APPLICATION OF HYDROGEN OXYGEN ISOTOPES IN KARST HYDROGEOLOGY OF THE JINGPING HYDROPOWER STATION

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1 INTRODUCTION

The Jingping hydropower poject area is located at the Yalongjiang loop in Mianning and Yanyuan Counties, Sichuan Province. To obtain rich and cheap electric power resources, a 18 km long diversion tunnel will be cut to get about 300 m water head for generating electricity by means of natural drop.

With an area of some 400 km^2, the project area is typical high mountain deep valley landform, where the main peak of the Jingping Mt. is over 4000 m a. s. l., with relative height of 2100 m to 3000 m. The outcropped strata mainly are Triassic, of which carbonate rock with sandslate intercalation accounts for more than 70 % and is marbleized to different extent. All these form a NNE synclinore with the Jingping Mt. as its main body, and its axis is in a watershed area. The dip angles are between 65° and 68°. In addition to Jingpingshan and Qingna strike faults, tectonic fissures are well developed.

Distributed in the centre of the area, the marble of the Baishan Formation, Middle Triassic (T_{2b}) represents a main karst aquifer with the thickness between 750 m and 2270 m. To the south and north of the marble there are two large springs, Mofanggou and Laozhuangzi, with an average annual flow rate of 5.566 m^3/s and 2.46 m^3/s, respectively. It is flanked by the intercalated marble(T_{2y}), acting as a moderately and less developed karst aquifer with the thickness of about 1500 m and scattered spring flow from 2 l/s to 100 l/s. The karst water is fed by precipitation and drains to the Yalongjiang River. It is an isolated hydrogeologic unit and hydraulically has no connection with others (Fig. 1).

2 ISOTOPE COMPOSITION IN NATURE WATER AND ITS DISTRIBUTION

The regime observation of precipitation, large karst spring and tunnel water was conducted along with the hydrogeologic investigation in the period from April, 1990 to June, 1992. All smaples were taken from 59 smapled points. Of them, 149 groups were analyzed for D, T and ^{18}O, and 58 groups for D and ^{18}O. The tunnel water smaples were taken from

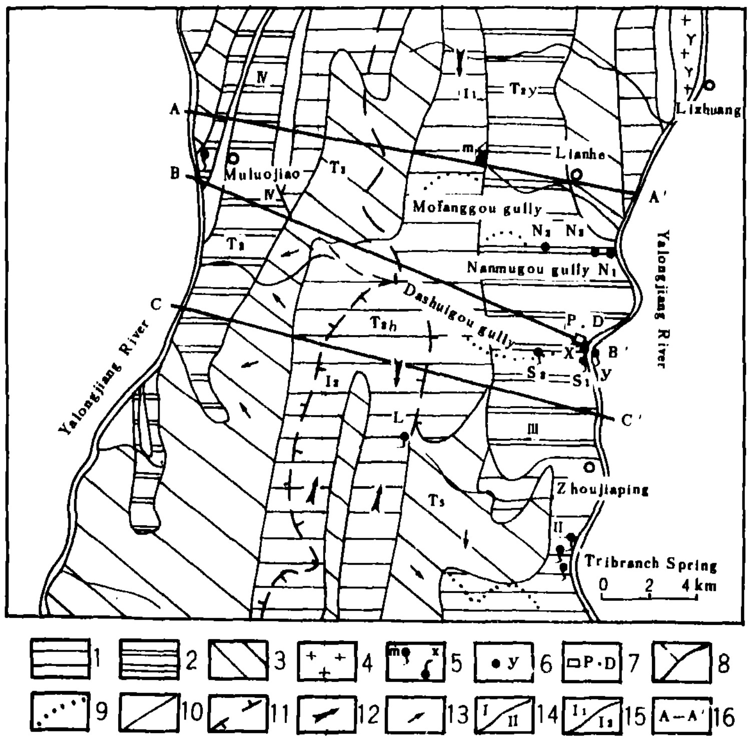

Fig. 1 Karst geological map around the proposed site of the diversion tunnel of the Jinping project area

