Hindawi
Geofluids
Volume 2021, Article ID 5597548, 12 pages
https://doi.org/10.1155/2021/5597548

Research Article

Identification of Hydraulic Connection Points between Different Confined Aquifers in the Liyazhuang Coal Mine

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Received 21 February 2021; Revised 29 March 2021; Accepted 21 April 2021; Published 8 May 2021

Academic Editor: Yingfang Zhou

Water inrush from coal seam floors is one major geological obstacle hindering safe and efficient production activities in mines. Determining the source of water inrush can facilitate its prediction and guide decisions regarding measures for prevention and control. The process of identifying the location of hidden hydraulic contact points in different confined aquifers forms the basis of hydrogeological explorations. It is also the basis for categorizing mine areas prone to water inrush and making qualitative decisions regarding the prevention and control of water inrush. In this study, the positions of hidden hydraulic contact points between the Ordovician Fengfeng and Shangmajiagou formations in the basement of the Liyazhuang coal mine were determined using numerical simulations of the flow fields. First, each node of the finite element grid was considered as a water inrush point to determine the water level at other nodes. Subsequently, the error between measured and simulated water levels, determined based on the flow fields, was determined using the least squares method. The node with the minimum error was then considered as the hidden hydraulic contact point. The simulation results for the flow field indicate a distance of 5000 m between the hydraulic connection and the water inrush points located between the peak formation and the Majiagou aquifer in the Liyazhuang coal mine. Furthermore, the hydraulic relationship between them is poor. Observational data of water inrush from the floor of the No. 2 coal seam and the water level of the confined aquifer in the Liyazhuang coal mine, including the water quality test data of different Ordovician ash aquifers, show that the source of water inrush from the floor of the No. 2 coal seam is the aquifer of the Fengfeng Formation. This finding is consistent with the results of the numerical simulations of the flow field. The results demonstrate that, in mining areas subjected to high pressures, numerical simulations of the flow field can serve as an effective tool for determining the location of hidden hydraulic contact points.

1. Introduction

The primary goal of conducting explorations in coal mining area with high water pressures is to identify three aspects: the location and size of the water inrush from the coal seam floor and the water horizon. The most commonly used methods to accomplish this task include analyses of the geological structure [1], observations of the borehole water level, water quality tests, observations of the mine face, the construction of models [2, 3], and numerical simulations [4–8]. Provided the water barrier between the coal seam and the Ordovician ash aquifer is sufficiently thick, the located of water inrush from the coal seam floor often lies in the distribution area of the fault [9] and the karst collapse column [10]. Using borehole water level observations and water quality test results from different layers, the source of the water inrush can be identified. Subsequently, the extent of water inrush can be determined.

Although fault zones can include fracture zones and fracture development zones, mine practices have established that

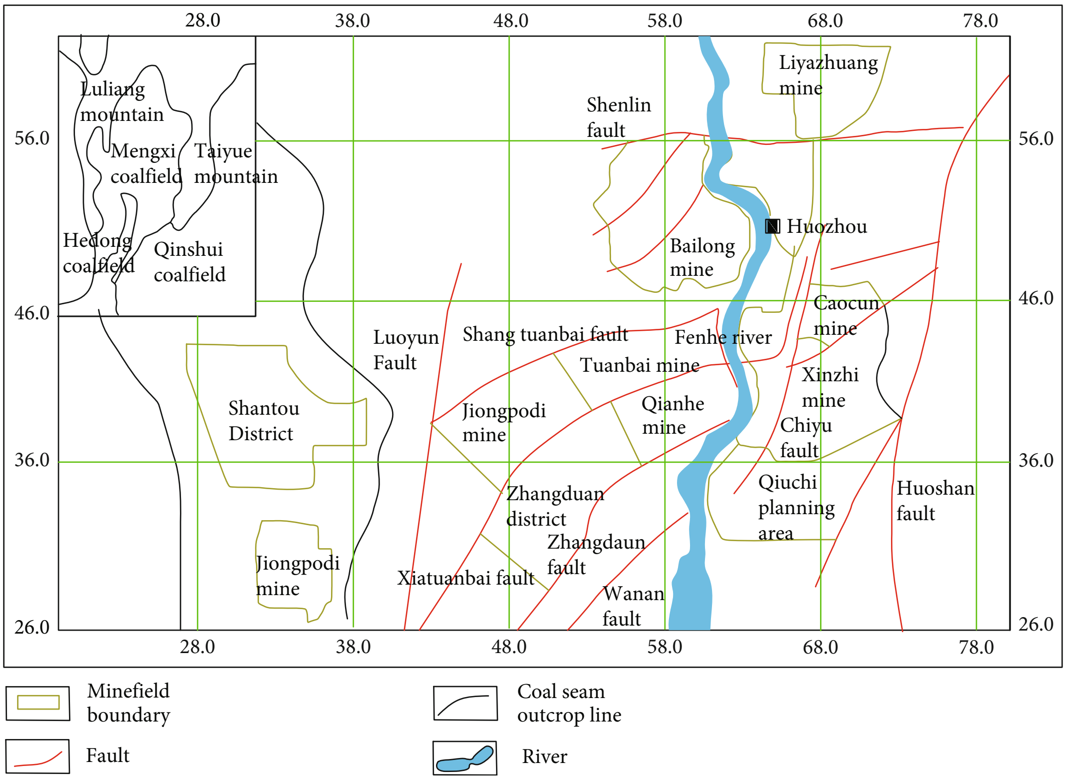


Figure 1: Regional structure sketch of the Huozhou mining area.

not all fault zones conduct water. This indicates that differences in material composition, cementation degree, and stratigraphic assemblage in the fault zones are important factors determining whether a fault conducts water. However, these factors are often difficult to explore [11, 12]; karst collapse columns are also associated with similar problems [13].

