitted. The model was verified by using the water level dynamic data at different times. The accuracy of the water level fitting of some boreholes is detailed in Figures 3-8 to 3-9, and the average water level error is around 1m. As can be seen from the figure, in the model identification verification period, the absolute error between the calculated water level and the measured water level between the two mostly meet the requirements, the individual point error is larger, but the overall basic match, to achieve the model identification and verification requirements, the numerical model established this time basically reflects the simulation area of the groundwater movement law, can be applied to the subsequent coal seam mining dynamic prediction study.

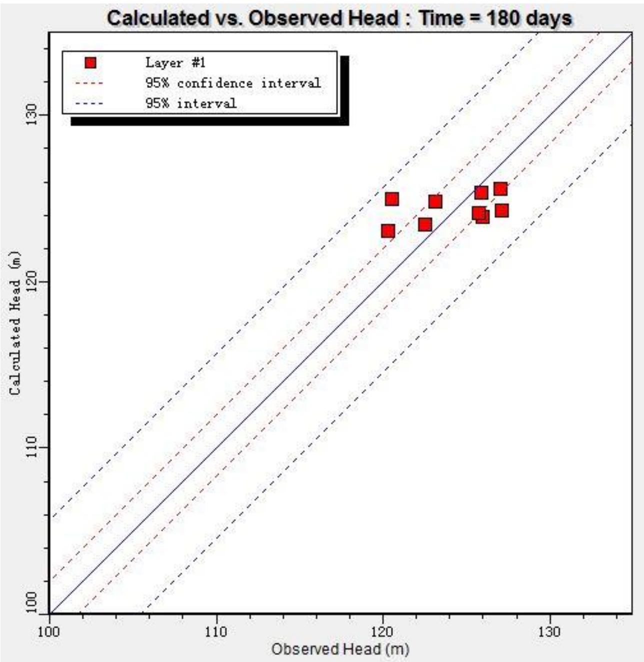

Figure 3-8 Fitting curve of water level in recognition period

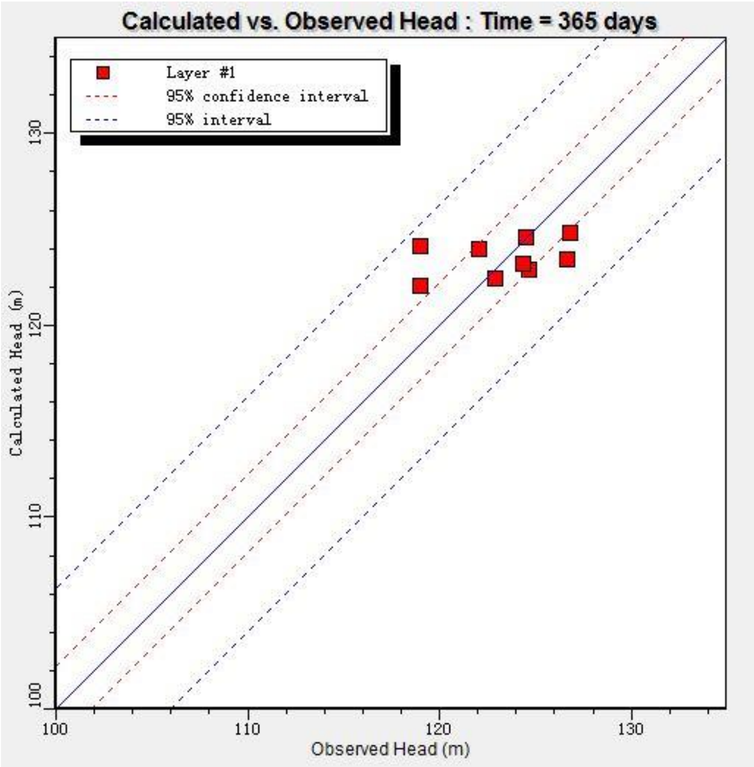

Figure 3-9 Water-level verification curve during verification period

3. Simulated predictions of water surges

Considering the need to protect groundwater resources, the safety of mine production and the degree of data possession, the numerical model based on the above identification and verification, design different schemes: the first scheme to maintain natural conditions for the prediction of water influx. The second programme uses curtain grouting methods to grout in the direction of incoming groundwater at the mine boundary, forming a water retaining wall and changing the nature of the boundary for water influx prediction.