1. Continuously bedded marble; 2. Interbedding pure and unpure marble, marl and green sandstone; 3. Sandy slate; 4. Granite; 5. Samping point and its number for karst spring; 6. Samping point and its number for Yalongjiang River; 7. Samping point and its number for tunnel water; 8. Perennial or intermittent gully; 9. Dry gully; 10. Geologic boundary; 11. Terrain watershed; 12. Groundwater flow direction; 13. Recharge direction of allogenic water; 14. Code and boundary of hydrogeologic unit; 15. Code and boundary of hydrogeologic subunit; 16. Proposed site of tunnel and its code

from two tunnels 30 m apart.

2.1 The Distribution of Natural Water δ Values in the $\delta D - \delta^{18}O$ Plot

The water points of the Yalongjiang River, Mofanggou Spring, Laozhuangzi Spring are shown in Fig. 2 as serial sample pionts, and others were plotted by mean values. All points are round the standard precipitation line, and most of them on the left of the line. The correlation equation is:

$$\delta D = 7.61^{18}O + 8.21 , \quad r = 0.97$$

The surplus of D (d) is 14.1‰, which implies that all types of water are recharged by precipitation. The surface water and groundwater don't evaporate in a great degree because there exists swift transformation among the groundwater, precipitation and surface water. The δ values of water samples are similar to a great extent to the precipitation δ values. Therefore the line of correlation equation can represent the local rainwater line. The slope of the former is smaller than that of the latter, and $d>10$ ‰, which means that the precipitation cloud cluster comes mainly from the drier western region.