According to the North China C-P coal measures [14–16], the determination of the water inrush source from the floor is often focused solely on Ordovician limestone aquifers or coal measures aquifers [17]. However, limited attention has been devoted to which section of Ordovician limestone the water inrush is derived from. Many marl aquifers are distributed in the eighth member of the Ordovician limestone group, and there exists a substantial difference between the water storage capacities of each Ordovician limestone aquifer group. If the water inrush source is not identified, the layer of the water inrush source also remains unknown. This causes difficulties in the accurate estimation of the amount of water inrush, which, in turn, affects prevention and control measures and mining activities in later stages [18].

The Huozhou Coal Power Group is currently mining the No. 2 coal seam of the Liyazhuang coal mine. The seam has a floor elevation of 190–390 m, and the Ordovician ash confined water head is 481.93 m ~516.2 m, representing a typical mining area with high water pressure. The water inrush from the coal seam floor occurred, and the initial water inrush point was 350–410 m^3/h. After more than two years of drainage, the water inflow gradually decreased and reached a stable level. Observations of the borehole water level indicate that the aquifer water level of the Fengfeng formation is decreasing in a large-scale funnel structure, while the aquifer water level of the Majiagou formation remains unchanged. In the present situation, it is difficult to accurately investigate whether the fault zone and karst collapse column conduct water. Existing borehole water level observation data and the water quality test data of different aquifers aid in determining the connectivity and difference between the aquifers of the Majiagou and Fengfeng formations, which are determined through the numerical simulation of the flow field. This provides a theoretical basis for the categorization of areas prone to water inrush and qualitative decision-making regarding prevention and control measures.

2. Geological Survey

The Liyazhuang coalfield is located on the eastern edge of the Huozhou coalfield, to the west of the northern plate of the Huoshan fault zone, which lies in the Shilin fault zone of the Lingshi uplift. The minefield structure is controlled by the Shilin fault zone in the south and the Huoshan fault zone in the east (shown in Figure 1). As a whole, it is a monocline structure trending northeast and dipping southeast; the dip of the strata is approximately 10°. The main coal-bearing strata are the lower Permian Shanxi Formation and the upper Carboniferous Taiyuan Formation (shown in Figure 2). The No. 2 coal seam of the Shanxi Formation is currently being mined. The average thickness of the Fengfeng Formation under the floor of No. 2 coal seam is 108.85 m, the lithology of the first member of the Fengfeng Formation (O_2f^1) is thick argillaceous limestone, gypsum-bearing argillaceous limestone, and marl, which is relatively waterproof layer, the thickness of the Shangmajiagou Formation is 188.11 m, and

