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Studying leakage from left abutment of Xiaolangdi hydropower station using tracing method

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ABSTRACT

Leakage from no.30 drainage gallery at left abutment of Xiaolangdi hydropower station was studied using tracing methods of environmental isotopes, chemical composition, etc. The result was made by the means of analyzing the data of environmental isotopes, direction of groundwater, temperature field, etc, which was that the leakage water of drainage holes in the north of no.30 drainage gallery might come from the reservoir water passing through the fracture zone of the fault F28 and then inrush into permeable $T_1^{3\text{-}1}$ *stratum. The result was confirmed by the interconnection experiments. The research result about the leakage from no.30 drainage gallery would play a great role in designing curtain of left abutment.*

Key words: Environmental isotopes; chemical composition; tracing method; left abutment; drainage gallery

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INTRODUCTION

Studying the leakage from dam using environment isotopes is an important content in isotope hydrology in the latest decades. Environmental isotopes of D, T and ^{18}O in water have been broadly used in hydrogeologic investigation as important nature tracer. Much scientific research fruits have been attained about the application of environmental isotopes in the hydrology. For example, Fontes J C and Edmunds J N [1], Coplen T B [2] and Gat J R [3] have systemically summarized about them，and latest books include the ones of Mazor E [4], Ian D. Clark and Peter Fritz [5]. IAEA also has discussion meetings in scheduled time, and has specially published works about the isotopes of H and ^{18}O [6] [7].

The related information of leakage from dam can be attained by the distributing law of the environment isotopes D, T and ^{18}O in the surface water and groundwater, by the comparison of the isotopic character in the precipitation, groundwater and seepage water, and by applying the altitude effect and the latitude effect of the isotopes in the precipitation. So the recharge sources can be accurately separated, and the scientific reference can be put forward to supply the engineering measures for dam.

1. INTRODUCTION OF TRACING METHODS

2.1 THE principle of the tracing method using environmental isotopes

The isotopes of groundwater are similar to DNA of body, but the sources of groundwater need several isotopes to confirm mutually, which is different with the DNA evidence [8]. So we can obtain much valuable hydrogeological information by studying isotopes of groundwater.

Precipitation provides water to surface water bodies (including rivers) and groundwater. Because of elevation, latitude, land and seasonal effects, isotopic variations are noticed in the precipitation. These lead to different isotope characteristics in the water origining from different sources. So the water sources can be identified by the isotopes of the water. Also the chemical composition of the water can be used as the auxiliary mean to identify the water sources [9].

2.2 THE principle of the tracing method using artificial tracers

2.2.1 Determining the seepage velocity of groundwater using dilution method in single borehole

When the tracer is homogeneously mixed in water column in the borehole, the axis of the filter tube perpendicular to the streamline of aquifer, and the horizontal waterflow goes through the filter tube continuously and uniformly, without interference of vertical flow, thus the following formula can be applied [10]:

$$V_f = \frac{\pi (r_1^2 - r_0^2)}{2 r_1 \cdot \alpha \cdot t} \ln \frac{N_0}{N_1} \tag{1}$$

Where v_f is the seepage velocity of groundwater, and r_1 and r_0 represent, respectively, the radiuses of borehole and probe. T is the interval of two measuring times, and α is a coefficient needed for the correction for the hydrodynamic disturbance of the nature groundwater flow produced by the presence of the borehole. N_0 is the initial tracer concentration and N_1 is the concentration after tim t.

2.2.2 Determination of flow direction of groundwater in single borehole

The radioactive tracer flows to the outside of the borehole with a certain dispersion angle mainly along the direction of waterflow. Dispersion angle is concerned with the velocity of waterflow, aquifer structure and the sizes of soil particles. The radioactive intensities around the borehole are different, which are reflected by the radioactive tracer in the aquifer. The greatest intensity corresponds to the direction of groundwater flowing out of borehole. So the direction of groundwater flow can be determined by measuring the radioactive intensities around the borehole [11].