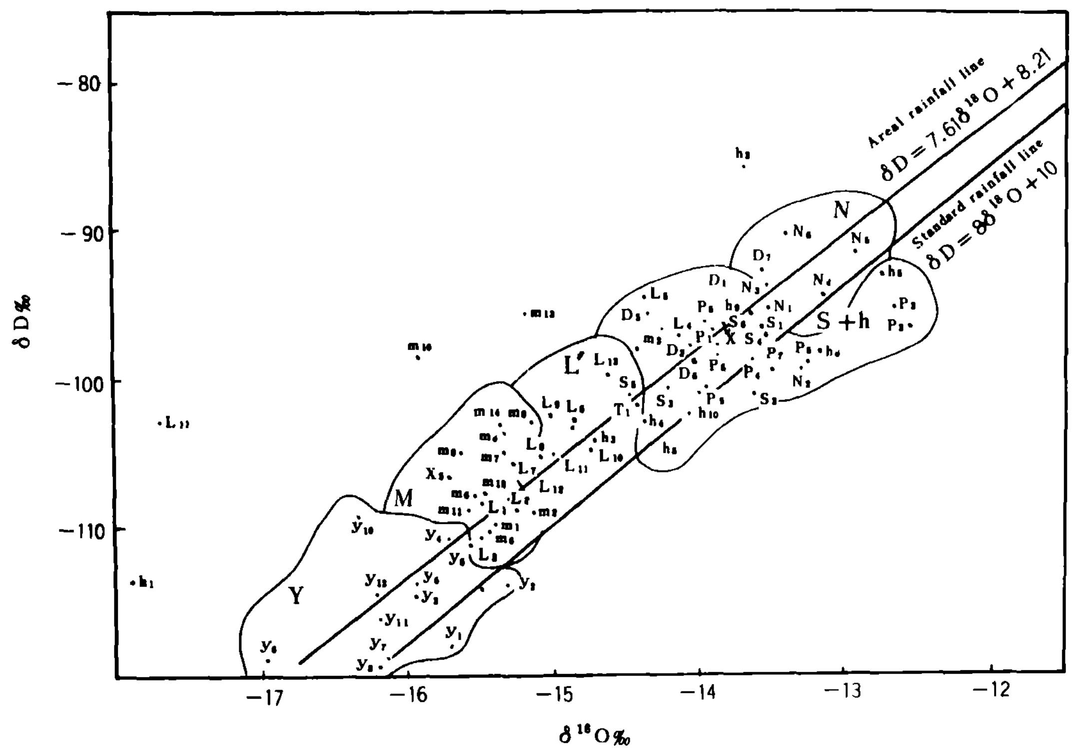

Fig. 2 δ^{18}O versus δD plot

y—Yalongjiang River water; m—Mofanggou Spring; L—Laozhuangzi Spring; T—Tribranch Spring; X—Xiaoshuigou Spring; S—Dashuigou Spring; P— Tunnel No. 1; D—Tunnel No. 2; h—Surface water in unit IV; Y—Range of Yalongjiang River sample distribution; M—Range of Mofanggour Spring sample distribution; L′—Range of Laozhuangzi Spring sample distribution; S+h— Range of sample distribution for Dashuigou of unit I and unit IV; N—Range of sample distribution for Nanmugou of unit I

2.2 Fluctuation of Isotope Composition

The high values of isotopic contents in the Yalongjiang River appear in the period from April to July and the low values from September to November. The average maximum variation of δ^{18}O is 1.5‰ (Fig. 3). While in Mofanggou Spring and Laozhuangzi Spring, the high values appear in the period from July to September and the low values from December to February of next year. The average maximum variation of $\delta^{18}O$ is 1.2 ‰. The fluctuations for both springs synchronize, and the amplitudes are similar. However, each of them possesses its own characteristic values, which indicates that both springs are relatively isolated with the similar water flow features.

In tunnel No. 1 at a distance of 1447 m from its entrance the change of isotope contents with time is similar to that of Laozhuangzi Spring. It is because the features of both medium are similar. But the variation in $\delta^{18}O$ of the former is much smaller, and averages 0.56‰. In tuunel No. 2 there is a large water gushing point at a distance of 2846 m from its entrance. The synchronous observation of the water points at a distance 2846 m in tunnel No. 2 and at a distance 2820 m in tunnel No. 1 showed that both they have similar and stable fluctuation of isotope contents.

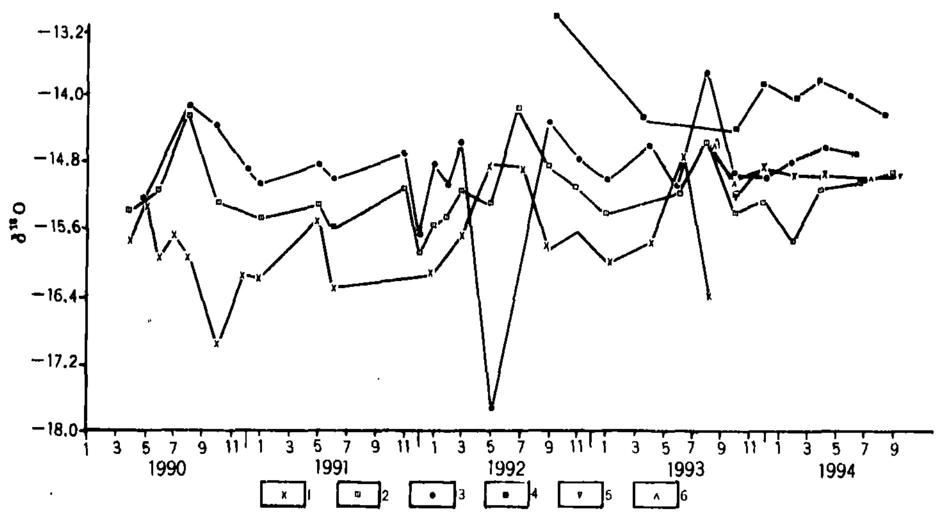

Fig. 3 Plot of $\delta^{18}O$ against time

1. alongjiang River; 2. Mofanggou Spring; 3. Laozhuangzi Spring; 4. 1447 m from the entrance of tunnel No. 1; 5. 2820 m of tunnel No. 2; 6. 2846 m of tunnel No. 2 (point of large water gushing)

3 ELEVATION EFFECT OF $\delta^{18}O$ OF PRECIPITATION

3.1 Calculation of Elevation Effect

Seven samples were taken for calculating elevation effect within an area over 400 km² in the east and west sides of the Jinping Mountain in April, 1990 (Fig. 4).