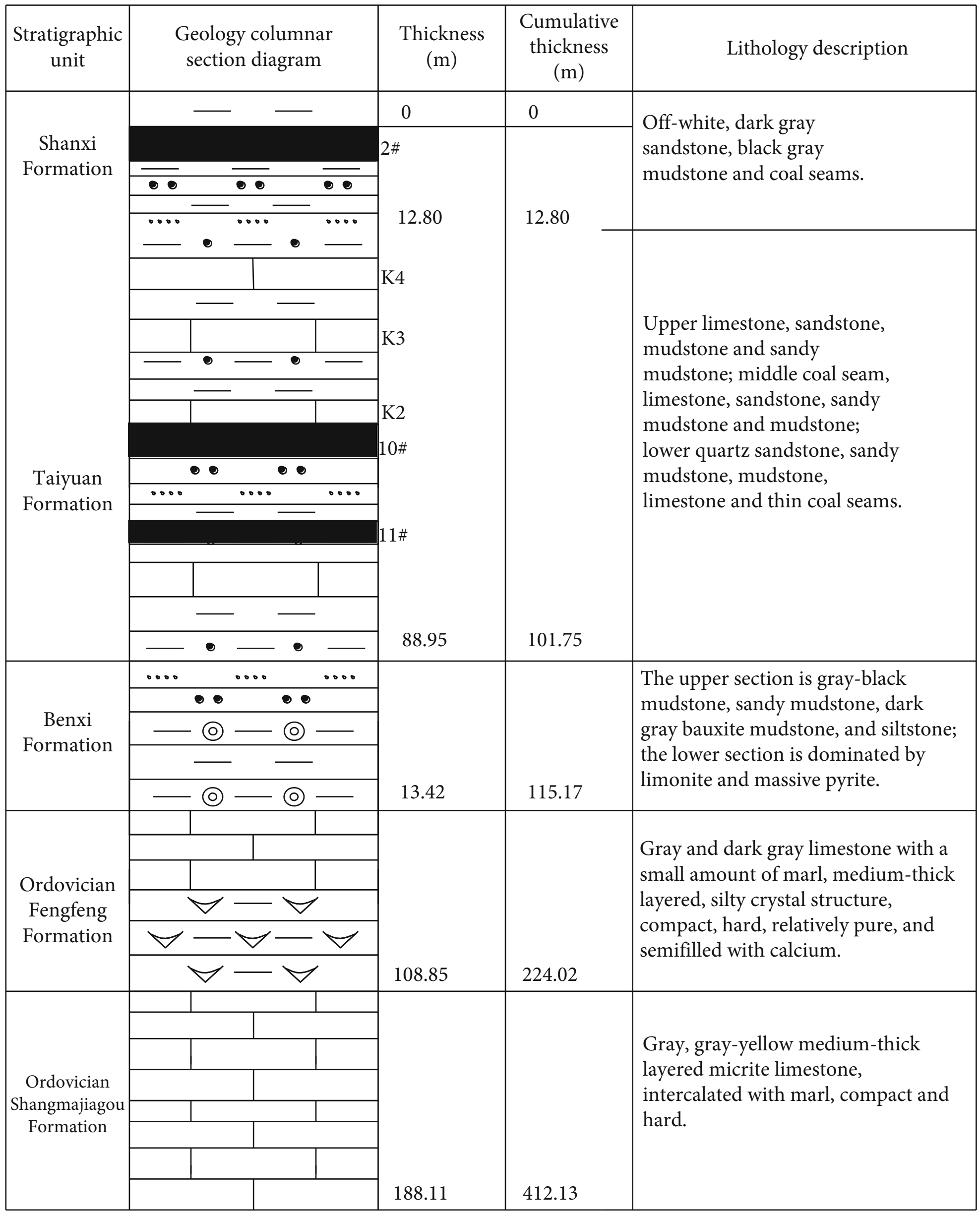


Figure 2: Geological columnar section diagram of the Liyazhuang coal mine.

the static water level is 510.94~516.2 m. In the minefield, NNE-trending stepped normal faults with a drop of 5-15 m are mainly developed, and there is a fault with a drop of more than 50 m. At the same time, NNE, NW, and EW-trending broad and gentle anticline structures are also developed in the well field. Liyazhuang minefield is located in the strong flow zone and gathering area of the Guozhuang spring karst water system (spring area). The recharge area of the Guozhuang spring area is located in the exposed area of cold ash and Ordovician ash in the west, which is directly recharged by atmospheric precipitation. The leakage recharge of the Fenhe River Valley in the area from Lingshi to Guozhuang and the groundwater in the east are collected and recharged to the lower reaches of the valley. A strong flow zone and gathering area of karst water have been formed on both sides of the Fenhe River in Lingshi-Shilin-Guozhuang (shown in Figure 3).

(1) loose quaternary deposits, (2) carboniferous, Permian sand shale, (3) O_2 limestone, (4) O_2 dolomite, (5) gneiss, (6) spring, (7) fault, (8) underground water level, and (9) drilling on the digital water inflow in m^3/h·m. The following is the depth of the hole (m). The value 35.9 refers to the unit inflow of the borehole m^3/(h m). The value 8.6 refers to the spring discharge (m^3/s). From left to right, the first fault should be the counteroff layer, and the arrow is facing up; the second tomography should be a broken layer, and the arrow is facing down. That is, the left and right fault arrows are interchanged.

3. Survey Results and Analysis

The water inrush originated from the fault zone of the floor of the No. 2 coal seam during mining. Consequently, outflow measures were adopted. In addition, the water

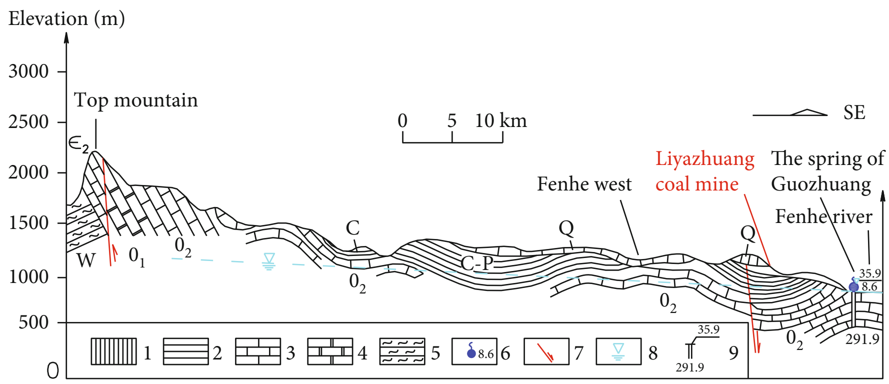


Figure 3: Hydrogeological profile of the Guo Zhuang Spring domain:

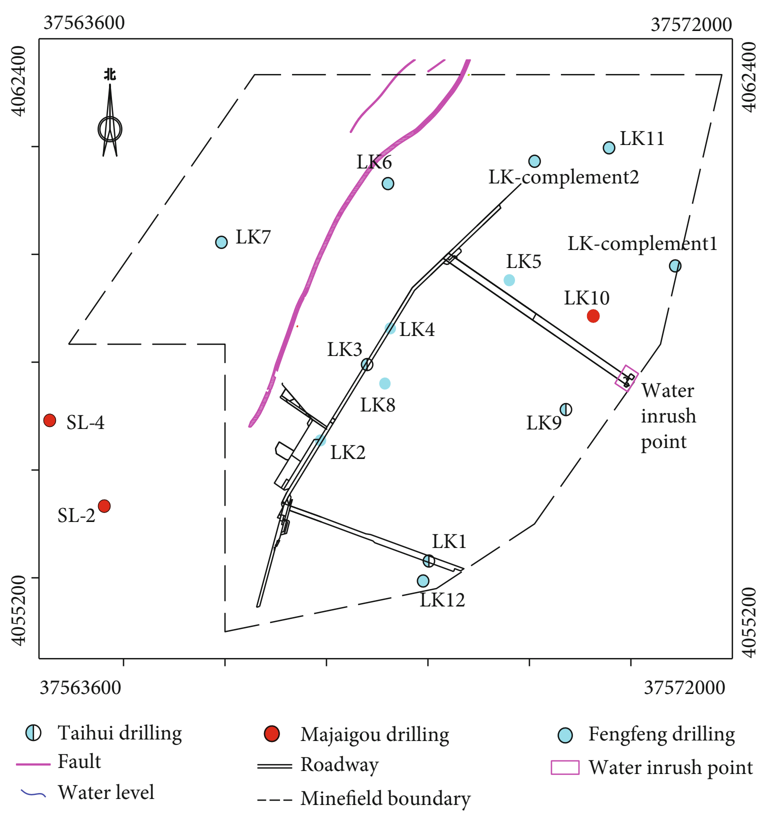


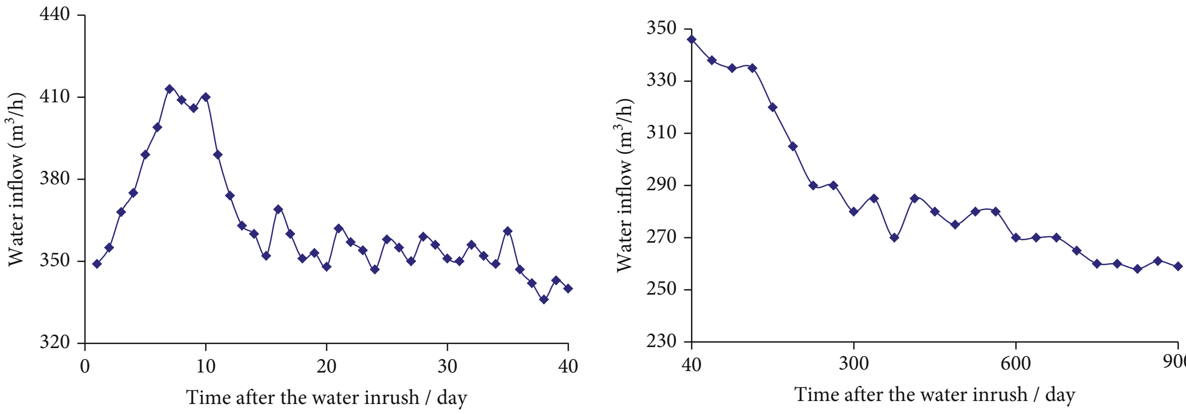
Figure 4: Layout of observation holes.

inflow at the water inrush point and the changes in the water level at each aquifer observation hole (shown in Figure 4) were monitored constantly.

3.1. Variations in Water Inflow at the Inrush Point. The water inrush exhibited an initial increasing trend, which gradually changed to a decreasing trend. In the initial stages, the water inflow volume gradually increased, reaching a maximum of 413 m^3/h at 7^{th} day. The inflow volume remained high over the next two to three days with slight fluctuations, before beginning to decrease. As the water inrush continued, the volume fluctuated from the 10^{th} to the 18^{th} day, decreasing from 410 m^3/h to 351 m^3/h (i.e., a reduction of 59 m^3/h). Thus, the magnitude of decrease was large (shown in Figure 5(a)). Although a subsequent slight upward fluctuation was noted, the overall change was a reduction in the inflow volume. The water inflow reduced from 346 m^3/h to 270 m^3/h within ten months (40-300 days). And 21 months after water inrush, the water inflow has reached approximately 260 m^3/h, and the water volume has remained unchanged. The change presented in Figure 5(b) exhibits a relatively stable value.

3.2. Variations in the Water Level at Each Observation Hole

3.2.1. Dynamic Characteristics of the Water Level in the Ordovician Fengfeng Formation (O_2f) Limestone Aquifer.



(a) The water inflow variations within forty days after water inrush (b) The water inflow variations within 900 days after water inrush

FIGURE 5: Variations in water flow at the water inrush point with time.

The change in the water level of the limestone aquifer of the Fengfeng Formation after the water inrush is mainly related to the distance between the observation holes and the water inrush point (as shown in Table 1 and Figure 6(a)). When the water inrush point is closer (such as in the case of LK_5), the decrease in the water level is greater. In contrast, if the observation hole is further away from the water inrush point, the decrease in the water level is less significant. For the LK_7 observation hole, the water level does not change because it is far away from the water inrush point, and a fault exists near the LK_7 observation hole. The fault separates the Fengfeng Formation aquifer; thus, after the water inrush, the water level of the LK_7 observation hole does not drop significantly.

In general, the aquifer water level of the Fengfeng Formation exhibits notable variations over the three time periods after the water inrush. During the early stages of water inrush (i.e., the first 1–2 months (0-56 days)), the cumulative decrease in the water level is relatively large (8.4 m to 35.12 m). During the middle stages of water inrush (3–5 months (90-150 days)), the decline in the water level reduces significantly, with a cumulative decrease of 17.61 m to 42.78 m. Thereafter, the water level remains stable, and the change in decline is small. This is because water sources from other locations continue to replenish the Fengfeng Formation, and the groundwater flow field is basically stable; with continuous drainage, the decline in the water level becomes relatively small.

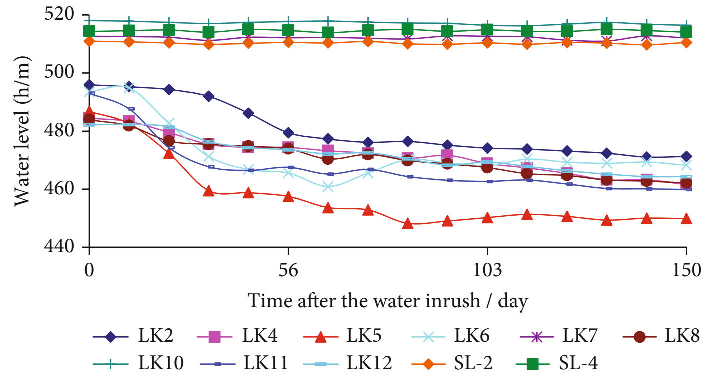
3.2.2. Dynamic Characteristics of the Water Level in the Limestone Aquifer of Upper Majiagou Formation (O_2s) in Ordovician. The LK_{10} Ordovician limestone observation hole of the Shangmajiagou Formation in the minefield is the closest observation hole to the water inrush point; it is located at a distance of 899 m from the water inrush point. If the data from the SL-2 and SL-4 observation holes of adjacent mines are considered, the water levels at the three observation holes have remained essentially the same over the past two years (shown in Figure 6(b)). This indicates that the aquifers of the Fengfeng and Shangmajiagou formations are relatively independent aquifer rock groups.