2.2.3 Temperature tracing

It is confirmed by the practical cases that temperature tracing is an effective measure to trace the flowing of groundwater [12]. Temperatures of strata's surface and the river water vary with the seasons, while the temperature of the deep groundwater is mainly related to rock mass and ground temperature, increasing with the buried depth, and is less affected by the seasons. When water supplies the aquifer with different temperatures, there will be temperature anomalies in strata. Abnormal temperature zone is often regarded as a permeable formation.

2.2.4 Interconnection experiments

Interconnection experiments constitute one of the essential stages in investigations related to dam leakage. These experiments are frequently undertaken to obtain an irrefutable proof of the hydraulic connection between two water bodies, generally indicated or supported by previous investigations using one or several of the techniques described in the previous tracing methods [13]. Briefly, the experiments consist of the injection in a water body of a determined amount of an appropriate tracer and the subsequent determination of its arrival at boreholes or springs located downstream. So the hydrodynamic properties of natural flow can be obtained by the tracing curve of the tracer got at boreholes located downstream.

2. CASE STUDY

The leakage from the left abutment of Xiaolangdi reservoir was great since operation in 1999. Curtain reinforcement was constructed in 2001, but the leakage amount only decreased 20%. When reservoir water level exceeded the elevation of 235m, the leakage increased rapidly, which mainly located around no.30 drainage gallery, the crown of the underground workshop, and the upstream abutment wall. The elevations of bottom of no.30 drainage gallery was 117-126m, the elevations of the bottom of drainage holes in no.30 drainage gallery were 85.0m, and the ones of part holes were 100m. The paper discussed the leakage water from no.30 drainage gallery for further curtain reinforcement.

3.1 General situation of leakage and hydrogeology of rock bodies at left abutment

Bedrock strata at Xiaolangdi area mainly consisted of Permian system (P) and Triassic system (T). Quaternary loose sediments were mainly distributed over terrace and river valley. Bedrock strata could be divided into five petrofabrics: P_2^1, P_2^2, P_2^3, P_2^4, and T petrofabrics. The T_1^4 and $T_1^{3\text{-}1}$ strata at left abutment were permeable, and $T_1^{3\text{-}2}$ stratum was low permeable. $T_1^{6\text{-}1}$-$T_1^{3\text{-}1}$ strata had been vertically disclosed at left abutment. Attitude of strata was:50°-60°∠8°-9°, and faults were approximately vertical to dam axes. Rock body between two faults was rather cracked, and integrality was weak, and more than ten secondary small faults had developed. Part rock body formed drape, and largely affected leakage and the stabilization of dam. Mainly three groups joints developed at left core wall. The three joints had the striking direction of NNE, NWW and NNW respectively. The development situations of each petrofabric were different. The rock body of $T_1^{6\text{-}1}$ petrofabric was affected by weathering and unloading, and joint and cranny were dense. Joint much developed in the depth of 8-9m in terrane. The joints of group NNE mostly cut strata, and extended very largely, and several wide open crannies developed in the core wall. The maximum breadth could attain 20~30cm. More than 10 permeability joints developed in the T_1^4 petrofabric group. These joints had the striking direction of NWW. Extending length in the cut-stratum direction was longer than 10m. Joints largely developed in the $T_1^{5\text{-}2}$, T_1^4, and $T_1^{3\text{-}1}$ petrofabric groups, which had greater hard petrofabric groups content. Generally joints densities were 2~3 joints per meter, and joints densities of $T_1^{5\text{-}2}$, $T_1^{5\text{-}1}$, and $T_1^{3\text{-}2}$ petrofabric groups were 1~2 joints per meter. Most joints faces were flat and harsh, and breadths were 0.5~1.5mm, and joints were filled with calcareous thin film. There existed three biggish along-river faults. F236 fault had the striking direction of 100° and dip angle of 65°, and the trend direction was SW, and the vertical fault displacement was 65m. The breadth of F236 fault zone was 3m. F238 fault had the striking direction of 105°and dip angle of 87°, and the trend direction was NE, and the vertical fault displacement was 15m, and the breadth of fault zone was 2-3m. F240 fault had the striking direction of 105° and dip angle of 85°, and the trend direction was SW, and the vertical fault displacement was 12-15m, and the breadth of fault zone was 0.5m. The substance of the faults zones was argillaceous breccia, and there existed F28 fault, which intersected with axes of dam. The F28 fault had water-tight conformation. But it was found that there existed rather strong leakage at the fault zone by tests, which was showed in Fig. 1 and Fig. 2.

