Quantitative Evaluation Mining Impact on Unconsolidated Aquifers In Western China's Inner Mongolia-Shaanxi mine Region

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Abstract The degree of quantitative research about the groundwater disturbance caused by coal mining is insufficient. in this paper, it is concluded that the spatial scale of deformation and destruction caused by mining is the main factor to control the loss of groundwater, and presents numerical method to deal with the fractured zones into a drainage boundary , the parameter partition for the bending zone, and the resubdivision for the surface subsidence area. finally, in the case of coal mine, the simulation results shown that the loss of groundwater resources is about 1.90*104m3/d due to the mining disturbance.

Keywords Groundwater; loose aquifer; quantitative evaluation; numerical simulation;fractured zone

Introduction

The western region of China is the main base for the exploitation of coal resources. Groundwater is the main water resources which has the extremely important ecological function in this area [1,2], under the influence of large-scale and high intensity of coal resources exploitation, it is inevitable to cause the destruction to the groundwater, which aggravate the water resources shortage and the destruction of the ecological environment in the region, this problem has become more and more concerned by the china government and society.
In developed countries, because of the difference of national basic energy structure, there are few researches on the dynamic disturbance of groundwater caused by coal mining, which mainly focuses on the problem of mine water pollution risk assessment and closure of mine reclamation[3,4].Chinese scholars had used different methods to study the problem of groundwater dynamic response, but has not formed a recognized, more systematic evaluation method, these are mainly macro analysis, the evaluation of the quantitative degree is obviously insufficient.

In recent years, the numerical method has been developed rapidly in the evaluation, prediction and management of water resources. which greatly improves the quantitative analysis of groundwater resources evaluation[5].such as some scholars put mine water inflow as the discharge of pumping wells by artificially given a certain amount of pumping water, or to increase the parameter of surrounding rock permeability by multiplied certain proportion coefficient (such as 1.2 and 1.5 times etc.)[6-10], but the amount of pumping water or coefficients are given with strong subjectivity, ignored the groundwater response mechanism from coal mining disturbance. in this paper, the author combines the study of overburden failure with the simulation of groundwater system, the mechanism of mining influence on groundwater is analyzed. presents numerical methods to deal with the factor of deformation and destruction caused by mining in the groundwater numerical model, To establish a computer numerical evaluation model for the disturbance of groundwater system with high degree of quantification.

Disturbance mechanism of coal mining on groundwater

Damage and deformation of surrounding rock under the influence of mining disturbance

The mining scholars and groundwater research scholars have a more consistent understanding for the damage and deformation caused by coal mining, it is considered that the overlying strata in the coal seam mining is divided into the caving zone, fracture zone and curved zone from mined coal seam to surface (fig.1), this is the classical theory of "covering rock zoning"[11]. at the same time, the surface subsidence area is formed on the ground surface, Thus, the typical mining overburden disturbance can be summed up as "three zones and one area ". because the fracture zone directly connected with caving zone , and has strong hydraulic conductivity, so the two zones are collectively referred to as the "water conducted fractured zone", hereinafter referred to as fractured zone H_f.

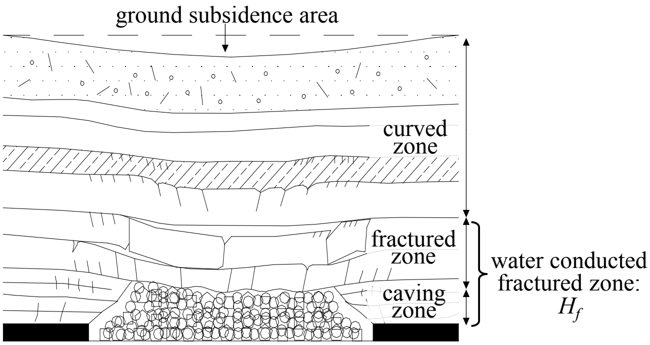


***Figure 1** the diagram of three zones and one area*

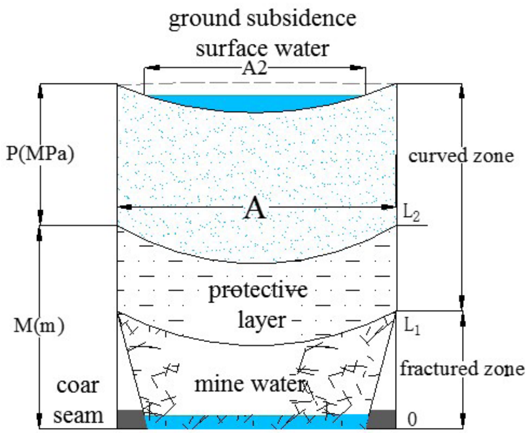


***Figure2** the disturbance of groundwater system*

The influence mechanism of "three zones and one area" on groundwater

In general, the amount of groundwater resources loss caused by coal mining is mainly composed of three parts, The amount of leakage from the overlying aquifer to the mining space is Q_1, and the leakage of water supply in the lateral aquifer is Q_2, which is caused by the water loss caused by surface subsidence water Q_3:

(1) the leakage amount of groundwater (Q_1)

In order to facilitate the analytical method, the water conducted fractured zone is defined as a trapezoidal. As shown in fig.2, the plane area of fractured zone is A (m^2); the fractured zone height is L_1 (m); the thickness between the loose aquifers and the coal seam is M(m); the permeability coefficient *K(m/d);* the water pressure at the plate of loose aquifer is p (MPa); u is the actual flow rate of groundwater in the protective layer; R for groundwater bulk density (N/m^3), take the roof of the coal seam as the "0" datum, according to the classical groundwater dynamic analysis method[12]:

the water head values at the top (L_1 height) of the fractured zone is:

$$H_1 = L_1 + P / r + u^2 / 2g$$

Because of large mine water drainage, the fractured zone is directly connected with the atmosphere, so the pore water pressure is atmospheric pressure at the top (L_1 height) of the fractured zone, $P = 0$, then:

$$H_1 = L_1 + u^2 / 2g$$

The water level value at the top of the protective layer is H_2 (on L_2 height):

$$H_2 = L_2 + P / r + u^2 / 2g$$

According to Darcy's law, the amount of water leakage (Q_1) can be expressed as:

$$\begin{aligned} Q_1 &= K * A \frac{(M - L_1 + P / r)}{M - L_1} \\ &= K * A(1 + \frac{P}{(M - L_1) * r}) \end{aligned} \qquad \textit{(Equation 1)}$$

When fracture zone extends directly to the loose aquifers or even surface, the protection layer thickness is zero, the leakage forms do not obey the Darcy's law, the groundwater will directly along the conducted fractured zone into the stope, eventually leading to the aquifers to be drained at the top of the mined spacer.

(2) lateral drainage (Q_2)

In general, the loss of groundwater resources in the aquifer is dominated by lateral drainage Q_2. According to the " Large diameter well method " based on the steady flow analysis:

$$Q_2 = 1.366K \frac{(2H - S)S}{\lg R_0 - \lg r_0} \qquad (Equation 2)$$

In the formula2, permeability coefficient K, m/d; water head height H, m; groundwater drawdown S due to mine drainage, the radius of influence R0, m; the radius of reference for mining space r_o,m;

The aquifer is assumed to be homogeneous and infinite, the natural water level approximate horizontal, R0 can be calculated using the following formula $R_o=r_o+R$,,, Where F is the scope of the excavation area, m². From the formula 4 we can see that the water flowing fractured aquifer area revealed F is larger, the greater the amount of underground water leakage.

(3) the loss amount of groundwater invalid evaporation (Q_3)

When the depth of the mining coal seam is larger, the mining fractured zone can not break through the protective layer which below the loose aquifer, and the depth of ground subsidence is greater than the depth of the groundwater, the surface water will be formed in the ground subsidence. so the groundwater is converted into surface water, which causes the groundwater from phreatic evaporation to surface water evaporation, which increases the amount of evaporation, it is a form of the loss of groundwater resources. the phreatic evaporation capability parameter is E_1, the water surface evaporation capability parameter is E_2, and the area of surface water is A_2 (M_2),the amount of groundwater invalid evaporation:

$$Q_3=(E_2-E_1)*A_2 \quad \text{(Equation 3)}$$

Quantitative evaluation method of mining disturbance of groundwater

The numerical treatment technology for the “fractured zone”

When fracture zone extend to a certain height, the groundwater from the fractured aquifer along the fractured zone cracks into the mining space, result in the aquifer lateral recharge is cut off at the top of the mining space. The groundwater has formed a “discharge strips” along the contact zone between the fractured aquifer and fractured zone (fig.3). Similarly, groundwater along the fractured zone cracks into the mining space, constitute a relatively stable supply for mine water. Finally, the aquifer groundwater level which cut by the fracture is reduced to the bottom plate of the aquifer.