TABLE 1: Variation in the water level of Ordovician limestone before water inrush as a function of distance.

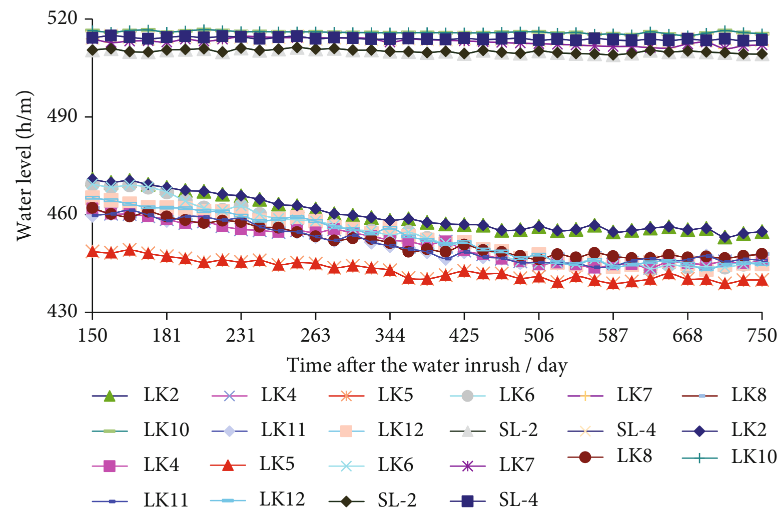
Name	Hole number	Aquifer	Distance from water inrush point (m)	Water level value before water inrush(m)
Fengfeng Formation	LK_2	O_2f	3727	495.84
	LK_4	O_2f	2921	484.89
	LK_5	O_2f	1874	492.62
	LK_6	O_2f	3564	495.67
	LK_7	O_2f	5090	513.75
	LK_8	O_2f	2916	484.37
	LK_{11}	O_2f	2047	493.71
	LK_{12}	O_2f	3281	481.93
Majiagou Formation	LK_{10}	O_2s	899	516.20
	SL-2	O_2s	6391	510.94
	SL-4	O_2s	6908	514.83

3.3. Chemical Characteristics of Water Quality. According to the percentage liter equivalent of cations (Na^+, Ca^{2+}, and Mg^{2+}) and anions (Cl^-, SO_4^{2-}, and HCO_3^-) determined through explorations of the borehole water and underground inrush water sources, three lines of water quality are drawn, as shown in Figure 7.

As can be seen from the figure, the content of Na^+ in the cations of karst water in the Taiyuan Formation is 83.83–89.29%, the content of HCO_3^- in the anions is 66.29–70.23%, and the hydrochemical type is HCO_3-Na. The content of Na^+ in the cations of karst water in the Fengfeng Formation is 62.01–88.17%, the content of HCO_3^- in the anions is 39.23–51.24%, the content of SO_4^{2-} is 25.47–42.11%, and the hydrochemical type is $HCO_3 \cdot SO_4$-Na. In the Majiagou Formation, the Na^+ content in the karst water cations is 30.65–39.64%, the Ca^{2+} content is 42.08–46.46%, the HCO_3^- content in the anions is 31.07–39.55%, the SO_4^{2-} content is 55.7–61%, and the hydrochemical type is $SO_4 \cdot HCO_3$-Ca·Na. These statistics demonstrate that there are evident differences among the three water quality types.



(a) Variations in the water level within 150 days after water inrush



(b) Variations in the water level within 750 days after water inrush

Figure 6: Variations in the water level at the observation holes with respect to time.

During the early stage of water inrush, the content of Na^+ in the water accounted for 76.05% and 78.35%, respectively, and the HCO_3^- content accounted for 69.74% and 67.13%, respectively. The hydrochemical type of HCO_3-Na was similar to the water quality of the Taiyuan Formation. This is mainly because of the hydraulic connection with the aquifer of the Taiyuan Formation during the water inrush. Subsequently, the anion HCO_3^- content accounted for 54.68%, 44.84%, and 41.19%, respectively, and the SO_4^{2-} content accounted for 20.77%, 25.84%, and 28.70%, respectively. The water quality type of $HCO_3 \cdot SO_4$-Na was similar to the Fengfeng Formation, but it was considerably different from that of the Majiagou Formation. The above results show that the source of water inrush mainly comes from the karst water of the Fengfeng Formation.

4. Numerical Simulations of the Hydraulic Relationship between Aquifers of Fengfeng and Majiagou Formations

The Liyazhuang mining area is located in the hydrogeological unit composed of the Fenhe faulted basin and the surrounding Huoshan and Luliang mountains. The main aquifers in the Ordovician strata in this area are those of the Fengfeng and Shangmajiagou formations. The Ordovician karst water recharge is mainly the Ordovician limestone in the exposed area of Fenhe River valley and Lvliang Mountain.

