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The Characteristics of Thermal Reservoir Hydraulic Field in Wumishan Group, Tianjin

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ABSTRACT

The geothermal resources of Wumishan group reservoir in tianjin is mainly developed and used for heating. With the large-scale development and utilization, the buried depth of water level in the Wumishan group reservoir decreases year by year, and the geothermal resource reinjection has been increased in recent years. Under the condition of geothermal reinjection, the hydraulic characteristics of the geothermal reservoir in the Wumishan group reservoir have always attracted people's attention. This paper mainly analyzes the plane distribution characteristics of the reservoir dynamic field under the condition of Tianjin reinjection and the influence of reinjection on the dynamic field of the Wumishan group reservoir.

1. RESERVOIR CHARACTERISTICS OFWUMISHAN FORMATION

The Wumishan reservoir of Jixian system is generally distributed in the south of the Ninghe-Baodi fault, mainly lies in the Cangxian uplift area east of the Tianjin fault (the buried depth is less than 1000m). To the west of this fault, only a small area is distributed in the southwest corner of the Dacheng uplift area. However, the buried depth in the depressions on both sides is generally more than 4000 m, and only a small area distribution exists in the northeast corner of Jizhong depression and Cangxi uplift area. The total area is 3550.99 km^2 that the buried depth is less than 4000m (Fig. 1).

The stable flow temperature of Wumishan group reservoir geothermal well head is 70-113℃, and the fluid quality types are mainly Cl • HCO_3 • SO_4-Na, Cl • SO_4 • HCO_3 - Na and Cl • SO_4 - Na. The pH value is 7.5-8.5, and the salinity is generally 1700-2200 mg/L, locally more than 5000 mg/L. The trend salinity of is gradually increasing from the north east to the south west.

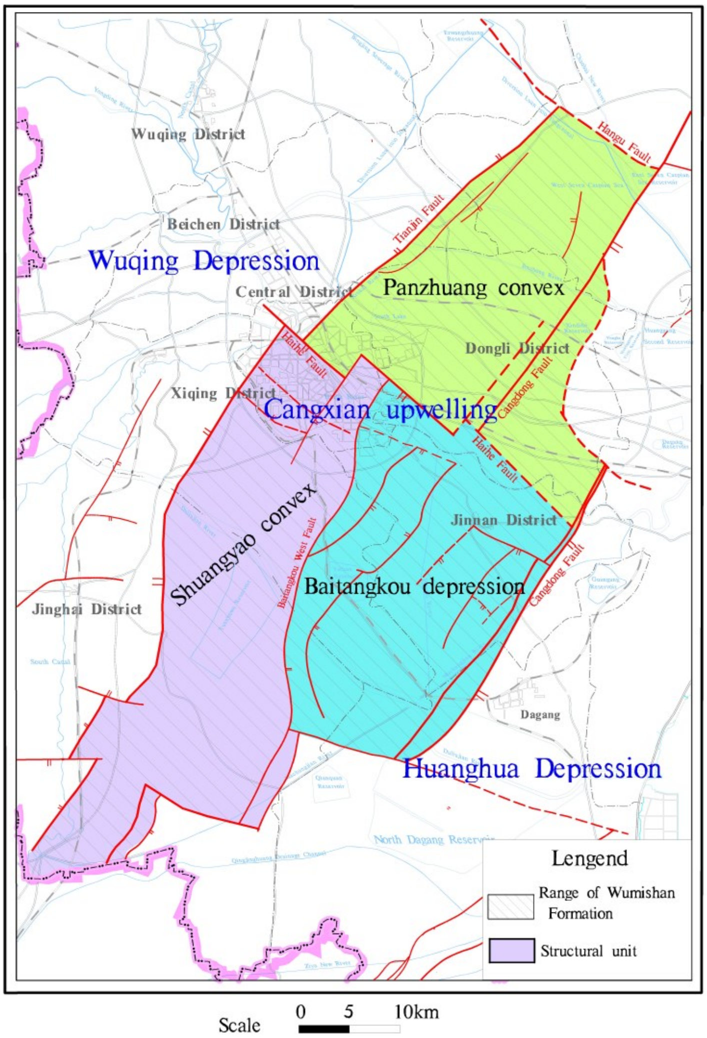

Fig. 1 Tectonic geological map

2. DEVELOPMENT AND UTILIZATION STATUS OF WUMISHAN RESERVOIR

2.1 Geothermal Wells of Wumishan group reservoir

By 2018, there were 281 geothermal Wells in the Wumishan group reservoir in Tianjin, including 165 exploited Wells, 114 reinjection Wells and 2 special monitoring Wells.