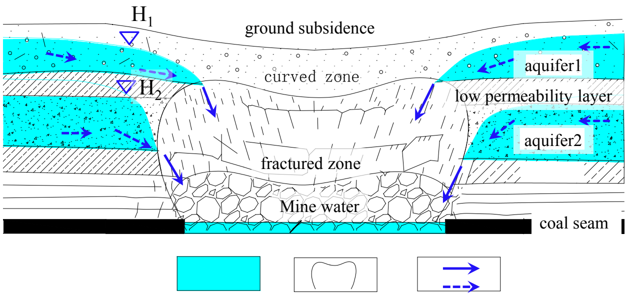


Figure 3 *the relationship between groundwater and water flowing fractured zone*

In the Visual MODFLOW model, the contact zone or discharge strips between the aquifer and fractured zone are treated as the "drainage" boundary to realize the numerical treatment of the vertical leakage Q_1 and the lateral discharge Q_2.

In the model the drainage (Drain) boundary is calculated as:

$$\begin{cases} Q_{1,2} = C_D\left(H - H_D\right) & H > H_D \\ Q_{1,2} = 0 & H \leqslant H_D \end{cases} \quad \textit{(Equation 4)}$$

which ,C_D—Cell permeability parameter,m^2/d;H —water head, m;H_D —Elevation of drainage or elevation of aquifer floor, m.

Numerical treatment technology for "curved zone"

Generally, the fractured zone will be extend to the surface when the shallow seam is mined, and the overlying strata can not form the "curved zone". However, the curved zone is formed between the fracture zone and the ground surface when the deep buried coal seam is mined. According to previous research results[13,14], although the "curved zone" rock layer is not formed the fractured cracks with the high conductivity, because of the change of the in-situ stress state, the rock is deformed, which leads to the change of the permeability of the overburden in the different section of the curved zone.

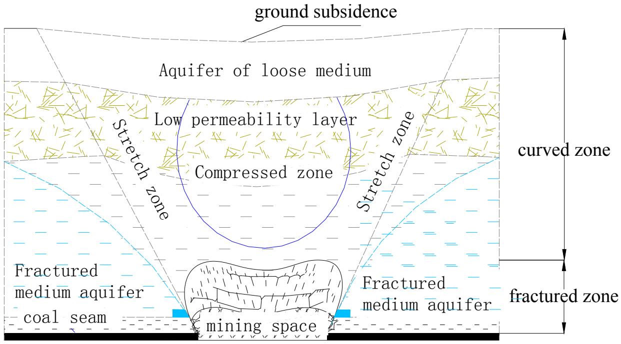


Figure 4 *the bending zone*

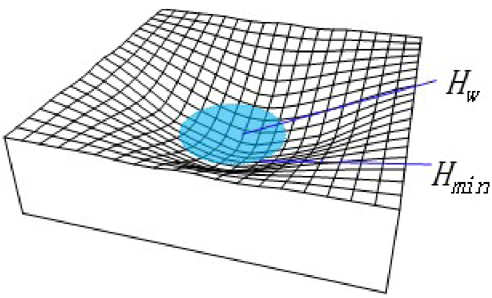


Figure 5 *the ground subsidence*

As shown in fig.4, Because the rock stratum of the curved belt is still continuous medium, and groundwater movement still obey the Darcy flow, So the parameters of the permeability can be partitioned according to the changing tendency of the rock stratum permeability before and after mining, Re assignment of the permeability coefficient in the partition, this is the numerical processing technology for the "curved zone" in the groundwater model.

Numerical treatment technology for "ground subsidence"

On the one hand, ground subsidence reduces the depth of the groundwater level, the lower the depth of groundwater level, the greater the amount of water evaporation. On the other hand, when the ground surface subsidence is greater than the depth of groundwater, the groundwater evaporation is converted into water surface evaporation, thus increasing the loss of groundwater resources. As shown in fig.5, ground elevation of groundwater model is re divided according to the predicted results of the ground subsidence or the measured results.

Note that, we should try to run the model after re changing the ground elevation, in order to analyze the relationship between the elevation value H_{min} at the lowest point of the ground subsidence and the elevation value Hw of groundwater level, When $H_{min}<H_W$, the groundwater is exposed on the surface, so the water evaporation coefficient should be modified to the surface evaporation coefficient in the groundwater area; When the $H_{min}\geq H_W$, groundwater is not exposed to the surface, so the groundwater discharge is still the phreatic evaporation, the groundwater evaporation will increase because of groundwater depth reduction.

Case study

This paper takes the Bulianta mine as the case which located in west China, the mining coal seam is No.1^{-2} and 2^{-2} of the Jurassic, and coal seam buried less than 150m, the surface is completely covered with the quaternary loose sand medium, and overlying bedrock thickness in less than 80m. loose layer thickness in 15 ~ 30m. as shown in fig.6 and fig.8a, in natural conditions before the coal mining, the loose aquifer groundwater mainly receive precipitation infiltration recharge, and exposed to surface in valley cutting zone, thus forming a perennial or seasonal rivers, such as BuLian river, Huojitu river and so on, those surface water is groundwater discharge zones.

