

## A Study of the Groundwater Reservoirs and Regulation in the Alluvial Fan of the Hutuo River

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**Abstract:** Based on analysis of the geology and hydrogeology of the alluvial fan of the Hutuo River, Hebei province of China, this paper studies the groundwater reservoir's regulated space, storage capacity and regulated water in system. On this basis, a groundwater numerical simulation model was established. Using this model and taking into account specific regulating schemes, this paper evaluates the regulation and storage capacity of groundwater reservoirs and the effect of conjunctive operation of surface water and groundwater. Results show that the funnel area of the study area status storage space is  $12.83 \times 10^8 \text{ m}^3$ . Groundwater level after the regulation has clearly rebounded; improving groundwater supply and ensuring stable water supply in Shijiazhuang city of Hebei province, this clearly has important practical significance.

**Keywords:** the alluvial fan of the Hutuo River, the groundwater reservoirs regulation, Numerical simulation model, Regulation and storage capacity

### Introduction

The groundwater reservoir is a water storage entity, which is built underground where its regulating space is the aquifer. That is to say, the water is stored in the soil or in the rock pores, fissures or caverns (Zhu SY et al., 2008). The groundwater reservoir must be located in the natural underground water storage space with certain conditions. The natural storage capacity of the aquifer has been expended through human intervention (Li WL et al., 2006). The north of China is in arid and semi-arid areas, thus groundwater is the main water-supply source. As the population and economy development, water demand increased sharply, which forced large scope and unconventional exploitation of groundwater, seriously damaged the groundwater water environment. Groundwater mining was concentrated in the pediment plain. Due to the serious

overdraft of the groundwater, the groundwater level had dropped significantly. It has formed a large regional decline funnel of groundwater in Beijing, Baoding, Shijiazhuang, Handan, Xingtai, Anyang, Xinxiang and other places. Most of these funnels were water-rich regions and ideal water sources in the past. Under the current mining conditions, groundwater descent funnels can be used as an underground reservoir to improve the environment of groundwater supply, there should be a combined regulation of ground water and surface water with artificial and natural water storage to better utilize the groundwater resources.

The study area is located in the plain of Taihang Piedmont slope areas, and focuses on the alluvial fan of the Hutuo River. Shijiazhuang, capital of Hebei province, is located in the upper-middle alluvial fan, its groundwater resources have developed a large cone of depression of groundwater, due to groundwater overdraft in recent years. Many researchers had conducted studies on storage of groundwater in the region, which provides a wealth of information (Fei HY et al., 2001; Zhang

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GH, Fei YH, 2004; Zhang GH et al., 2005; Zhang Y et al., 2009; Xu GM et al., 2009; Gui QP et al., 2011; Wang JJ et al., 2009). Based on systematic analysis of the precedent achievements and the hydrogeological conditions in the research areas, we will establish the groundwater numerical simulation model and use this model to take into account specific regulating schemes. This paper evaluates the regulation and storage capacity of the groundwater reservoir and the effect of conjunctive operation of surface water and groundwater, which provides the scientific basis for establishing alluvial groundwater reservoirs of the Hutuo River.

### Physical-geographical condition

The study area is located in the plain of the Taihang Piedmont slope areas, dominated by Hutuo River alluvial fan. The ground elevation reaches 110 m and decrease to 60 m from west to east, high in the west and lower in the east. The slope is steep in the western piedmont, and flat in the east. The study area has a warm temperate sub-humid and semiarid continental monsoon climate; the average temperature is about 13 °C. Average annual precipitation is 531.4 mm, with uneven distribution of precipitation during the year, mainly concentrated in July to September, and the majority is torrential rain. The Average evaporation is 1,972 mm. The Hutuo River is the main river in the district.

### Hydrogeological condition

The mainly aquifer is composed of Quaternary loose rock strata. According to the hydrogeological characteristics, the aquifer can be divided into two main groups, shallow and deep aquifers. The shallow aquifer is composed of Holocene ( $Q_4$ ) and late Pleistocene ( $Q_3$ ) strata. The main lithology is sand cobble, sand gravel, coarse sand with sand-clay, and argillaceous sand clay. The sand cobble, sand gravel, and sand are characterized by good sorting and have strong permeability and water yield properties. The aquifer group which belongs to phreatic water has no stable upper confining bed