3.1 Prediction of water surges under natural conditions

In keeping with the natural conditions, coal mine S coal mining process, hydraulic conductivity fracture zone fully developed to the water barrier, coal seam direct water-filled aquifer water directly into the pit, in order to ensure safe production, the need for direct coal seam water-filled aquifer for water evacuation, so the need for water inflow prediction. The flow field at the end of the model identification as the initial flow field of the prediction model, take the average monthly precipitation for many years as the model prediction period monthly precipitation, rainfall infiltration coefficient zoning and take the same value with the identification model, boundary conditions, hydrogeological parameters and zoning with the identification of the validated model, according to the mine mining program in the continuous adjustment of the mining range, the simulation of the amount of water gushing virtual mining wells laid in the mining lot, by repeatedly Adjust the virtual well mining volume, with the passage of time, the cumulative virtual well mining volume increases, the aquifer groundwater level decreases, so that the aquifer groundwater level above the S group coal seam decreases and stabilizes below the bottom of the aquifer, at this time the total mining volume of the virtual mining wells is the mine mine water influx. After the model calculation, mining lot S group coal seam above the aquifer flow field as shown in Figure 3-10, mining lot S group coal seam mine water gush is about 2700m^3/d.

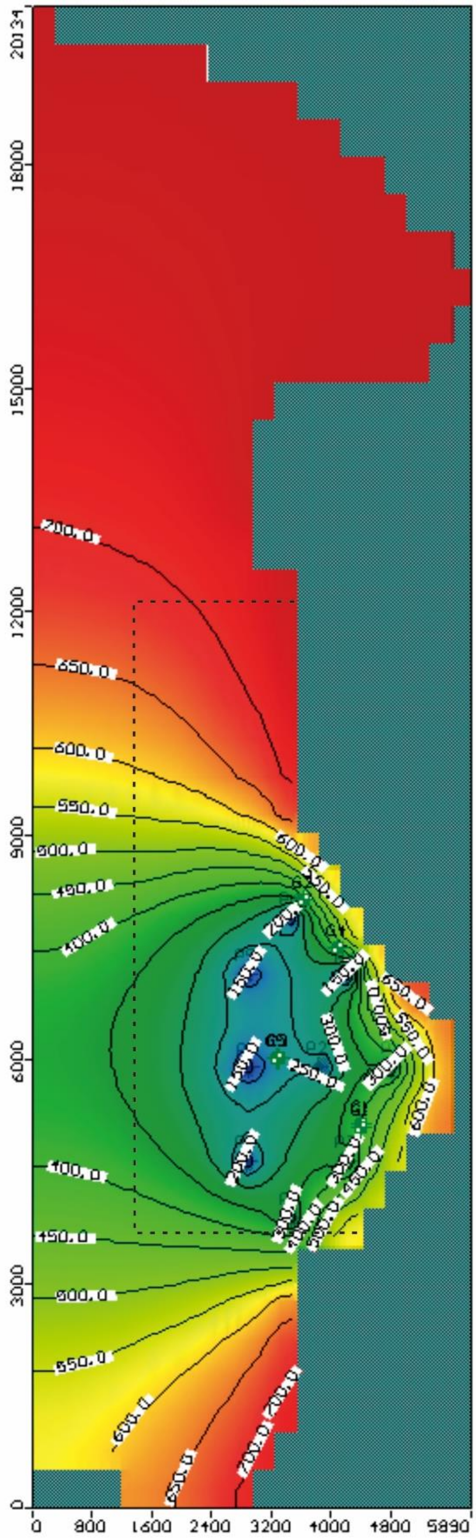

Figure 3-10 Flow field diagram of water-bearing layer under natural conditions

4.2 Prediction of water surges under man-made conditions

Based on water conservation coal mining to take the curtain grouting way in the mine boundary groundwater in the direction of the incoming grouting, the formation of a water retaining wall, change the boundary conditions, the formation of water barrier boundary, other conditions are the same with the first program for the simulation of water influx prediction. Man-made conditions under the aquifer flow field diagram as shown in Figure 3-11, mining lot S group coal seam mine water influx is about 470m^3/d.