The correlation equation is:

$$\delta^{18}O = -2.63\times10^{-3}H - 6.15\ , \quad r = 0.98$$

We have $H = -380 \times \delta^{18}O - 2388$

where H is elevation.

The gradient of $\delta^{18}O$ of precipitation is $-0.263‰$ per 100 m, falling in the normal range of global typical gradient. The mean recharge elevation of karst spring in the area can be calculated by use of this elevation equation. The results are given in Tab. 1.

3.2 Determination of the Recharge Area of Aquiferous Units

(1) The Mofanggou Spring and Laozhuangzi Spring are located in the unit I, and have the calculated mean recharge elevation lower than their own actural elevation by 167 m and 217 m, respectively. It may be affected by the snowmelt, because $\delta^{18}O$ of snows ($-6.8‰$) in the recharge area is very high.

The greater evaporation is related to the dry and windy season from October to May of next year.

(2) The locations of Dashuigou, Nanmugou, Xiaoshuigou Springs and tunnel water are in the unit Ⅱ. It can be seen in Tab. 1. Their calculated mean recharge elevation are lower than or approximate to their respective actural ones. It can be considered that the groundwater of both the gullies, where the three springs outcrop, is recharged by the local rainwater of their respective catchment areas.

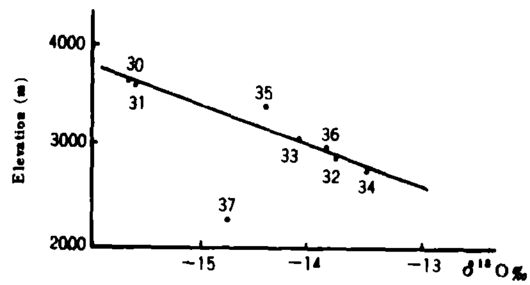

Fig. 4 Relation of $\delta^{18}O$ to the mean elevation of the recharge area

(3) No. 28 and No. 29 springs are outcropped near the boundary of the unit I. The fact and calculation show that both they drain the groundwater of the unit I. The calculated mean elevations of h_4 and other water points located in this unit are below 3000 m, which indicates that they are recharged locally.

4 RECHARGE, RUNOFF AND DISCHARGE OF KARST GROUNDWATER

4.1 Recharge and Discharge of Karst Water

4.1.1 Vertical recharge and mutual recharge between surface water and groundwater

The distribution of groundwater δ values is closely related to the elevations of recharge area. In Fig. 2 the data points for the Yalongjiang River water, Mofanggou Spring, Laozhuangzi Spring, surface water, and groundwater of the units Ⅱ and Ⅳ are grouped in groups and arranged upwards successively along the line, i.e., their recharge areas are from higher elevation to lower successively, which indicates the karst groundwater is phreatic type with the distribution area coincident with the recharge area, and the vertical recharge by precipitation.

Tab. 1 Calculated mean recharge elevation of karst springs

Hydrogeologic unit	Location of water point		Elevation of water point (m)	$\delta^{18}O$ ‰	Calculated mean recharge elevation (m)	Amount of serial samples	Mean recharge elevation (m)
I	Mofanggou Spring		2170	−15.23	3437	27	3604.14
	Laozhuangzi Spring		2100	−14.88	3255	25	3472.13
II	Tribrance Spring	South	1520	−14.46	3107	6	2703.08
		Middle	1450	−14.97	3301	8	2936.12
III	Dashuigou Spring	No. 2 at upper reaches	2300	−13.58	2772	1	
		No. 24 at middle reaches	1920	−13.59	2776	1	3143
		No. 25 at lower reaches	1435	−14.34	3061	2	
	Xiaoshuigou Spring		1345	−13.91	2898	3	
	Nanmugou Spring	No. 26	2265	−13.52	2750	1	2882
		No. 27 at lower reaches	1910	−13.32	2674	1	
IV	Shiguanshangou Spring No. 28		2740	−15.13	3411	1	
	Jiexinggou Spring No. 29		3200	−15.63	3601	1	
	Sipingzigou Spring No. h4		2250	−14.37	3073	1	2997