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and has been exploited widespread. The specific capacity is generally 100-200  $\text{m}^3/\text{h}\cdot\text{m}$  in the axial region of the alluvial-pluvial fan, and becomes smaller in the wings, generally 30-100  $\text{m}^3/\text{h}\cdot\text{m}$ . The deep aquifer is composed of middle Pleistocene ( $Q_2$ ) and early Pleistocene ( $Q_1$ ) strata. The main lithology is gravel stratum and gravel sand clay. It is characterized by bad sorting. A tendency to weather and erode, and have weak permeability and low water yield properties. The specific capacity is generally more than 50  $\text{m}^3/\text{h}\cdot\text{m}$  in the axial region of the alluvial-pluvial fan, and generally 20-60  $\text{m}^3/\text{h}\cdot\text{m}$  in the wings. There are no continuous aquifuges or aquitards on top of the aquifer group, so there is a close hydraulic connection between the shallow and deep aquifers.

The main groundwater recharge patterns are: precipitation recharge, surface water recharge, lateral recharge from the west mountain, and irrigation return recharge. The main groundwater discharge patterns are artificial exploitation and runoff to the east and south; the variation of underground water-level with precipitation and the exploitation groundwater; precipitation infiltration-mining, which has obvious seasonal variation.

### Storage conditions of groundwater reservoirs in alluvial-pluvial fan of the Hutuo River

The capacity of groundwater storage depends on storage and throughput of the aquifer system.

### *Calculation of the regulation and storage space of groundwater reservoir*

Groundwater storage is used of the formations which can permeable and storage underground water as water storage space which we can use to regulate the water resources. There are strict limit to the storage space of groundwater reservoirs, which are different to the surface water reservoirs. Bottom boundary groundwater storage space is determined by the groundwater flow field before the regulation, and the groundwater flow field changes with the exploration and recharge of groundwater. The upper boundary of the storage

space is in the manual control, that is to say, its purpose is to prevent negative environmental effect.

The underground storage space makes full use of the large groundwater depression cones formed by mining the groundwater of The Hutuo River alluvial fan. The water level at the end of 2003 acts as the bottom boundary of underground storage space in the cone of depression. Because the groundwater descent funnel is located in Shijiazhuang city, its upper border is bounded at 14m under the surface in the urban areas, taking into account the flow of gradient, the perimeter boundary is set to 11-13 m under the surface. The side borders which is in the upper cone of depression of groundwater (the north-western border). Taking into account the ground elevation in the top of the storage center, the boundary is about 60 m, so we will along the 60 m watermark to outline; the groundwater downstream of the funnel (the southern and eastern border) is bordered by currently extended territories. The plate area of the underground reservoir is 506.00 km<sup>2</sup> calculated by the volumetric method. The regulation and storage capacity of the underground reservoir is  $11.2643 \times 10^8 \text{ m}^3$ .

### Analysis of the underground reservoir

### storage capacity

The storage zone is located in the upper part of the alluvial fan of the Hutuo River, in the axial region of the alluvial-pluvial fan. A typical single-layer sedimentary structure is found in the river course. It is formed of continuous sand and gravel deposits from top to bottom, and is a cohesive soil lens. The upper part of the south side of the river is covered with a layer of silt and silty clay 2-5 m thick. The lower stretch is a continuous sand and gravel layer or discontinuous thin layers of clay. The clayey soil layers gradually thickens (3-6 m) and multilayer (5-8 layers) in the wings of the Fan, forming a multilayer deposition structure with sand, gravel and gravel clip silt. The continuity of cohesive soil is better.

The upper storage layer is sand and coarse sand with gravel primarily, and the thickness is 5-22 m. The bottom is dominated by sand, gravel and gravel, the thickness is 3-8 m, its thickness and range is less than half of the upper storage layer. In general, the rock structure of the Hutuo River underground reservoir is simple, it is composed of a continuous thick layer of sand, gravel and cobble, the layer of which is thickness and wide range, the water transmissibility is good in all directions (show in Fig.1), and the storage layer has a strong storage capacity.

