Analysis of Groundwater Flow Velocity and Direction along
the Zihe River in the Dawu water Source

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Abstract: In the observation wells installed along the Zihe River in the Dawu water source, the AquaVISION Colloidal Borescope produced by Geotech Company of the United States was used to measure the groundwater flow velocity along the Zihe River. We analyzed the measurement results based on the drilling information. The results showed that, (1) The groundwater flow velocity along the Zihe River in the Dawu water source area was between 56.798 and 122.599 m/d, and the average flow velocity was 95.380 m/d. The groundwater flow velocity of observation wells along the Zihe River was generally faster. The flow velocity of the SW447 well in the upstream of the Zihe River was the largest, and the average flow velocity was 122.599 m/d. The overall groundwater flow along the Weihe River flowed from south to north. (2) The control factors of groundwater flow velocity were mainly: large amount of water pumping, local geological structure, related hydrogeological conditions, etc.

1. Introduction
Dawu Water Source is a rare extra-large groundwater source in northern China, and is the most important urban water supply groundwater source in Zibo City[1]. The Zihe River crosses the entire Dawu water source from the southwest to the northeast, and it is of great significance to make a thorough investigation of the groundwater flow velocity and direction along the Zihe River for the protection and development of the water source. Han Qingzhi of China University of Geosciences (Wuhan) used the isotope single well dilution method to test the flow velocity in the Quaternary pore aquifer at the bottom of the Yangtze River in Wuhan[2]; Fan Jinglong, from the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, used the MODEL GFD4 groundwater flow velocity meter to measure the flow velocity of groundwater in the hinterland of the Taklimakan Desert[3]; Ma Anli of Anhui Hydrological Exploration Team used electric instrument to detect the flow velocity of groundwater in a mine field in Jining, Shandong Province[4]; Du Guoping, Zheng Xilian and others combined high-tech aviation orientation technology with isotope dilution logging technology to develop an intelligent groundwater dynamic parameter measuring instrument[5]. Some foreign scholars have also explored the measurement of groundwater flow velocity. M. O. Ofomola et al. used dipole-dipole resistivity techniques and two-dimensional resistivity imaging techniques for radial resistivity detection to measure the flow velocity and direction of parts of the Nigerian delta caused by groundwater contamination caused by dumping[6]. Maldaer et al. measured the flow velocity of karst fissure water by hydraulic dilution method and tracer dilution method[7]. The American Chamber of Commerce in the Desert Research Institute in Boulder, Nevada, used a colloidal hole detector to measure the laboratory laminar
velocity at 0.10 cm/s and the tracer test at a speed of 0.11 cm/s[8]. The results of this paper use the AquaVISION Colloidal Borescope, due to the limited observation wells set up in this work, it does not fully represent the groundwater flow along the Zihe River in the entire Dawu water source area. In order to accurately determine the flow velocity and direction along the Zihe River, it is necessary to further increase the density of the observation well.

2. The generality of the study region
The Zihe River has two sources, the east side originates from the foot of the mountain in the north of Lushan, and the west side originates from the foot of the mountain side of Yuwangshan. In the past, there were many tributaries in the upper reaches of the Zihe River, and the source was short and steep. Therefore, there were soaring and falling, the peak height was small, and the sand and rivers were urgent. Since the completion of the water storage in the upstream Taihe Reservoir and Renhe Reservoir, the amount of water coming from the downstream river has decreased sharply. In most years, the water flow has been cut off. The riverbed slope is 3.7 ‰. The meander is developed, and the river curvature is 1.18. The Weihe River mainly flows through the limestone area where fractured karst is developed. The riverbed is composed of loose deposits such as gravel and gravel. The water permeability is extremely strong and the vertical leakage is serious. It is said that the “Zihe 18 leaks”.

The Zihe fault zone consists of 3-5 faults roughly parallel to the Zihe River, all of which are tensile faults. The two main faults on the west bank of the Zihe River tend to the southeast, and one main fault on the east bank tends to be the northwest, forming the Zihe graben. The fault zone is stepped down, with a maximum drop of 200-400m. The lithology of the rock formation in the fracture zone is dominated by limestone, dolomitic limestone and argillaceous limestone. The rock formation is steep and strong, and it is the largest water control structure in the Dawu hydrogeological unit.

The Zihe River Valley develops on the northeast to the Zihe River fault, forming an open and asymmetrical trapezoidal fault valley. The river valley is developed with river heart beach and I and II terraces, and local three-level terraces. The valley is 1~3km wide, and the floodplain is 1~2m higher than the riverbed. It consists of sand (gravel) stone. The first-order terrace is 5~10m higher than the floodplain. The second-order terrace is 10~15m higher than the first terrace. It consists of clay sand, gravel layer, etc. The third-order terrace is a bedrock terrace, and the basement is Ordovician limestone. The karst development of the bedrock in the modern riverbed valley is serious and the river water is seriously lost.