2.2 The production and reinjection quantity in Wumishan group reservoir

In 2018, the Wumishan group formation is the reservoir with the largest annual exploitation intensity of geothermal resources in Tianjin, accounting for more than half of the total annual exploitation of geothermal resources in the year. The irrigation quantity and the irrigation rate of Wumishan group increased year by year. In 2018, there were 110 reinjection and reinjection systems, including 106 reinjection and reinjection systems in the same layer and 4 reinjection and reinjection systems in different layers. The total amount of geothermal exploitation in this reservoir is $2633.15\times10^4 m^3$, and the total amount of reinjection is $1637.04\times10^4 m^3$, with the reinjection rate of 62.17%.

2.3 The utilization of Wumishan group reservoir

The geothermal fluid ofWumishan group reservoir in Tianjin is mainly used for heating and domestic water, while the other part is used for hot spring bathing, breeding, mineral water and other purposes. According to the statistical results of the development and utilization of geothermal resources in 2018, the proportion of heating and domestic water in the total amount of annual exploitation reached 78.2% and 21.3% respectively, and the proportion of agricultural and industrial utilization, bathing and other special uses was 0.5%.

3. THE DYNAMIC CHARACTERICS OF WUMISHAN GROUP RESERVOIR

In the natural state, the supply, runoff and discharge of geothermal fluid basically maintain a dynamic balance, and the hydrodynamic field maintains a relatively stable state. The exploitation and utilization of geothermal fluid changes its original equilibrium state, and the most direct reflection is the change of reservoir pressure (water level). Through monitoring the geothermal well water level in the Wumishan group reservoir, the monitoring data are collated and analyzed to find the characteristics and variation rules of reservoir dynamic field, providing scientific and reasonable basis for the development and utilization planning and decision-making of geothermal resources.

3.1 The collation method of dynamic monitoring data

In the process of water level monitoring data processing, it is necessary to conduct uniform temperature correction for the water level values measured at different temperatures in order to eliminate the effect of wellbore effect. Due to the conduction and diffusion characteristics of heat, it can be approximately considered that the temperature of the geothermal fluid in the geothermal well has a linear relationship with the depth, so the water level depth of the corrected water level can be calculated by equation -1.

$$h_2 = H - \frac{\rho_1}{\rho_2}\left[H - \left(h_1 - h_0\right)\right] \qquad \textbf{(equation-1)}$$

Type:

h_2 -- buried depth of water level after correction (m); H -- buried depth at the middle point of water intake section (m);
ρ1 -- average density of water column before correction (kg/m^3); h_1 -- depth of observed water level (m);
ρ2 -- average density of water column after correction (kg/m^3); h_0 -- base point height (m).

For the purpose of unified comparison, the observed water level was converted according to the liquid surface temperature of 20℃, which was used to characterize the buried depth of the water level and the pressure field of reservoir in geothermal Wells. Unless otherwise specified, the buried depth of static water level used in this paper is converted to the buried depth of water level at 20℃ liquid surface temperature.

3.2 Plane characteristics of Wumishan group reservoir dynamic field

In 2018, the buried depth of reservoir water level in the Wumishan group was 75.28- 173.88m in the south of Hangu fault, which was further increased compared with the water level of 73.28- 169.62 m in 2017. Except for some areas in the southwest of Jinghai, the north of Dongli and Xiqing, the water level in other areas is generally more than 140m. In 158 geothermal Wells with water level monitoring data, The water level of 38% geothermal wells was buried more than 150m deep. The buried depth of water level along the northern section of Cangdong fault and the west side of Baitangkou west fault is relatively shallow, ranging from 134 ~ 148m. Several water level funnels were formed in the central city, Zhangguizhuang in the Dongli, Xianshuigu and Gegu in the Jinnan area and Wangwenzhuang in the Xiqing, etc. (Fig. 2), and the water level in the center of the funnels was generally more than 160m deep. The range of buried depth contour traps at the water level of 156m expands rapidly (Table-1).