The data points for the uints III and IV are deviated to the right compared with that of the units I and II, which implies that the surface water and groundwater of the units III and IV possess evaporation effect to a certain extent. The groundwater of the units III and IV is recharged by the surface water of gully as well as precipitation, which makes the $\delta^{18}O$ values higher. In general, the gully drains the surface runoff and karst groundwater, and may feed groundwater on the localities with low gradient of its longitudinal section during flood season. In the units III and IV the surface water and groundwater are recharged by each other.

4.1.2 Hydraulic connection between aquiferous units

In Fig. 2, the data points of Mofanggou Spring are in clustered distribution, so are those of Laozhuangzi Spring, surface water and groundwater of the units III and IV. All these show that each of them is an isolated water system. A perennial watershed exists for the two large springs. The unit I is separated from the unit II by a relatively water-resisting layer. The δ values of water for the outside section of the tunnels (before 2760 m from the entrance of tunnel No. 1 and 1964 m of tunnel No. 2) all fall into the range where those for the unit Ⅱ are. In the inside section of the tunnels to the point of large water gushing (2846 m of tunnel No. 2) within 1000 m distance, until 3948 m of tunnel No. 1 the δ values of tunnel water fall into the range where those for the unit Ⅰ are. The phenomenon above mentioned indicates that a close hydraulic connection exists locally between the units Ⅰ and Ⅱ.

4.2 The Recharge Sources of the Tunnel Water

4.2.1 The recharge sources of the outside section of the tunnels

In Fig. 2, the data points of outside section fall into the range of S+h, which indicates that the main recharge sources of tunnel water are infiltrating precipitation in Dashuigou gully catchment area. Of ten water points in tunnel No. 1; the P_1(273 m), P_2(297 m), P_5(373 m) and P_7(527 m) are deviated more from the rainfall line, of nine water points in tunnel No. 2, only the D_5(700 m) is deviated more from the rainfall line, which implies that surface water has mixed with groundwater.

In the outside section of the tunnel, being 23 TU in average, the values of ^3H are higher than the annual average ones of precipitation measured in a meteorological station (3000 m a. s. l.) in the study area (14 TU in 1992, 15 TU in 1993). The causes may be as follows: (1) the water has got recharge from the unit Ⅰ with higher elevation, and (2) precipitation before 1970 has remained. From the observation for the fluctuation of isotope content at 1447 m, the variation in $\delta^{18}O$ reaches 0.56‰~1.14‰, which implies that the second cause is impossible. It is responsible for that the calculated mean recharge elevations are higher than the actual ones of the water points in this section, and that the tunnel groundwater is recharged by surface water and groundwater from higher elevation area of the unit Ⅰ as well as local precipitation.

4.2.2 The sources of the large water gushing and the water from the inside section of the tunnel

The large water gushing occurred at the point of 2846 m from the entrance of tunnel No. 2, the initial discharge was 5 m^3/s, and the stable discharge was 2.45 m^3/s. Before its occurrence, the δ value for the 2760 m of tunnel No. 1 and the 1964 m of tunnel No. 2 had been in the limits of L and M of the unit Ⅰ (Fig. 2), but the value of ^3H (2 TU) was lower for the 1995 m of tunnel No. 2, which shows that the gushing water was from outside. Since the large water gushing occurred, monitoring has been carried out in situ and at the 2820 m of tunnel No. 1. In Fig. 3, the two curves for the gushing water and the water from the 2820 m of tunnel No. 1 have similar slope and are located within the range of the curves for the two large springs, which means that they are mixed water of the two large springs. As mentioned above, until the 3948 m of tunnel the δ values are within the limits of two large springs, which indicates that the water of the inside section of tunnel is mainly recharged by the two large springs.