3. Method and result
3.1. Observation well point arrangement
The observation well points are shown in Figure 1. The observation wells are arranged along the Zihe River. The observation wells from north to south are: SW595, SW632, SW401, SW407, SW429, SW447. We used the AquaVISION Colloidal Borescope produced by Geotech Company of the United States was used to measure the groundwater flow velocity along the Zihe River.
3.2. Observation result
The observation time is from March 19 to April 13, 2018. We measured the different depths of the six monitoring wells. The measurement results are shown in Table 1, Table 2.

| Well number | Depth (m) | Measuring point elevation (m) | Direction (°) | Velocity (m/d) |
|-------------|-----------|-------------------------------|---------------|---------------|
| sw632-1-3   | 239       | -175.37                       | 322.71        | 129.303       |
| sw632-2-2   | 157       | -93.37                        | 309.18        | 89.165        |
| sw595-1-1   | 53        | 25.45                         | 296.29        | 119.762       |
| sw401-1-2   | 236       | -145.21                       | 253.48        | 69.757        |
| sw401-2-1   | 134       | -43.21                        | 194.32        | 182.261       |
| sw401-2-2   | 150       | -59.21                        | 196.87        | 62.262        |
| sw407-1-7   | 206       | -110.69                       | 89.91         | 55.805        |
| sw407-2-1   | 160       | -64.69                        | 112.06        | 62.448        |
| sw429-1-1   | 255       | -95.59                        | 89.26         | 63.517        |
| sw429-3-1   | 179       | -19.59                        | 7.90          | 67.082        |
| sw429-2-1   | 231       | -71.59                        | 100.06        | 55.588        |
| sw429-4-1   | 158       | 1.41                          | 140.41        | 41.006        |
| sw447-2-1   | 182       | -7.37                         | 302.4         | 106.382       |
| sw447-3-3   | 130       | 45.63                         | 268.11        | 103.252       |
| sw447-1-6   | 223       | -47.37                        | 74.65         | 158.164       |
Table 2 Monitoring well flow velocity and direction measurement results

| Well number | Depth(m) | Measuring point elevation(m) | Direction(°) | Velocity (m/d) |
|-------------|----------|------------------------------|--------------|---------------|
| SW632-1-3  | 239      | -175.37                      | 322.71       | 129.303       |
| SW632-2-2  | 157      | -93.37                       | 309.18       | 89.165        |
| SW595-1-1  | 53       | 25.45                        | 296.29       | 119.762       |
| SW401-1-2  | 236      | -145.21                      | 253.48       | 69.757        |
| SW401-2-1  | 134      | -43.21                       | 194.32       | 182.261       |
| SW401-2-2  | 150      | -59.21                       | 196.87       | 62.262        |
| SW407-1-7  | 206      | -110.69                      | 89.91        | 55.805        |
| SW407-2-1  | 160      | -64.69                       | 112.06       | 62.448        |
| SW429-1-1  | 255      | -95.59                       | 89.26        | 63.517        |
| SW429-3-1  | 179      | -19.59                       | 7.90         | 67.082        |
| SW429-2-1  | 231      | -71.59                       | 100.06       | 55.588        |
| SW429-4-1  | 158      | 1.41                         | 140.41       | 41.006        |
| SW447-2-1  | 182      | -7.37                        | 302.4        | 106.382       |
| SW447-3-3  | 130      | 45.63                        | 268.11       | 103.252       |
| SW447-1-6  | 223      | -47.37                       | 74.65        | 158.164       |

4. Result analysis

4.1. Flow velocity and direction analysis of well point in the lower reaches of Zihe River

SW595 well monitored one water flow zone. Groundwater flow direction at 53m is 296.29° (West North 26.29°), velocity is 119.762m/d. SW595 and SW632 are located on the east and west sides of the Zihe River. The monitoring well drilling information is shown in Table 3. Both wells are located on the Zihe fault zone. The flow direction of the two wells is northwest. It is indicated that several main faults in the Zihe fault zone are located in limestone and have no water-resistance. The Zihe fault zone itself becomes a place for collecting groundwater and storing groundwater, and it also serves as a good channel for karst groundwater to run northward.