3.3 Plane characteristics of Wumishan group reservoir water level drop

In 2018, the annual decrease of water level in the Wumishan group reservoir is 1.98 - 7.34m, and the annual decrease of most geothermal Wells is 3 - 5m, which is slightly smaller than that of last year. Geothermal Wells are concentrated in the central area, Dongli, Jinnan, Xiqing and Jinghai district. The annual decline is relatively large, generally more than 4m, the annual decline of water level in the high value area is more than 6m, and the annual decline of some areas is more than 7m (Table -2). Most of

Wumishan group reservoir areas have an annual decline of 3- 4m, which is less than 3m in Nankai district, local areas of Xiqing, north of Jinzhonghe and south of Daqiuzhuang in Jinghai (Fig. 3).

In total, the water level of Wumishan group reservoir continues to decline, and the annual decline of central city area, Dongli, Jinnan and other central mining areas has been reduced compared with that of 2017, while the annual decline of the rest areas is basically the same year-on-year. The annual decline of most geothermal Wells is concentrated in 3 - 5m, and the water level is generally buried deeper, forming multiple funnels.

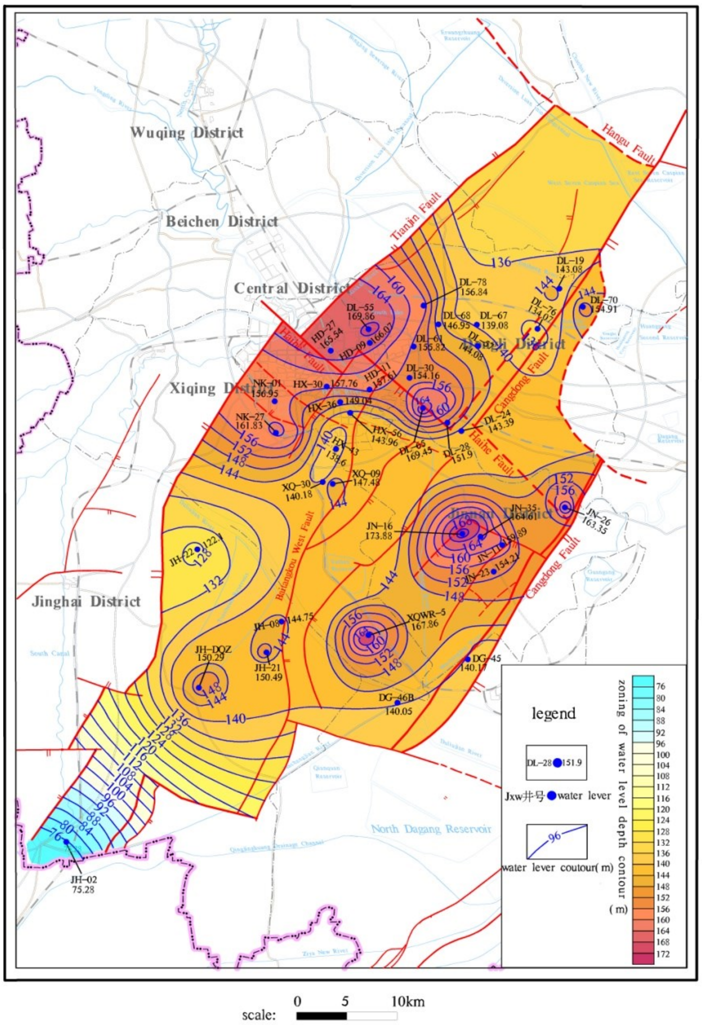

Fig. 2 The buried depth contour map of water level at 20℃ for the Wumishan group reservoir in 2018.

Table-1 The statistical table of regional distribution of more than 156m water level and area in 2018

Funnel area	Water level >156m regional area （km²）		The water level of Funnel center (m)	Distribution range
	2017 year	2018 year		
the central city-Dongli	115.95	173.80↑	169.86	Hedong, Nankai, Hebei, Dongli and Xiqing, etc..
Xianshuigu in the Jinnan	19.30	42.12↑	173.88	Xianshuigu and Beizhakou town in the Jinnan
Zhangguizhuang in the Dongli	---	14.63↑	169.45	Zhangguizhuang town and Civil aviation university, etc. in the Dongli
Wangwenzhuang in the Xiqing	---	10.39↑	167.86	Wangwenzhuang in the Xiqing
Gegu in the Jinnan	2.22	3.69↑	163.35	North of Gegu town in the Jinnan