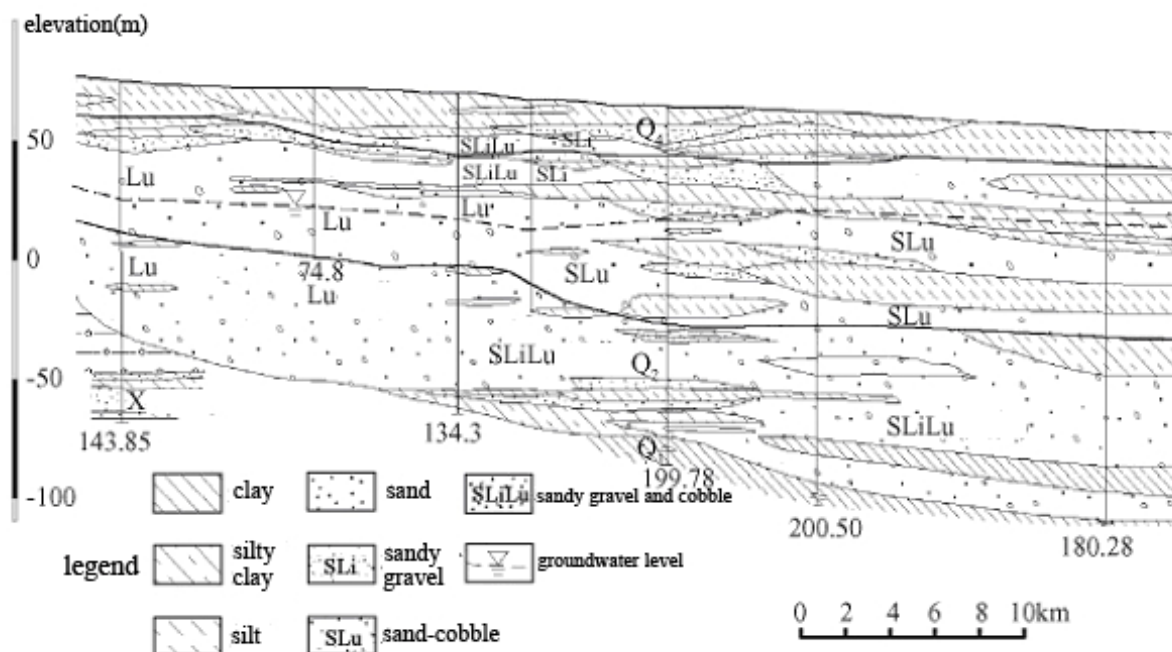


Fig.1 Hydro-geologic profile in the groundwater reservoir area of the hutuo River

## **Regulation and storage of the water source**

Regulation and storage of the water source is the key to the construction of underground reservoirs. The water supply of the Hutuo River underground reservoir is mainly from the Huangbizhuang reservoir, following a South-to-North water transfer.

The Huangbizhuang reservoir located in the upper reaches of the Hutuo River underground reservoir is a large surface reservoir, its discarded water should be the best source of adjustment to groundwater storage. The discarded water and reservoir inflow is positively related, mainly under the influence of atmospheric precipitation. The total regularity coincided with lows and highs hydrological cycle-the discarded water is higher in high water periods and lower in low water periods. For predicting the discarded water of the Huangbizhuang reservoir in different hydrological years, and taking into account the changes in the hydrological environment, we selected the discarded water and precipitation statistics from 1970-2000. The regression equation was established, where the discarded water was the dependent variable (y) and the previous years rainfall and this years rainfall were independent variable (x). We used the regression equation to predict the annual discarded water of Huangbizhuang reservoir as  $7271 \times 10^4 \text{ m}^3/\text{a}$ .

The middle route project of South-to-North water transfer will be established in 2014, after 2014 the annual average water inflow from South-to-North water transfer in HeBei province is  $30.39 \times 10^8 \text{ m}^3$ , for a 25% assurance rate the water inflow is  $32.96 \times 10^8 \text{ m}^3$ , for a 50% assurance rate the water inflow is  $31.88 \times 10^8 \text{ m}^3$ , for a 75% assurance rate the water inflow is  $29.27 \times 10^8 \text{ m}^3$ , and for a 90% assurance rate the water inflow is  $23.22 \times 10^8 \text{ m}^3$ . From the above analysis, the annual variation of water inflow is not very large, but in wet years and flat years they still have some water which can be used as the source of adjustment of groundwater storage. The available water in the flat

year and wet year is respectively  $1.49 \times 10^8 \text{ m}^3$  and  $2.57 \times 10^8 \text{ m}^3$ . If it can be used as water for the adjustment of groundwater storage, the alluvial fan of the Hutuo River should be the best choice. We recommend it as water for adjustment of groundwater storage.