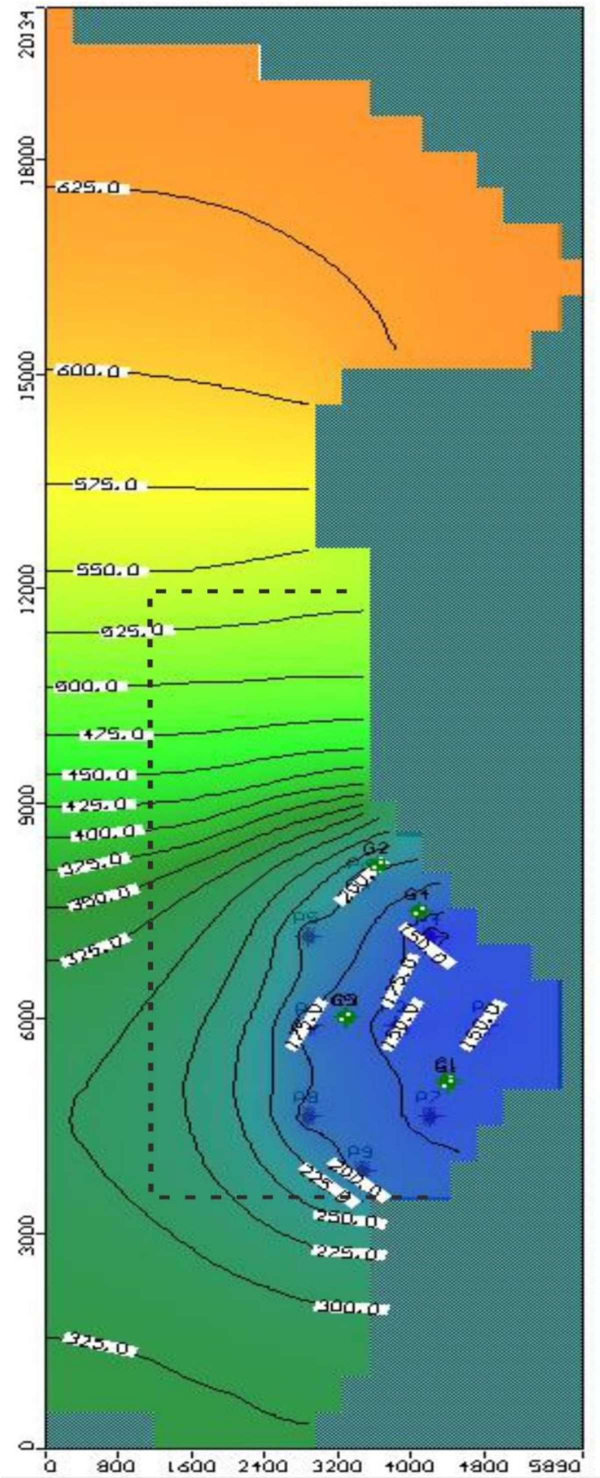

Figure 3-11 Flow field diagram of water-bearing layer under artificial conditions

5. Conclusions and shortcomings

(1) By using the method of numerical simulation, the conceptual model and mathematical model of the hydrogeology of the study area were established, and the numerical model of the groundwater flow in the study area was constructed using the finite difference method by using the Visual MODFLOW numerical simulation software to simulate and predict the water influx of coal seam mining.

(2) Based on the concept of water conservation coal mining, a scheme to change the boundary conditions was designed. By comparing and analysing the change in water influx before and after the change in boundary properties, it is shown that the amount of water influx becomes

less under curtain grouting conditions, so that the groundwater that would have flowed into the area is partially blocked by the water retaining wall formed by the grouting.

(3) Although the results of the simulation reached the accuracy requirements of this work, but must recognize the shortcomings of the simulation work. For example, the lack of long-term groundwater level observation data in the study area has led to a short identification and verification time, which to a certain extent affects the accuracy and precision of the simulation. It is therefore necessary to continue to strengthen the collection of the required data and optimise and improve the model for the study area in the next few years.

References

[1] Wu Qiang. Progress, problems and prospects of prevention and control technology of mine water and reutilization in China[J]. Journal of China Coal Society, 2014, 39(5):795-805.

[2] Wu Qiang, Zhao Suqi, Sun Wenjie. Classification of the hydrogeological type of coal mine and analysis of its characteristics in China[J]. Journal of China Coal Society, 2013,38(6):901-905.

[3] Yin Shangxian. Reflections on the development of basic science of water damage control in coal mines [J]. Coal Engineering, 2016,18(S2):96-100.

[4] He XW, Yang J, Shao LN, et al. Problems and solutions of water resource utilization in China's mines[J]. Journal of China Coal Society, 2008,33(1):63-66.

[5] Jin Dewu. New development of water disaster prevention and control technology in China coal mine and consideration on methodology [J]. Coal Science and Technology, 2017,45(5):141-147.