According to the regional hydrogeological and structural maps (shown in Figure 1), Ordovician limestone outcrops are present in the Fenhe Valley, west of the Liyazhuang mining area, and the Shilin and Huoshan Faults are present in the southeast direction. Therefore, the study area is selected as follows: the Huoshan Fault to the east, the Shilin Fault to the south, the Fenhe limestone outcrop to the west, and the Lingshishan Fault to the north. The dimensions of the study area are 25000 m from the east to west and 20000 m from the north to south. In the simulations, this area comprises a total of 50451 nodes, and a grid size of 100 m, which is because the smaller the grid, the higher the calculation accuracy, but considering the calculation amount and computer running speed, first check the calculation grid, 500 m, 200 m, and 100 m, according to the test calculation grid is that 100 m, calculate the water level. The value is closer to the actual observation, the final grid score distance is determined to be 100 m. The average thickness of limestone in the Fengfeng Formation is approximately 29 m. A fault with a drop of more than 50 m, located near the LK7 observation hole,

Legend and drill number						
Taiyuan Formation	The drill number	LK_9	LK_3	LK补1		
	The water quality type	1	2	3		
Fengfeng Formation	The drill number	LK_2	LK_5	LK_6	LK_8	LK_{11}
	The water quality type	1	2	3	4	5
Majiagou Formation	The drill number	LK_{10}	SL-2	SL-4		
	The water quality type	1	2	3		
Water inrush	The date	3.26	4.3	4.2	5.1	5.18
	The water quality type	1	2	3	4	5

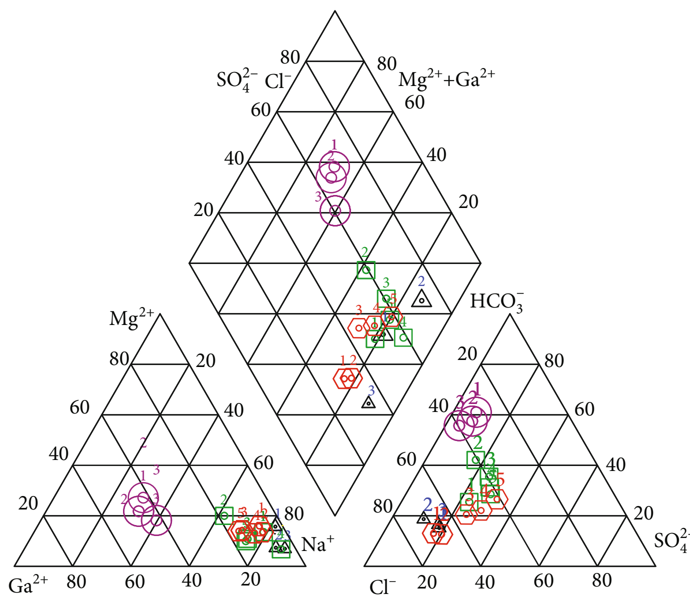


Figure 7: Hydrochemical classification of three lines.

northwest of the minefield, separates the limestone aquifer of the Fengfeng Formation. In the calculations, the unit water conductivity of the fault is set as zero. However, the thickness of the limestone aquifer in the Shangmajiagou Formation is 108 m, and the fault has limited influence on the aquifer. When calculating the equal water level line of the aquifer, the impact of faults in the area is neglected.

The estimated boundary conditions are as follows: the western boundary is the Fenhe limestone outcrop (which is considered as a fixed boundary), the eastern boundary is the Huoshan Fault, the northern boundary is the Lingshishan Fault, and the southern boundary is the Shilin Fault (which is considered as an impervious boundary). The water inrush point is considered as the confluence; the water source well near the mine Shilian roadway is considered the sink. The current water level observed at each observation hole is considered as the basis. The initial data of Fengfeng Formation and Majiagou Formation are shown in Tables 2 and 3.

Generally speaking, there are two-dimensional unsteady seepage and steady seepage calculation formulas for flow field calculation. The water level of the aquifer in the unstable seepage model is not only related to the boundary conditions, water conductivity coefficient, and source-sink term, but also varies with time. Therefore, the unstable seepage model can be used to simulate the aquifer where the water level changes greatly in different time and different seasons, or shortly after the occurrence of water inrush, the aquifer water level is not stable. The aquifer water level in the stable seepage model is only related to boundary conditions, water conductivity coefficient, and source-sink term and does not change with time. The water inrush accident of the Liyazhuang coal mine in this project has been a long time ago, and the water level of the aquifer

Table 2: The initial data and calculation results of the Fengfeng Formation.

Drill number	The original water level value (m)	The calculated water level value (m)
Lk2	456.20	453.45
Lk4	445.71	449.00
Lk5	441.65	441.63
Lk6	447.20	451.49
Lk8	448.63	448.62
Lk11	446.73	447.43
Lk12	443.97	451.29
The average water level value	447.155	448.989

The value of hydraulic conductivity in the $x-$ and y-direction is 0.315 m^2/s and 0.315 m^2/s. Variance: 3.5928. Error: 0.00409.

Table 3: The initial data and calculation results of the Majiagou Formation.

Drill number	The original water level value (m)	The calculated water level value (m)
SL2	509.24	513.71
SL4	513.12	518.29
Lk10	515.83	523.27
The average water level value	512.73	518.43

The value of hydraulic conductivity in the $x-$ and y-direction is 0.887 m^2/s and 0.693 m^2/s. Variance: 5.6961. Error: 0.00992.

has been basically stable, which belongs to a relatively stable aquifer; so, the steady flow calculation formula is adopted.

The water level of each point in the calculation area is inversely calculated according to the two-dimensional steady seepage equation (1), and the objective function (2) is established as the criterion for the end of the calculation; that is, variance between the observation point water level value and the measured water level value reaches the minimum, and the error between the calculated water level value and the observed water level value is not more than 1% is the final time of calculation (determined according to the accuracy of the current observation sensor is not more than 1%), so as to find the potential hydraulic contact points in the calculation area. According to the calculation results as shown in Tables 2 and 3, the isoline of each aquifer is drawn, and the possible hydraulic contact points are obtained; the isowater level lines of each aquifer are shown in Figure 8.

$$\left\{\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right)=W, \tag{1}$$

$$R(h)=\frac{1}{m}\sum_{i=1}^{m}\left(h_{i1}-h_{i0}\right)^2. \tag{2}$$

In Equation (1), h is the water level value (in m), T_{xx} is the hydraulic conductivity along the x-direction (in m^2/s), T_{yy} is the coefficient of water conductivity along the y-direction (in m^2/s), and W is the source and sink term (in m/s). In Equation (2), h_{i1} is the calculated water level value of point i (in m), and h_{i0} is the observation water level value of point i (in m); m is the number of observation holes.