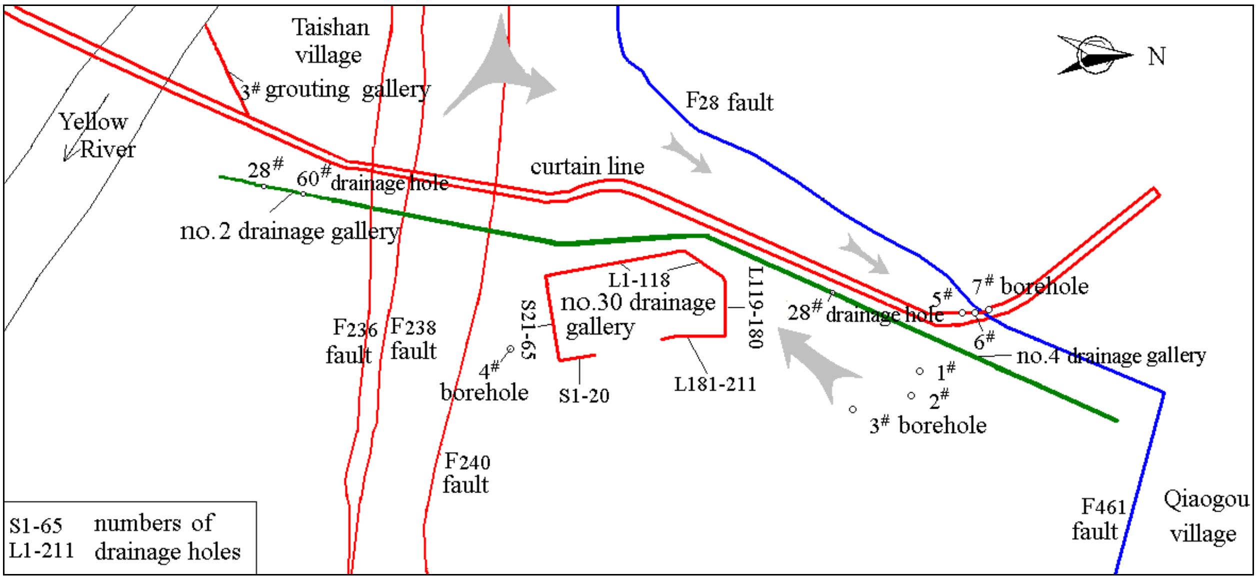


Fig. 1: Distribution of faults, no.30 drainage gallery, and observation boreholes at left abutment of Xiaolangdi Hydropower Station