Table 3 Monitoring well drilling information

| Well number | Drilling depth (m) | Depth section (m) | Geological age | Strata Information |
|-------------|--------------------|-------------------|----------------|--------------------|
| SW429       | 386                | 149-175.2         | O2w            | steel grey, leopard skin limestone, seriously broken |
| SW429       | 386                | 175.2-181.6       | O2w            | steel grey, leopard skin limestone, solution pores developed, no adjunct |
| SW429       | 386                | 229.5-240.4       | O2b            | steel grey, massive structure, seriously broken, main aquifer of the hole |
| SW429       | 386                | 248.8-259         | O2b            | steel grey, massive structure, seriously broken, main aquifer of the hole |
| SW632       | 365                | 154.7-171.7       | O2b            | argillaceous limestone, horizontal bedding development, Part of the core is flaky, high carbon content, local fissure development |
| SW632       | 365                | 236.3-242.2       | O2b            | steel grey cloud limestone, local fissure development, Rock mass is broken |
| SW401       | 270.02             | 66-77.4           | O2w            | The core surface is severely eroded by water and has honeycomb dissolution pores. |
| SW401       | 270.02             | 105-116           | O2w            | grayish white, thick layer, 20cm core is water-eroded, with honeycomb dissolution |
There are a series of factories around the area where SW401 is located. Linzi Rubber Factory uses a large amount of water, and the plant uses a large number of pumps to pump water all year round. According to relevant data, from January to June 2018, the amount of karst groundwater exploitation in the Linzi Rubber Plant was 10400m³/d. From July to August, the karst groundwater exploitation of the plant was 11400m³/d. From September to October, the plant's groundwater extraction volume was 16900m³/d. According to the drilling data, the 134-meter section of the well is the Ordovician O₂w. The core is broken and there is water dissolution. 20cm core was found to be water-eroded in the 105-116m depth section, and there were honeycomb dissolution pores. In the depth section of 66-77.4 meters, the surface of the core was found to be severely eroded by water, and there were honeycomb dissolution holes. At a depth of 134m in the SW401 well, the karst groundwater flow velocity in this area is as high as 182.261m/d, which is 2.9 times and 2.6 times the flow velocity at 150 and 236m respectively. The groundwater flow at 134m from the well was affected by the large amount of pumping from nearby plants, causing the groundwater flow velocity at this location to be too fast. Pumping water for a long time caused water erosion in the underground rock, accompanied by honeycomb dissolution holes.

SW407 monitored two water flow zones. The flow direction at 206m was 89.91° (East North 0.09°) and the flow velocity was 55.805m/d. The flow direction at 160m was 112.06° (East South 22.06°) and the flow velocity was 62.448m/d. The average flow velocity of this well was 59.127m/d.

4.3. Flow velocity and direction analysis of well point in the upper reaches of Zihe River

The SW447 well monitored three water flow zones, 130m, 182m and 223m respectively. The flow velocity at the three measuring points of the well was 103.252 m/d, 106.382 m/d and 158.164 m/d, respectively. The flow velocity at the three measuring points gradually increased from shallow to deep, indicating that the deep karst of the SW447 well is more developed. The flow direction at 223m was 74.65° (East North 15.35°). The flow directions at 130m and 182m were 268.11° (West South 1.89°) and 302.4° (West North 32.4°). The flow velocity was much different between the deep and shallow layers. The well is located in the Weihe fault zone, and the multi-stage intrusion of the diorite along the Zihe fault zone made the individual faults of the Zihe fault zone have water-resistance, which made the groundwater flow velocity vary greatly at different depths.

A total of four water flow zones were monitored in SW429, which were 158m, 179m, 231m and 255m. The groundwater flow direction at 158m was 140.41°, it was 50.41° east to south, and the groundwater flow velocity was 41.006m/d. The groundwater flow direction at 179m was 7.90° (North East 7.90°) and the flow velocity was 67.082m/d. Because the well was located in the Zihe fault zone, the fault zone was stepped down and the rock was severely broken. The groundwater flow direction at 155m and 179m in the well had changed by 132.51°. The flow velocity of 179m was 1.64 times the flow of 158m. The stratigraphic ages of 231 m and 255 m were the Ordovician O₂b, and the hydrogeological conditions were steel grey block structures, which were the main aquifers of the well. The flow direction at 231m was 100.06° (10.06° east to south) and the flow velocity was 55.588m/d. The flow direction of 255m was 89.26° (0.74° east to north) and the flow rate was 63.517m/d. The deep karst of this aquifer was more developed than the shallow karst. The average flow velocity of the four water flow areas of the SW429 well was 56.798m/d.
5. Conclusion

According to the data measured by AquaVISION Colloidal Borescope, combined with the drilling information, after analysis, the conclusion are as follows:

(1) The groundwater flow velocity along the Zihe River in the Dawu water source area is between 56.798 and 122.599 m/d, and the average flow velocity is 95.38 m/d. The groundwater flow velocity of the observation well along the Zihe River is relatively fast. The flow velocity of the SW447 well in the upper reaches of the Zihe River is the largest, and the average flow velocity is 122.599m/d. The overall groundwater flow along the Zihe River flows from south to north.

(2) The Zihe fault zone near the SW632 and SW595 wells in the lower reaches of the Zihe River has become a place for collecting groundwater and storing groundwater, and also a good channel for karst groundwater to run northward. The multi-stage intrusion of the diorite in the Zihe fault zone near the SW447 well in the upper reaches of the Zihe River makes the fault section of the Zihe fault zone here water-resistant, which makes the groundwater flow velocity vary greatly at different depths.

(3) The flow velocity of karst groundwater will be affected by the large amount of pumping from nearby factories. In the state of massive groundwater pumping, the flow velocity of shallow groundwater will be significantly faster, 2-3 times that of deep groundwater. Long-term pumping of groundwater causes water erosion in underground rocks, accompanied by honeycomb dissolution holes. At the same time, a large amount of pumping from the factory will also change the local groundwater flow. Groundwater near the river in the dry season seeps into the river, and the groundwater flows toward the river. Under the control of geological structures such as faults, the groundwater flow direction will also change at different depths.

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