The limestone water level of the Fengfeng Formation in the wellfield is a funnel-shaped isoline with the water inrush point as the lowest point. The lowest water level is 400 m, whereas the highest is 510 m. If we consider the water inrush point as a discharge point, the significant influence radius is approximately 3000 m, which covers half of the mining area. The dense water level under the LK_7 observation hole is a waterproof fault, which separates the limestone of the Fengfeng Formation. Therefore, after the water inrush from the coal seam floor of the mine, the water levels at other observation holes decrease, and only the water level at the LK_7 observation hole remains unchanged (as shown in Figure 8(a)). The high water level of the limestone aquifer of the Fengfeng Formation to the west of the wellfield is related to the high water level of the limestone aquifer of the Shangmajiagou Formation; it is the point at which the limestone aquifer of the Shangmajiagou Formation recharges into the limestone aquifer of the Fengfeng Formation (as shown in Figure 8(b)). However, because it is located far from the water inrush point approximately 5000 m, this recharge is limited and does not have a considerable influence on the equal water level of the limestone aquifer of the Fengfeng Formation. In addition, as this is the junction of the two mines and there is no mining face in this area, it has a limited impact on mining.

5. Discussion

Owing to the development of coal resources, water inrush from coal seam floors caused by the pressure during mining has become a major geological obstacle that endangers mine safety and efficient production [19]. In response, theories regarding water inrush from floors under pressure, such as "key layer" [20], "water inrush coefficient" [21], "thin plate structure" [22], "in situ fracture and zero failure" [23], "strong seepage passage" [24], and "lower three zones" [25] have been developed. The focus on the waterproof layer of the coal seam floor is mainly aimed at C_2b [18, 26] between the top of Ordovician ash and the floor of coal measures. The Ordovician aquifer underlying the coal measures is often treated as one entity [27–29]. The treatment, observation, and numerical analysis of water inrush from the coal seam floor of the Liyazhuang coal mine show that the Feng and Majiagou formations are independent but interrelated aquifers. Furthermore, the hydraulic contact point between these formations is not at the same position as the structural water inrush point from the coal seam floor. The smaller the distance between them, the greater is the damage caused to the mine by the water inrush, and vice versa. If the hydraulic contact point of the two aquifers in the Liyazhuang Mine is close to the water inrush point or at the same position, the Majiagou aquifer is thick (its thickness is 5–10 times greater than that of the aquifer of the Fengfeng formation), rich in water content, and has excellent water conductivity. Then, the water inrush from the coal seam floor of the Liyazhuang coal mine will be more than