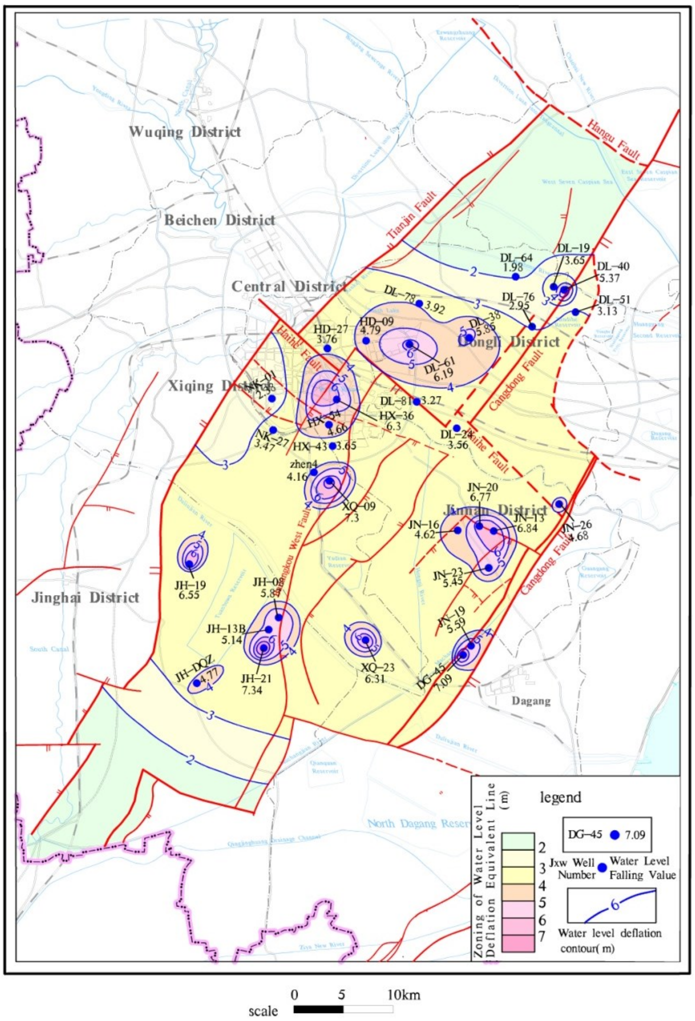

Fig.3 Contour map of Wumishan group reservoir water level drop in 2018

Table-2 The distribution area of 6m drop and high value center

Number	Area	Scope（km²）	the geothermal well of the most drop	The value of the most drop (m)
1	Xianshuigu in the Jinnan	6.39	JN-13	6.84
2	The center city	5.45	HX-36	6.3
3	Dasi in the Xiqing	4.02	XQ-09	7.3
4	Jinghai demonstration town	3.22	JH-21	7.34
5	Wangwenzhuang in the Xiqing	1.63	XQ-23	6.31
6	Dawangzhuang in the Dongli	1.35	DL-61	6.19
7	Daan village in the Dagang	1.16	DG-45	7.09

4. VARIATION RULES OF WUMISHAN GROUP RESERVOIR WATER LEVEL AND INFLUENCING FACTORS

4.1 Plane characteristics of water level funnel

The contour map of the static water level of the Wumishan group reservoir in 2018 reflects two levels of water level descending funnel (Fig. 4 and Fig. 5). The first-level water level descent funnel is bounded by the contour of 132m water level and distributed in the east of Daqiuzhuang town in the Jinghai district, and the north to Panzhuang town in the Ninghe, covering an area of 1781km^2. The static water level is generally 132-144m. In level drawdown funnel within five secondary drawdown funnels and their border with 144 m water level contour enclosure, the main distribution range is the central city, Dongli development zone, the Dongli lake, etc. with a total area of 685.48 km^2. The water level in the funnel center of the larger central city and Jinnan is about 170m, while the water level in other secondary funnels center is generally 144.66-154.91m.

Fig. 4 the consumption intensity of Wumishan group corresponds to the water level descending funnel in 2018

4.2 Decreasing rule of Wumishan group reservoir water level

According to the shape characteristic of water level drawdown funnel of Wumishan group reservoir, Ⅰ - Ⅰ 'and Ⅱ - Ⅱ' hydrogeological section are drawn along the Tangguantun – Pangzhuang and the central city - Jinnan (Fig. 5, Fig. 6, section position as shown in Fig. 4).