[6] Zhou Rulu, Dai Zhenxue, Li Ying. Theory and practice of mine water surge prediction [J]. Coal Science and Technology, 1998, 06:49-51.

[7] Wen Zhe, Wang Binhai, Cheng Zihua, et al. A review of mine water surge prediction methods [J]. Chemical Minerals and Processing, 2016, 45(9):71-74.

[8] Huang Huan. Prediction method of mine inflow and its development[J]. Coal Science and Technology, 2016, 44(S1):127-130.

[9] Cui Fangpeng, Wu Qiang, Lin Yuanhui, et al. Research on integrated water damage control technology and methods in Chinese coal mines [J]. Journal of Mining Science and Technology, 2018,3(03):219-228.

[10] Chen Qieqi, Liu Shucai, Yang Guoyong. The Development of Mining Water Inflow Predict Method[J]. Chinese Journal of Engineering Geophysics, 2009,06(01):68-72.

[11] Tian Hongsheng. Analysis of common methods in the prediction of mine water surges [J]. Groundwater, 2013, 35(3) : 25-27.

[12] Calculation procedures for the prediction of mine surge water. (DZ/T 032-2020) Ministry of Natural Resources of the People's Republic of China. 2020.04.30.

[13] Huang Qingshan, Luo Zujiang. Comparison of Analytical Method and Numerical Method in Mine Water Inflow Prediction[J]. Mining Safety and Environmental Protection,2015, 42(4):63-66.

[14] Luo Qing. Forecast of Mine Water Inflow Based on MODFLOW—Take the 6163 Working face of Qidong Mine as an Example[D]. AnHui University of Science and Technology,2020.

[15] Feng Xiang. The mine water inflow prediction research based on three-dimensional groundwater model in GMS[D]. China University of Geosciences (Beijing) , 2017.

[16] Xin Yumeng. GMS-based Forecast of Mine Water Inflow for the Coal Seam Roof of a Colliery in Inner Mongolia. Hebei University of Engineering , 2019.

[17] Li Yue. Numerical Simulation of Water Inflow in the 3085 Working Face of Donghuantuo Mine, Kailuan[D]. North China University of Science

and Technology, 2020.

[18] Chen Shilai. Impact on the Groundwater Environment and Water Inflow Dynamic Prediction During Underground Mining of Typical Mines[D]. China University of Mining and Technology(Beijing), 2015.

[19] Xu Ke. Roof aquifer water inrush risk evaluation and mine water inflow prediction in Taigemiao coal mine[D]. China University of Mining and Technology (Beijing), 2016.

[20] Liu Ji, Wang QiangMin, Yang Jian. Mine Inflow Simulation and Dynamic Prediction Based on Visual Modflow[J]. Safety in Coal Mines, 2018,49(3):190-193.

[21] Qian Minggao, Xu Jialin, Miao Xiexing. Green technique in coal mining[J]. Journal of China University of Mining and Technology, 2003(04):5-10.

[22] Fan Limin. On the water — preserved mining[J]. Journal of China Coal Society, 2017, 42(1): 27-35

[23] Zhang Fawang, Hou Xinwei, Han Zhantao, Song Yaxin, Yang Huifeng. Study on the "aquifer reconstruction" and its change law of coal seam roof under coal mining conditions[A]. Chinese Geological Society. Abstracts of the Sixth World Chinese Geoscience Symposium and the 2005 Annual Academic Conference of the Geological Society of China[C]. Geological Society of China:Geological Society of China, 2005:6.

[24] Xu HaiHong, Qiao Jiao, Wang Zheng. The influence of underground coal mining on groundwater and measures for water conservation while mining in Xiaozhuang mine[J]. Coal Geology and Exploration, 2014, 42(6): 64-67,72

[25] Fan Limin, Ma Xiongde, Ji Ruijun. Progress in engineering practice of water-preserved coal mining in western eco-environment frangible area[J]. Journal of China Coal Society, 2015, 40(08):1711-1717.

[26] Fan Limin. Water-preserved mining status area in Northwest China intensively coal exploited area [J]. China Coal Geology, 2017, 29(3): 48-53.

[27] Qian Minggao, Xu Jialin, Wang Jiachen. Further on the sustainable mining of coal[J]. Journal of China Coal Society, 2018,43(01):1-13.

[28] Fan Limin, Ma Xiongde, Jiang Zequan, et al. Review and thirty years prospect of research on water—preserved coal mining [J]. Coal Science and Technology, 2019, 47(7): 1-30.