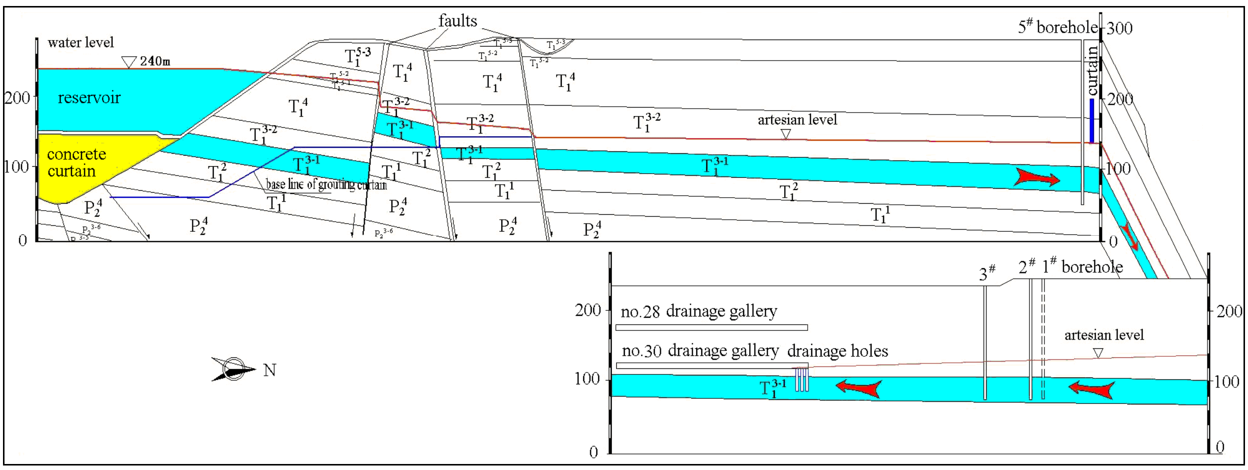


Fig. 2: Distribution of stratas, faults, confined water table and leakage pathway around Xiaolangdi left dam

3.2 ANALYSIS of isotopes and chemical components

Sampling points at the study area were shown in Fig.1, and the analysis results of isotopes and chemical components of the water samples were shown in Table 1. The values of isotope tritium at the area were high, which was mainly affected by upstream nuclear plants. The high values could play great role in tracing the sources of water.

The value of tritium was 8.3TU in groundwater of Taishan village, which located at the southwest of left abutment with distance of about 2km. The value of tritium was 6.2TU in groundwater of Qiaogou village, which located at the downstream of F28 fault. The tritium values of the two water samples were lower than that of other samples, and the ions contents of Cl^-, SO_4^{2-}, and Na^+ were significantly smaller than other samples. The chemical composition type of the two water samples were HCO_3^--Ca^{2+}-Mg^{2+}. The two water samples had different sources, which were shown in Fig. 3. Becauce the Taishan and Qiaogou villages were isolated by F461 and F28 faults, their water samples could represent different hydrogeologic units. Their tritium values could represent that of local precipitation (6-8TU).

Table 1: **The results of environment isotopes and chemical components of the water samples at the left abutment(ions' unit: mg/l)**

sampling point	K^+	Na^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	total dissolved solids	δD /‰	$\delta^{18}O$ /‰	T /TU
Deep reservoir water	4.4	109.0	64.3	32.1	233.3	113.9	152.8	20.0	729.9	-69	-9.4	18.7
Taishan village	0.8	20.8	80.0	20.0	314.2	8.9	42.3	6.7	493.7	-61	-6.9	8.3
Qiaogou village	0.8	13.6	73.0	14.2	259.9	4.27	30.6	8.9	405.1	-64	-8.1	6.2
tail water	4.2	113.0	66.7	32.7	216.6	117.5	150.4	20.3	744	-72.8	-7.9	17.1
dam toe	2.0	81.7	90.2	27.4	242.2	106.8	131.6	14.3	696.2	-65.9	-8.5	17.0
2-28	3.8	110.5	66.7	32.1	239.2	115.7	134.0	19.6	721.6	-66.8	-9.1	48.8
2-60	2.4	88.2	79.4	26.8	194.2	112.1	143.4	19.5	666.7	-61.1	-8.5	54.2
30-L18	2.9	81.1	78.5	25.9	194.9	109.6	141.0	17.5	651.4	-64.1	-8.5	33.7
30-S37	2.2	71.2	82.4	26.2	200.8	102.5	145.7	18.8	649.8	-61.1	-8.9	14.2
30-S7	3.8	107.3	72.6	29.7	233.3	115.7	141.0	20.5	723.9	-66.8	-8.9	44.2
30-L133	1.7	87.3	50.0	48.5	230.4	112.1	122.2	15.7	668	-68	-8.6	18.9
30-L194	1.5	78.8	62.8	41.4	230.4	101.5	138.7	20.0	675	-62.9	-8.6	8.6
4-28	4.37	106.29	72.18	27.12	218.6	113.9	143.4	18.8	704.6	-66	-8.8	59.7

(Note: 2-28 represented 28# drainage hole in no.2 drainage gallery, and 30-S7 represented S7 drainage hole in no.30 drainage gallery.)