According the figure, The figure shows that the overall form of water level section is roughly the same from 2007 to recent years, reflects on the secondary water level funnel vertical and horizontal extension, the water level of Wumishan group reservoir shows the declining trend in the whole region. The fluid recharges from the higher water head region to the funnel area, offset the local bigger drawdown caused by concentrated mining. Although there are some differences in the drop of water level at different places and in different years, the average drop rate has little difference over the years, generally ranging from 4 to 6 m/a.

By the change of water level section line nearly three years, the drawdown funnel of center city is obvious lateral extension in addition to further development, central water level deepening, and the funnel extension causes adjacent synchronous water level declines. The water level funnel in Jinnan district starts from nothing and shows a similar pattern of longitudinal and transverse expansion at the same time.

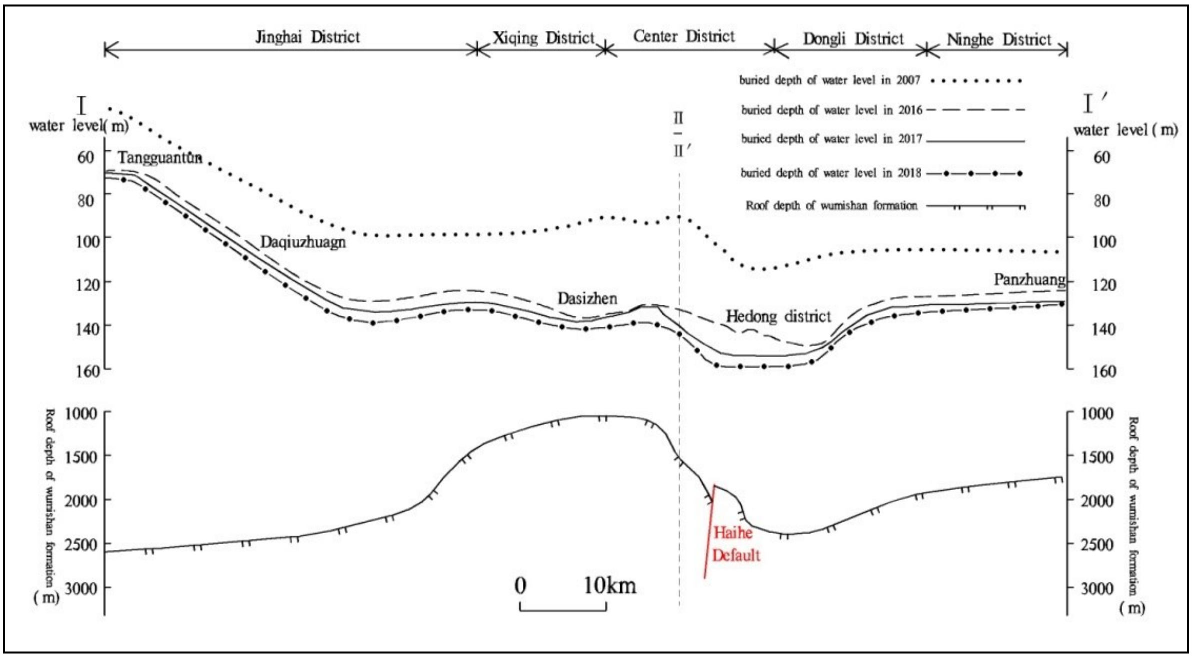

Fig. 5 Ⅰ-Ⅰ′ water level section

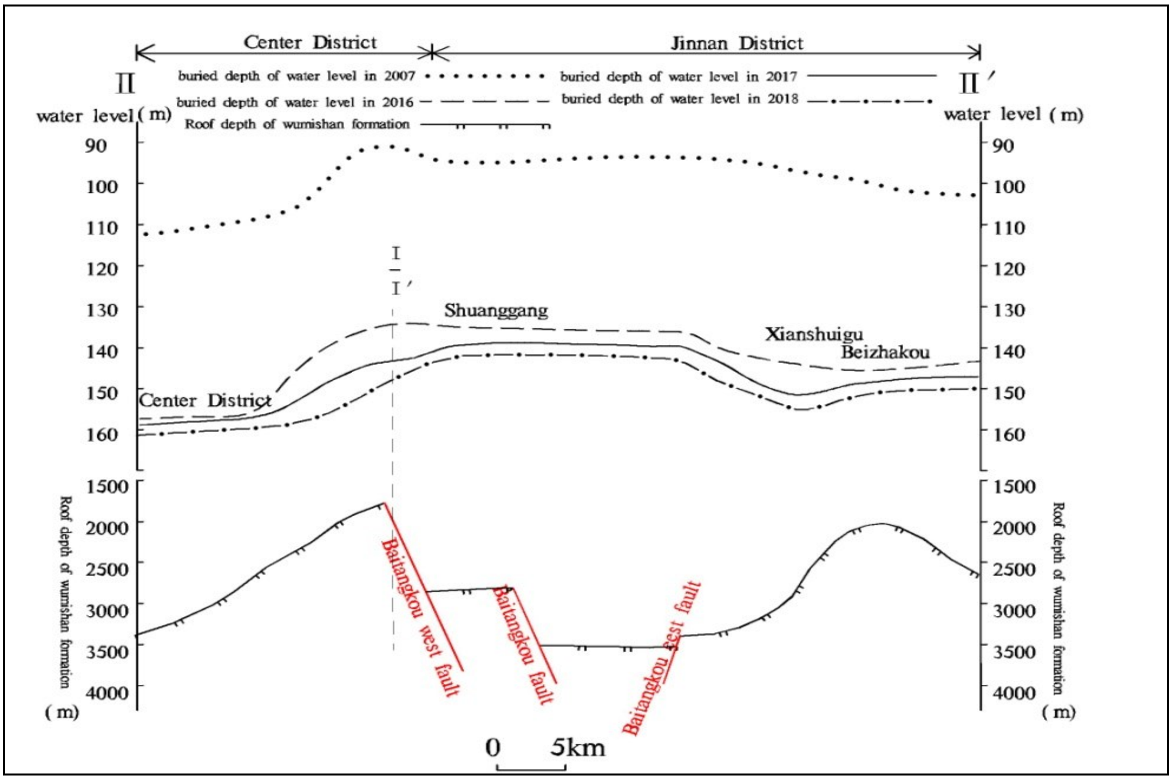

Fig. 6 Ⅱ-Ⅱ′ water level section

4.3 The influence of production and reinjection quantity on the dynamic characteristics of water level

Geothermal exploitation is the reason for the decrease of reservoir pressure. The production and reinjection amount of Wumishan group reservoir is increased year by year, and the reinjection rate is increased continuously, especially in 2018, with a new breakthrough of 62.17% (Fig. 7). With the increase of production quantity year by year, the water level of Wumishan group reservoir decreases year by year (Fig. 8). Due to reinjection quantity increased, the reservoir fluid consumption growth is slower and remained at around 1000 x 10^4 m^3 that maintains the relative stability of the water level drop rate, decline is not because the mining expansion and increased year by year, but with different years increase or decrease the corresponding fluctuations in consumption.

In 2018, due to the significant increase of recharge volume, the consumption of the Wumishan group decreased year on year, and the consumption intensity range above $4×10^4 m^3/a·km^2$ decreased to some extent, and the corresponding 5m drop. The contour trap range also decreased significantly.