4.3 The Characteristics of the Groundwater Movement in the Area

4.3.1 The strong circulation and exchange of groundwater

As Fig. 2 shows, all water points for the Yalongjiang River, the three large springs, and gully water in the both sides of the watershed, fracture springs and tunnel water are in a straight line, which indicates that the surface water flows quickly, and the evaporation is week. In the area, the terrain is precipitous and the longitudinal slope of the gully is steep, so the rainwater flows away quickly. As a result, the groundwater flows fast, and the surface water, groundwater and precipitation transform into each other quickly.

4.3.2 The fast flow and slow flow

There are two types of flow with different speeds in vertical section. The higher values of $\delta^{18}O$ of the two large springs appear in the period from July to September, so do the higher values of precipitation. It shows that in the seasonal variation zone and the saturated zone of the aquifer the groundwater has different flow speeds. In the saturated zone, karst is less developed, the water flows slowly. So the infiltrating water is mixed with the groundwater and the δ values of spring are steady. In the seasonal variation zone, karst is intensely developed, the storage capability is larger, and the water flows quickly.

Percolating underground, flood water in rainy season discharges directly to spring outlet and leaves unmixed with phreatic water in matrix. Therefore water drained in high level period appears to be flood water recharged in rainy season.

5 THE CALCULATION OF THE GROUNDWATER AGE AND SOME PARAMETERS

5.1 The Model for Dating of Groundwater

As described above, in the middle marble zone of the area two subunits of the unit I are the phreatic aquifer recharged directly by precipitation and drained by large springs. Generally, the hydrogeologic conditions may be included in the fully mixing model. Furthermore, the values of ^3H (18 TU) of two large springs are lower than that of the units Ⅲ and Ⅳ (23 TU in average), which means that the water in the unit I has resided in the aquifer longer and the two types of water have mixed to a certain degree. Due to the swift transformation of precipitation, surface water and groundwater, the variation in $\delta^{18}O$ of large springs approximates to that of the Yalongjiang River, it can be considered that the groundwater is not mixed fully and has the characteristic of piston flow. The piston flow model is used to calculate the groundwater age in consideration of the indication of mixing.

5.2 The Calculation of the Tritium(T) Age for Large Springs

5.2.1 The reconstruction of T content of rainwater

The T content in precipitation was steady before 1953 and equaled to 10 TU generally. It is only reconstructed up to 1953. The logT of precipitation is directly proportional to latitude value(logT∝L) in the Northern Hemisphere. Using the data of the Yierkuchic and the Hong Kong Stations over the period 1969~1976, we have the T content of the local precipitation over the same period by interpolation. The linear and logarithm correlation analysis is made of the interpolated T values in Jingping and the measured T values of precipitation in Ottawa and in Luan, Shanxi Province over the same period. Since Jinping is located in the west of the above mentioned stations and at high elevation, the large values are used. The T values from 1953 to 1968 are obtained by extrapolation based on the relation of the T values in Jinping and Ottawa. The T values of 1977~1988 are gotten by extrapolation of the relation of the T values in Jinping and Luan. And the T values of 1989 and 1990 are estimated based on those of karst water and the Yalongjiang River water. As a result, the full series of the T values of Jinping has been reconstructed.

5.2.2 Calculation of the tritium age of large spring water

Substituting the values of tritium reconstruction into the calculation by piston flow model and the full mixing model, the results are plotted as curves. The annual average T in the Mofanggou and the Laozhangzi Springs is 18.20 TU and 18.28 TU, respectively. According to the curve of the piston flow model, the latest ages are 1.8, 3.5, and 4.7 years. Considering the characteristics of the water isotope and water flow, we adopt 3.5 years. The age calculated with the full mixing model is 18.2 years, which does not fit with the characteristics of the water isotope and water flow.