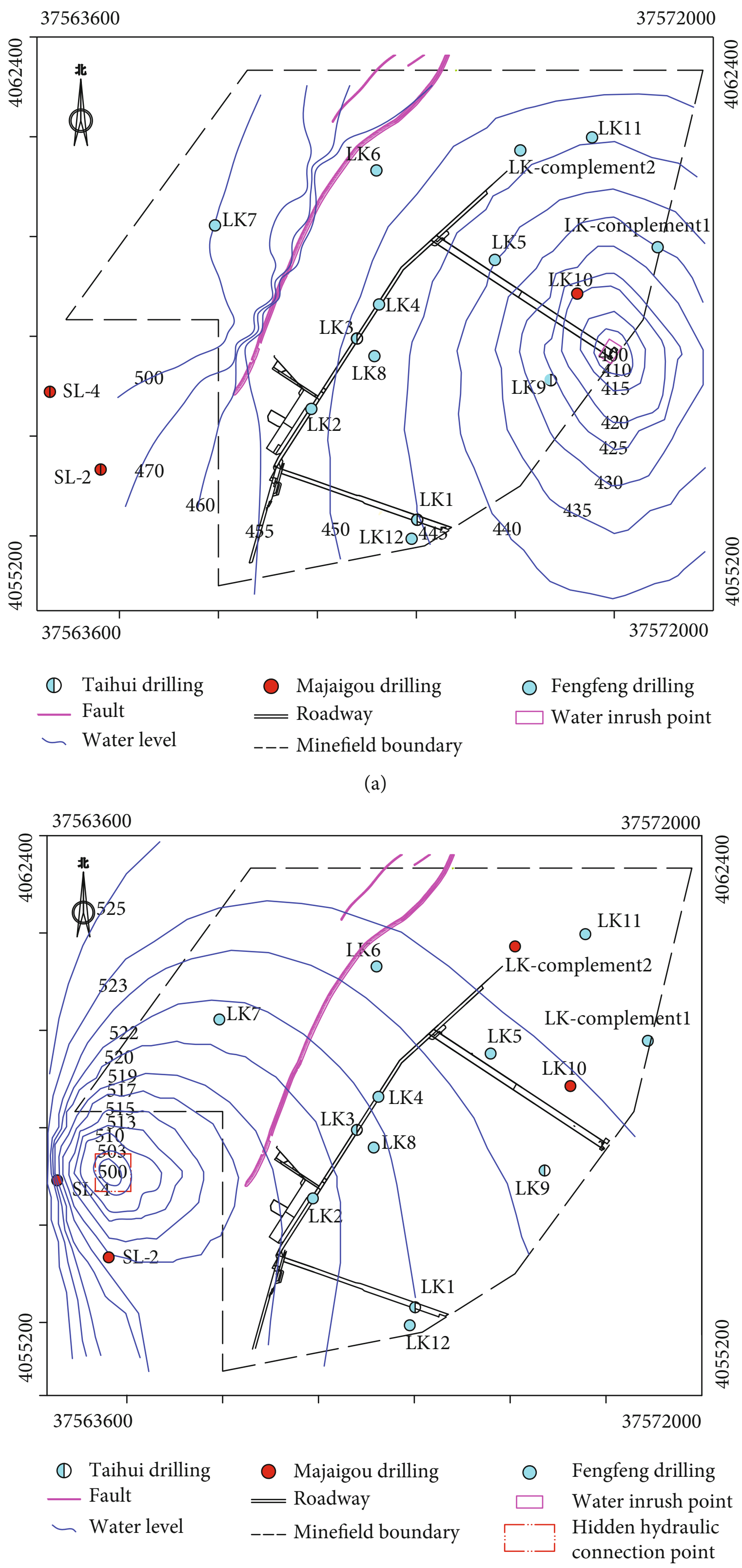


Figure 8: Water line of Ordovician aquifer: (a) equal water level in Fengfeng aquifer and (b) equal water level in Majiagou aquifer.

thousands of square meters per hour, which will bring catastrophic disasters to the mine. In addition, the measures of drainage and depressurization are not feasible.

Studies on the water-resisting layer in the Ordovician limestone are mainly focused on microsampling tests. Fu et al. [30] performed a sampling test on the Wangjialing Fengfeng Formation, showing that the first section of the Fengfeng Formation has strong water isolation capacity. The test by Mu Lin [31] on the water-blocking ability of the Fengfeng Formation at the Sihe field (Jincheng mining area) showed that there exists a significant difference between the hydrogeological characteristics of the Fengfeng and the Upper Majiagou formations, and that a strong water-blocking layer has developed between them. However, it is not possible to ascertain whether there exists a hydraulic connection between the two or the degree of connection. Currently, mine water inrush sources can be quantitatively analyzed based on the isotope method [32]. LIF and CNN [33] and Bayesian [34] methods using PCA and MCMC can be used to identify mine water inrush sources. Furthermore, water sources can be identified based on the grey correlation degree [35] and the dynamic weight-set pair analysis model [36]. However, the connection points between water sources cannot be predicted. The numerical simulation of the flow field shows that there exists a hydraulic connection point between the aquifer of the Fengfeng and Majiagou formations in the west of the wellfield, which is 5000 m away from the structural water inrush point of the coal seam floor. This indicates that the two confined aquifers of the Ordovician ash in the Liyazhuang Mine are connected. The equal water level map of the flow field simulation shows that the connection between the two confined aquifers of Ordovician ash is poor in the mining area. This is also confirmed by the water inrush and drainage in the Liyazhuang Mine.

The rules for water prevention and control stipulate that, when the water inrush coefficient exceeds 0.1 MPa, the coal quantity is temporarily stagnant, and the water inrush coefficient is between 0.06 and 0.1 MPa; mining can be performed after hydrophobic depressurization or floor grouting sealing, and reinforcement measures are implemented. Currently, the Ordovician limestone confined aquifer is generally regarded as a whole in China, and no hydrophobic depressurization measures are utilized. Generally speaking, the measures of drainage and depressurization are not taken, but the measures of grouting reinforcement are adopted, which has the advantages of huge project quantity, high project cost, and pollution of Ordovician ash water source.

The location of the hydraulic connection point of the limestone aquifer of the Ordovician Majiagou and Fengfeng formations can be determined using the combination of observational data regarding the confined water level, results of the water quality tests, and numerical simulations of the flow field. When the distance between the water inrush point and the hydraulic contact point of the confined aquifer is large and the connectivity is poor, the source of water inrush is limited, even if the pressure bearing capacity of the coal seam floor is high. Measures such as drainage and depressurization can be adopted to a section of the coal seam under pressure, without the need of applying grouting reinforcement measures. According to the proposed method, the target area of the hydrogeological exploration can be further reduced; moreover, verification holes can be arranged at the hidden hydraulic contact points, and efficient explorations can be carried out.

6. Conclusions

Results of the numerical simulations of the flow field conducted in this study show that the distance between the hidden hydraulic contact point and the water inrush point of the Ordovician Fengfeng and Shangmajiagou formations in the coal measures basement of the Liyazhuang mine is 5000 m. Although the hydraulic relationship between them is poor, the water inrush source is the water-bearing rock formation of the Ordovician Fengfeng Formation. The amount of water is limited, which indicates that some pressure-bearing coal seams can be mined after employing drainage and depressurization measures.

In coal mining areas with water pressure, numerical simulations of flow field can be used to determine the location of hidden hydraulic contact points; therefore, such simulations constitute an effective method for determining the source of water inrush. Additionally, these simulations can provide theoretical guidance for the hydrogeological explorations of mines subjected to pressure, in terms of characterizing areas prone to water inrush and qualitative decision-making regarding water prevention and control measures.

Abbreviations

h: The water level value (m)
Txx: The hydraulic conductivity along the x-direction (m^2/s)
Tyy: The coefficient of water conductivity along the y-direction (m^2/s)
W: The source and sink term (m/s)
h_{i1}: The calculated water level value of point i (m)
h_{i0}: The observation water level value of point i (m)
m: The number of observation holes.

Data Availability

All data used to support the study is included within the article.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

The authors appreciate the financial support from the National Natural Science Foundation of China (No. 51574174) and Foundation of Shanxi Institute of Energy (No. ZZ-2018103).

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