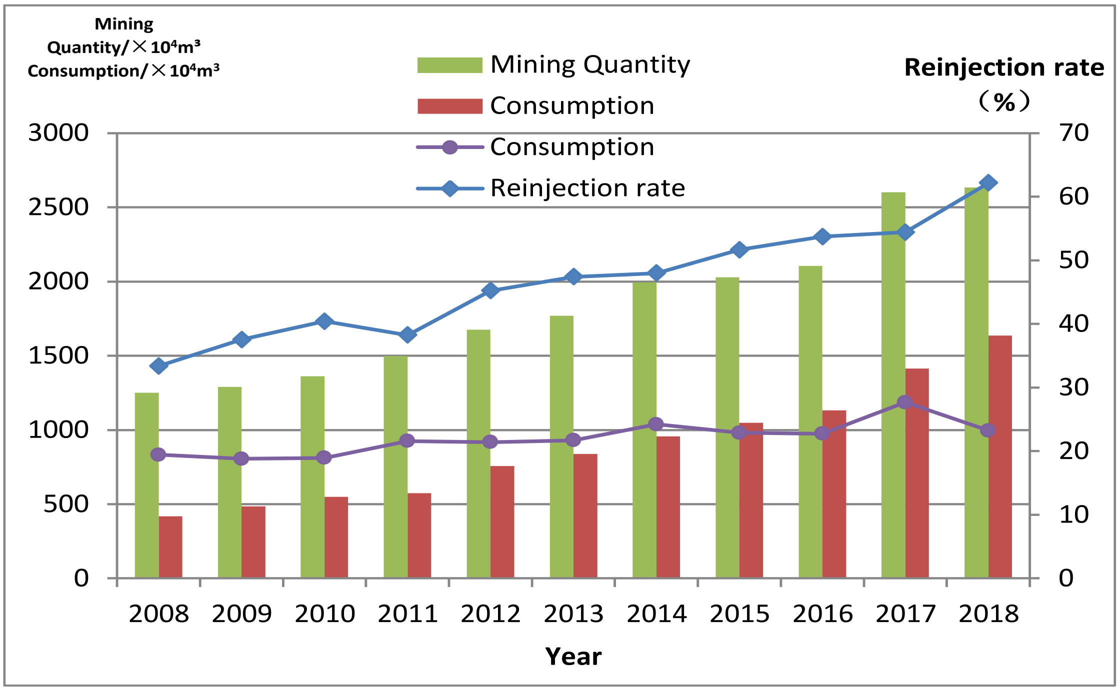

Fig. 7 the growth curve of mining and reinjection quantity and reinjection rate in Wumishan group reservoir

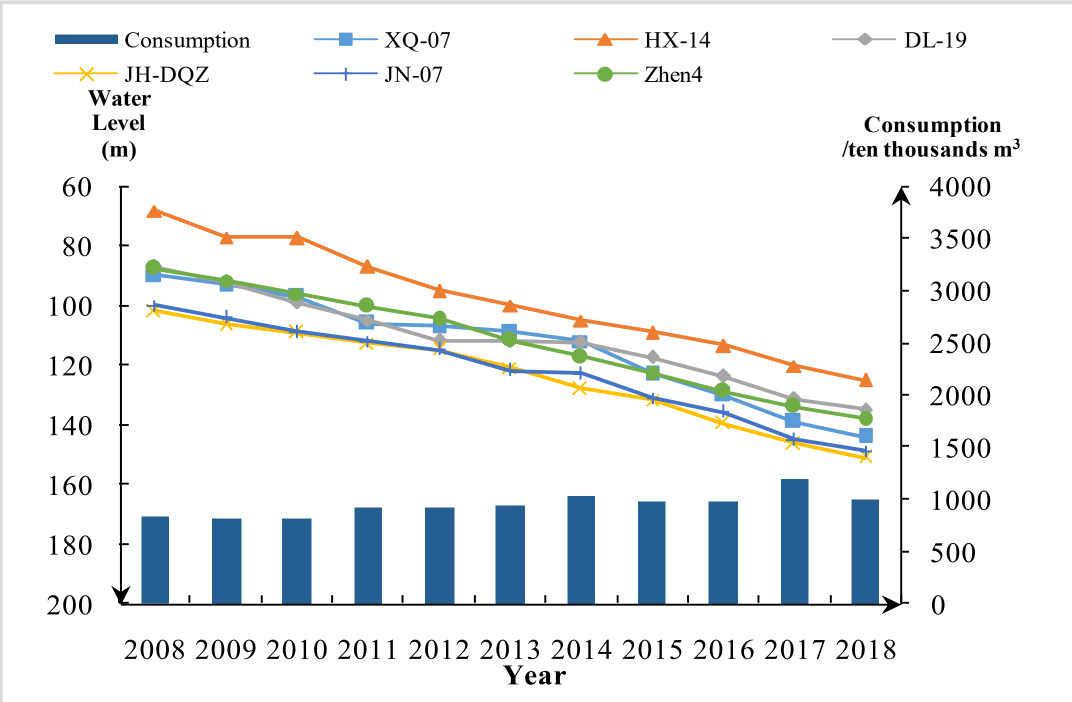

Fig.8 the curve of geothermal fluid consumption and geothermal well water level in Wumishan group reservoir

4.4 The influence of structural conditions on reservoir water level

The water level is restricted by the formation buried depth, fault conductivity and fracture development, etc. In Cangxian uplift area, the water level is more deeply buried in areas with large formation depth in the descending funnel caused by concentrated mining, such as Hedong, Nankai and Jinnan Xianshuigu. the roof burial depth of Wumishan formation is more than 3000m, corresponding to the center of the descending funnel (Fig. 9).