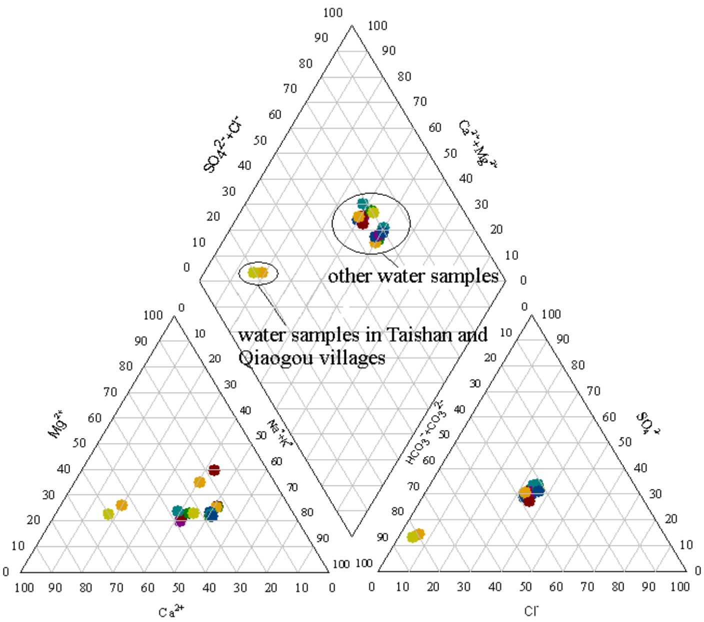


Fig. 3: Piper diagram for the water samples at left abutment

3.3 Analysis of drainage water in no.30 drainage gallery

Tests revealed that the sources of drainage water in no.30 drainage gallery were more complex. According to the data of rate of flow, the north of the drainage gallery yielded more water than the other sides, above 50% water of whole drainage gallery in the north. The temperatures of the water in the north were about 17.9 ℃ in the end of July 2002, which were higher about 1~2℃ than that of water in other sides. There existed a similar phenomenon in April 2002.

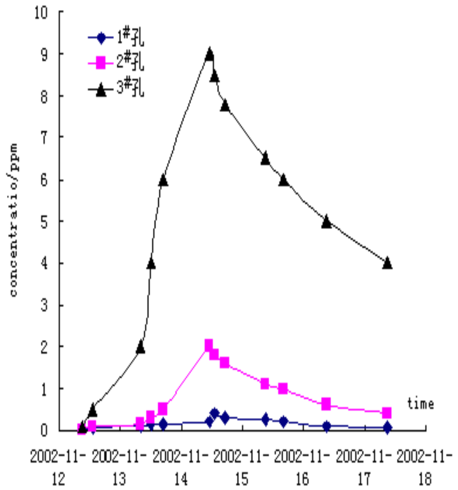
The environmental isotopes δD and T of L133 drainage hole in the north were in accordance with that of deep reservoir water, only little different in the value of $\delta^{18}O$, which might be the substitution of isotopes in water-rock interaction. So we doubted that the leakage passway of water in the north of no.30 drainage gallery was long, and buried depth was deep. The water might come from deep leakage around the dam, so the water temperatures in the north of drainage gallery were higher. The tritium value of north drainage hole of L133 was 18.9 TU, very consistent with that of deep reservoir water(18.7 TU), which showed that the deep reservoir water rapidly supplied the drainage water. The lithology survey of left abutment found that the strata of T_1^4 and T_1^{3-1} were permeable. The curtain was shallow away from the plant at the left abutment, failed to fully cut off permeable stratum T_1^{3-1}. So deep reservoir water must pass the F28 fault zone into stratum T_1^{3-1}, and drain out in the L119-L169 drainage holes in the north of no.30 drainage gallery, for the north drainage holes exposed permeable stratum T_1^{3-1}.