5.3 The Calculation of Other Hydrogeologic Parameters

5.3.1 The calculation of the large spring resources

For the Mofanggou Spring Basin, the equation is

$$V_m = T_m \times Q_m$$

where T_m—the groundwater age of the Mofanggou Spring Basin;

Q_m—the annual average discharge of the Mofanggou Spring;

V_m—the resources of the Mofanggou Spring;

thus $V_m = 3.5 \times (5.566 + q) \times 86400 \times 365 = 658.5 \times 10^6 m^3$,

where q—the other outflow discharge from the spring basin, $q = 0.4\ m^3/s$.

For the Laozhangzi Spring Basin, the discharge is $2.46\ m^3/s$, so the resources are $271.52 \times 10^6\ m^3$.

5.3.2 The average aquifer thickness of the large spring basin

For the Mofanggou Sping Basin:

$$M_m = \frac{V_m}{A_m \mu}$$

where A_m is the area of the intake area of the Mofanggou Spring Basin; μ is the specific yield. thus

$$M_m = 658.5\times10^6/(208.55\times10^6\times0.003) = 1045.24 \text{ m}.$$

For the Laozhuangzi Spring Basin, the area is 85.39 km^2, so we got the thickness of the aquifer M_l = 1044.31 m.

5.3.3 The depth of karstification near the spring outlet

In the Mofanggou Spring Basin, the average recharge elevation is 3437 m, the thickness of the aerated zone is about 500 m. The average elevation of the aquifer roof is 2585 m. The elevation of the karstic base level is 1541 m, so near the spring outlet the depth of karstification is about 629 m.

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锦屏水电工程区岩溶水文地质研究中氢氧同位素的应用

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摘 要

锦屏水电工程区位于四川省冕宁县、盐源县境内雅砻江大河湾处。利用河湾的天然落差，拟开凿长约 18 km 引水隧洞，以取得约 300 m 的发电水头，获得丰富而廉价的电力资源。

工程区面积约 400 km^2，属典型高山深谷地貌。锦屏山主体山峰高程在 4000 m 以上，相对高差达 2100～3000 m。出露地层以三叠系为主，碳酸盐岩占 70%以上，并有程度不同的大理岩化，其间夹砂板岩，组成以锦屏山为主体的 NNE 向复式向斜，轴部在分水岭地带。地层倾角 65°～68°。除锦屏山、青纳等走向断层外，构造裂隙发育。

中三叠统白山组(T_{2b})大理岩是工程区主要岩溶含水岩组，厚 750～2270 m，分布于中部，南北有磨房沟和老庄子两个大泉，年平均流量分别为 5.566 m^3/s 和 2.46 m^3/s。两侧为 T_{2y}间层大理岩的中等或弱岩溶含水岩组，厚 1500 m 左右，分散状泉水流量 2～100 l/s。本区岩溶水受大气降水直接补给，向雅砻江排泄，与外界无水力联系，为一独立的水文地质单元。

本区共设有同位素水样点 59 个，D、^{18}O、T 149 组，D、^{18}O 58 组。根据同位素水文地质分析取得如下认识：(1)两个大泉分别是两个亚含水单元的稳定排泄中心，具有常年性分水岭；(2)平硐水外段主要是当地大气降水补给，其次还有地表沟水和 I 单元水补给，内段为 I 单元水补给；(3) I 、II 含水单元之间由于构造原因局部水流联系密切；(4)本区地下水循环交替强烈，在垂直剖面上具有快速流和慢速流的特征；(5)两个大泉地下水主要具有活塞流水流特征，计算地下水平均年龄为 3.5 年。含水层厚度为 1045 m，泉口岩溶发育深度为 629 m。

关键词 水电工程 岩溶水 氢氧同位素 四川锦屏

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