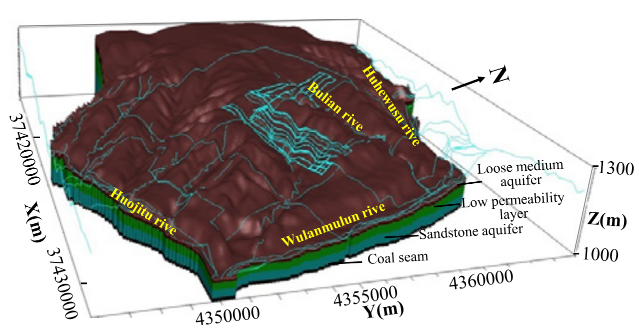


***Figure 6** Sketch map of study area*

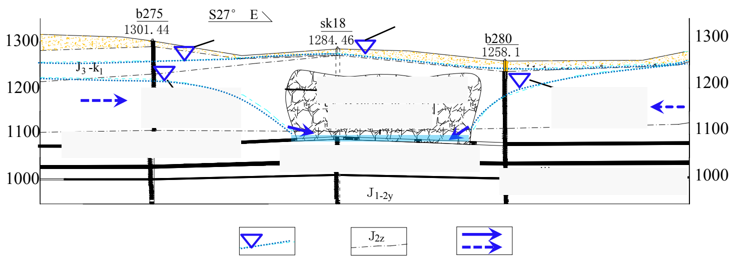
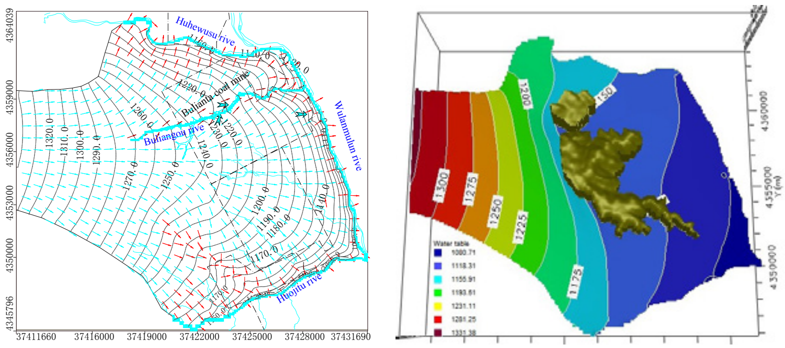


Figure 7 *Groundwater level contour (2006 measured: m)*

The Bulianta coal mine large-scale development of coal resources began in 2002, the actual output reached 35 million tons/year in 2012,as shown in fig.8b, due to the disturbance of coal mining, the fractured zone will be extend to the surface when the shallow seam is mined, and the overlying strata can not form the "curved zone".



a (2002) *b (2012)*

Figure 8 *Groundwater level contour (2012 calculated :m)*

In 2012, with the increase of mining area, the damaged aquifer area increased, a huge water level drop funnel is formed with the mining sector as the center. as shown in fig.8b, the water level dropped by about 30m, The aquifer is directly drained at the top of the mined area (yellow area). the amount of groundwater discharge to the mining space (the amount of groundwater leakage) is reached $1.9*10^4 m^3/d$ (tab. 1).

Table 1 *Comparison of calculation results*

Computing method	water ($\times 10^4 m^3/d$)	problem
Quantitative numerical analysis	1.9	**reasonable:** the total loss of groundwater into the mining space
Mine measured drainage	0.852	**too small:** does not include the amount of accumulating water in mine and reuse water for coal mining
Large diameter well analytical calculation	4.4	**too large:** Large diameter well method assumes that the conditions for the four catchment, infinite aquifer, homogeneous, does not conform to the actual hydrogeological conditions

Summary

(1) The spatial scale of the formation of “the fracture zone and the curved zone “ is the main factor to control the loss of groundwater: the larger area of fractured zone by coal mining disturbance, the higher the fracture zone, the stronger the permeability of the curved zone layer, and the greater the amount of groundwater seepage.

(2) Put forward the numerical processing technology for “fracture zone and curved zone ”in the groundwater model :the fracture zone can be simplified as a kind of drainage boundary condition, Re assignment of the permeability coefficient in the curved zone, and re divided the ground elevation in ground subsidence.

(3) The case simulation results shown that groundwater level decline more than 30m (2012), the loss of groundwater resources is about 1.90*$10^4 m^3$/d due to the mining disturbance.

Acknowledgements

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