## **Numerical simulation of groundwater reservoirs**

### **Generalization the hydro-geological conditions**

The main aquifer is the quaternary loose rock strata in the study area, the aquifer is generally divided into two main groups, the shallow and deep aquifer groups, and there is no stable aquifuge between them, so this simulation will generalize this into an aquifer layer. The aquifer is on the alluvial fan of the Hutuo River, and because the evident heterogeneity, it is as a non-homogeneous isotropic phreatic aquifer. The hydraulic gradient of groundwater runoff is moderate (except near the cone of depression), in the west is 2.5‰-4.1‰ and in the east is 0.3‰-0.4‰, considering the aquifer thickness is larger, the groundwater flow will look like two-dimensional flow. The western border of the study area is a convergence of mountainous and plain, which will be treated as the weakly-permeable boundary. The seepage of the dam of the Huangbizhuang reservoir has been implemented, but there is still a small amount of water leakage in the recharge zone, so this is also treated as a permeable boundary. The aquifer permeability is weak on the northern border, located on the junction of the Cihe and Hutuo River alluvial fan. There is little change in the equipotential line according to the groundwater flow field over the years, and the border is nearly perpendicular to the equipotential line, so the northern border can be treated as a confining boundary, only the northeast which has water flowing into the area acts as flow boundary. The east border is lined with Jiumen, Datong, Liyang, and Langcheng, the north border is lined with Nanzuo, Duan village, Beijia village,

Hanjiazhuang village, which are regarded as flow boundaries. The total area is 1,573.569 km<sup>2</sup>.

### Mathematic model

According to the above generalization, the mathematical model of groundwater movement is:

$$\begin{cases} \frac{\partial}{\partial x} \left[ K(H-D) \frac{\partial H}{\partial x} \right] + \frac{\partial}{\partial y} \left[ K(H-D) \frac{\partial H}{\partial y} \right] - E(x, y, t) - F(x, y, t) \\ - \sum_{i=1}^m Q_i \delta(x-x_i, y-y_i) + \sum_{j=1}^m Q_{\omega} \delta(x-x_j, y-y_j) = \mu \frac{\partial H}{\partial t}; (x, y) \in \Omega, t > 0 \\ H(x, y, 0) = H_0(x, y); (x, y) \in \Omega \\ K(H-D) \frac{\partial H}{\partial n} = q_e(x, y, t); (x, y) \in \Gamma_2 \end{cases}$$

H- groundwater level [L];

K- hydraulic conductivity [L/T];

D- lower confining bed elevation [L];

E- strength of vertical aquifer recharge [L/T], mainly include precipitation recharge and percolating recharge;

F- strength of aquifer exploitation [L/T], mainly include the agricultural, industrial and domestic water mining in suburbs and the countries;

Q<sub>i</sub>- the groundwater extraction of city water-works and self- wells [L<sup>3</sup>/T];

H<sub>0</sub>- initial level [L];

Ω- computational domain;

μ- specific yield;

q<sub>0</sub>(x,y,t)- recharge of the permeable boundary [L<sup>2</sup>/T].

The observation hole was made as coincident as possible with the node according to the triangle mesh to subdivided seepage field. The regional subdivision of groundwater seepage was made to correspond when subdividing the river. The nodes and triangular units were marked (the number of the nodes and units are 705 and 1,322 respectively).

The finite-difference method was used to make the numerical simulation of study area. The debugging and verification used observed data of the groundwater regime and discharge information of the Hutuo River. Model results show that the generalization of the hydrogeology condition is reasonable, and that the mathematical model is correct.

The groundwater storage space is evaluated in the numerical model for mutual authentication; the funnel area storage space is calculated to be 12.83×10<sup>8</sup> m<sup>3</sup>. This method gives similar results to the volumetric method.

### Groundwater Storage Programme and the Prediction

Based on the regulation and storage of the water source, the groundwater storage options respectively are referenced in Huangbizhuang reservoir discarded water and south-to-north water. The first program only uses the Huangbizhuang discarded water; the second programme uses the Huangbizhuang discarded water and the south-to-north water at the same time.

Using the numerical simulation model of groundwater storage, we predict the groundwater flow field in 2020 (show in Fig.2 and Fig.3). We can conclude from flow field patterns that the groundwater level of the funnel center in the Hutuo River alluvial fan is -14.62 m in the first scheme, and is 26.48 m in the second. That is to say, the center groundwater levels of the Hutuo River alluvial fan have different degrees of rebound after the introduction of the artificial storage water.