In the uplift area, the west side of Cangdong fault North and Baitangkouxi fault play an obvious role in conducting water and conducting heat, while Tianjin fault has the effect of blocking water. Fracture makes near reservoir water level dynamic characteristics to difference, generally speaking, the water level near conducting water fault is shallow, buried depth contour approximate parallel and fracture direction, away from conducting water fault and near the block water fault, the buried depth of water level is deep, contour approximately perpendicular to the strike of fault(Fig.1). Different development conditions of reservoir fractures will also lead to different dynamic characteristics of water level. For example, in the Xianshuigu and Beizhakou town, Jinnan district, the development of reservoir is unstable, the completing well condition is poor and the buried depth of dynamic water level is deep, the range of annual decline caused by the same mining intensity is larger.

Fig. 9 Corresponding relations among the roof buried depth of Wumishan group reservoir, fracture and the water level falling funnel

5. CONCLUSION

In 2018, the static water level of the Wumishan group reservoir is 75.28 - 173.88m, forming several descending funnels, and the water level at the center of the funnel is generally more than 160m. In 2018, the water level drop is 1.98 - 7.34m/a, generally 3-5m/a. On the whole, the decline of Wumishan group reservoir water level has decreased, but the funnel area still increased in 2018.

Although the reinjection quantity increased year by year, as the Wumishan group of reservoir exploitation for many years, the water level drop of different locations and different years exists certain differences, but the average decline rate difference is not big, generally for 4 - 6 m/a for many years. the scope of the declining funnel increases year by year, the water level of funnel center is deepening year by year. The largest water level of the funnel center is more than 170 m in 2018.

The water level in the wumishan group reservoir is greatly related to the structural position and the depth of the strata. Under the same mining conditions, the buried depth of water level is relatively shallow near the fracture of water conduction and heat conduction, which is roughly parallel to the distribution of the fault. Near the fracture of water resistance, the buried depth of water level is relatively deep, which is roughly perpendicular to the distribution of the fault, which provids a basis for the rational layout of geothermal Wells.

Through the analysis of mining quantity, reinjection quantity and water level dynamic characteristics, it is found that the reduction of net mining quantity plays a very important role in slowing down the decline rate of reservoir water level. Therefore, in order to slow down the decline of water level, the most effective method is to increase the reinjection quantity and reduce the net exploitation amount of Wumishan group reservoir.

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REFERENCES

Peng Zhanxiang. Numerical simulation of geothermal recharge and evaluation of geothermal resources in Wumazhan Formation, Dongli Lake area, Tianjin [D]. China University of Geosciences (Beijing). 2016.

Shen Jian. Research on surface water heat storage and recharge technology of Dongli Lake in Tianjin [D]. China University of Geosciences (Beijing). 2015.

Wang Guiling, Liu Zhiming, Liu Qingxuan et al. Numerical Simulation of Geothermal Abandoned Water Recharge in Xi'an Geothermal Field[J]. Journal of Earth, 2002, 23(2): 183-188.

Zhou xun, Chen mingyou, li cijun. Three-dimensional numerical simulation of deep underground hot water migration [M]. Geological press. 2001.

Shen jian, wang liancheng, zhao yanting. An analysis of the technical renovation methods of the old geothermal recharge system in the central urban area of tianjin [J]. Geological survey and research. 2016, 39(2): 153-156.

Zhao J., Zhou X., Yuan Y., et al., Changes in fluid flux and hydraulic head in a geothermal confined aquifer[J]. Environmental Earth Sciences, 2016, 75(5): 1-12.

Zhao J., Zhou X., Chen R., et al. Influence of variation in temperature on groundwater flow nets in a geothermal system[J]. Environmental Earth Sciences, 2015, 73(3): 1045-1056.

Zhou X., Chen M., Zhao W., et al. Modeling of a Deep-Seated Geothermal System Near Tianjin, China[J]. Ground Water, 2001, 39(3): 443.

Zong Zhenhai, Cai Yun, Gao Xinzhi, Yan Jiaxian, et al.. Dynamic monitoring report on the exploitation and utilization of geothermal resources in tianjin in 2018. Tianjin Geothermal Exploration and Development Designing Institute.