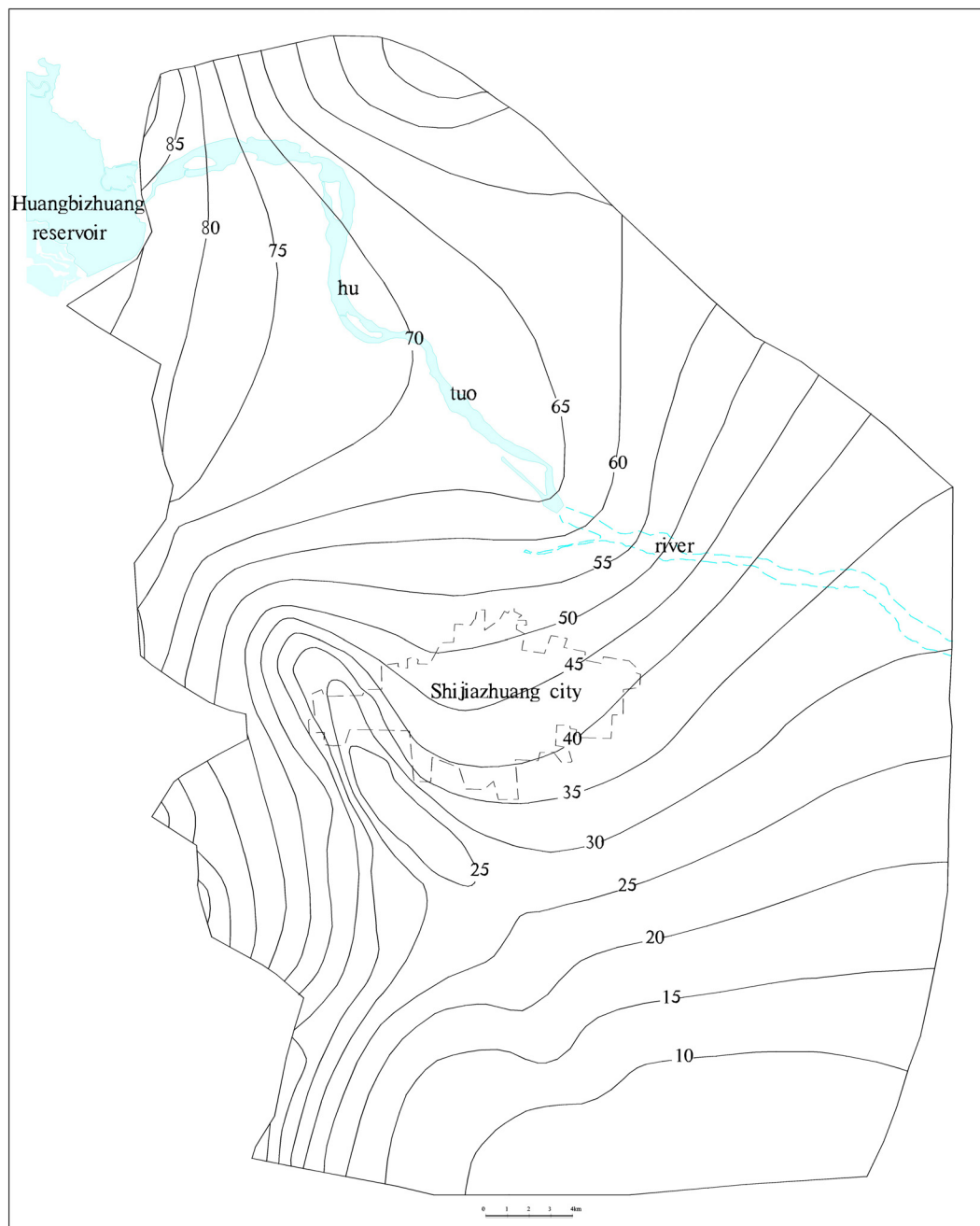


Fig.2 Prediction of groundwater flow field of Storage scheme 1

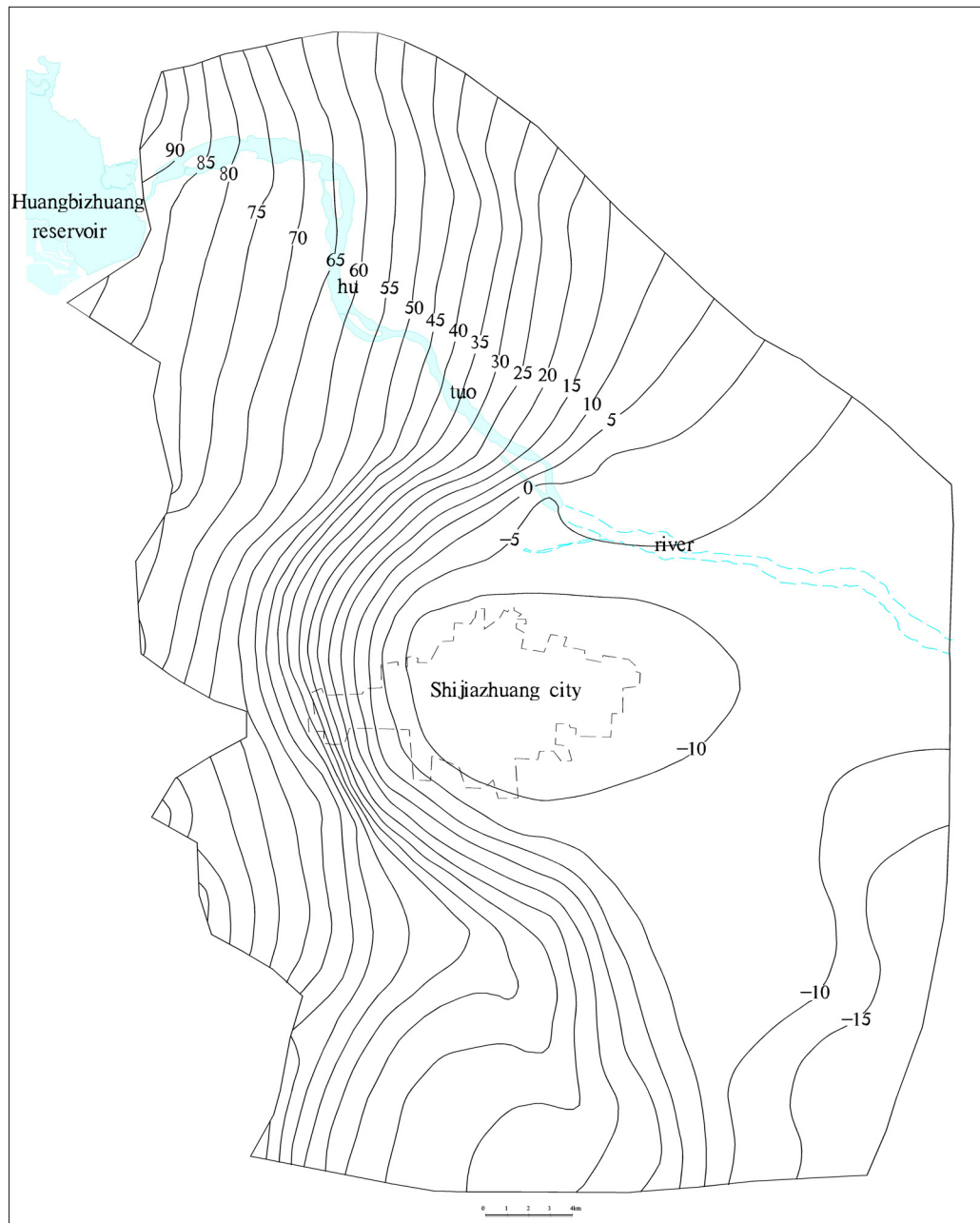


Fig.3 prediction of groundwater flow field of Storage scheme 2

## Conclusion

The storage construction conditions and water storage capacity as well as regulation storage were analyzed based on the analysis and summary of the previous research and the geological and hydro-geological conditions. It was found that the regulation and storage capacity of the underground reservoir is  $12.83 \times 10^8 \text{ m}^3$ , which is calculated by both the balance method and numerical method. By

using the Huangbizhuang discarded water and the south-to-north water, we propose different program for the underground reservoir. The groundwater levels of the Hutuo River alluvial fan have been shown to have different degrees of rebound in 2020.

It is practical to construct a funnel-type underground reservoir in overdraft funnels of plain area pore water, through the research of regulation storage of the Hutuo River alluvial fan. It can not only provide sufficient exploitable water sources,

solve the Supply-Demand Contradiction of water resources, but also mitigate or eliminate a range of environmental issues caused by long-term groundwater from mining, and promote the coordinated development between resources and environment as well as economy and society.

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