Six observation boreholes were drilled at the range of 200-500m on the north of no.30 drainage gallery, namely $1^\#$-$3^\#$, $5^\#$-$7^\#$ boreholes, for confirming the relation between the drainage water in the north of no.30 drainage gallery and F28 fault. The boreholes location was shown in Fig.1. $5^\#$, $6^\#$ and $7^\#$ boreholes located at dam crest, orifice elevation of 281m, and boreholes' depths of 210m. $1^\#$, $2^\#$ and $3^\#$ boreholes located at the platform of slope after dam, orifice elevations of 255m, 255m, and 230m respectively, and boreholes' depths of 177m, 175m and 150m respectively. The temperature and electrical conductivity of $1^\#$ and $2^\#$ boreholes had no obvious anomaly phenomena. But the temperature of $2^\#$ borehole was less than that of $1^\#$ borehole, which showed that $2^\#$ borehole was closer to the deep leakage pathway than $1^\#$ borehole. Obvious low temperature was found in $3^\#$ borehole below the depth of 130m, and the temperature in the borehole still showed a trend of decrease to the bottom. So $3^\#$ borehole didn't expose the deep leakage pathway. There existed two low temperature abnormal zones in $5^\#$ borehole. First zone was at the depth of 152~182m, and another located at the depth of 191~200m. The temperature in $6^\#$ borehole was similar to that in $5^\#$ borehole, and low temperature abnormal zone was at the depth of 191~200m. The sudden change of temperature was at the depth of 190m, namely there existed a strong leakage at the depth. Temperature and electrical conductivity were abnormal above the depth of 201m in $7^\#$ borehole, which showed obvious leakage.

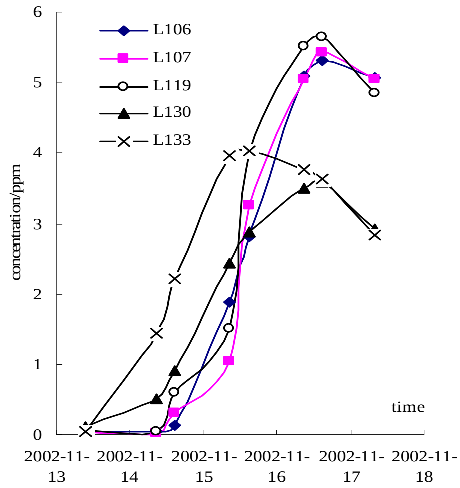
The tests for flow velocity and direction showed that the velocity of $1^\#$ borehole was small, the maximum value of 0.012 m/d, and the flow direction of $1^\#$ borehole was the direction of the axis of dam. The maximum velocity of $2^\#$ borehole was 0.035 m/d at the depth of 175 m, with the flow direction of southwest. The flow velocity of $3^\#$ borehole was large blow the depth of 120m, the maximum velocity of 0.4m/d and the flow direction of the southwest. The flow velocity of $3^\#$ borehole was greater than that of $1^\#$ and $2^\#$ boreholes. The flow velocity of $3^\#$ borehole was larger than 0.2m/d below the depth of 127m. So the leakage pathway was closer to $3^\#$ borehole. The maximum velocity of $5^\#$ borehole occurred at the depth of 196m, which belonged to T_1^{3-1} permeable stratum. Velocity variation was agreement with temperature anomaly distribution in $5^\#$ borehole. The flow velocity of $6^\#$ borehole was similar to that of $5^\#$ borehole, and the depth of $6^\#$ borehole exceeded the bottom of curtain. The flow velocity of $7^\#$ borehole was small. The leakage pathway must locate between $5^\#$ borehole and $6^\#$ borehole, and located in T_1^{3-1} permeable stratum below the curtain.

3.4 Interconnection experiment for confirming the leakage pathway

Interconnection experiments were frequently undertaken to obtain an irrefutable proof of the hydraulic connection between two water bodies. The tracer for interconnection experiments was uranine, for uranine was easily dissolved in water, non-toxic, and stable in water. Background values of uranine approximately equaled to zero in natural water bodies. Five kilograms of uranine were injected in $5^\#$ borehole at 11 am on 2002-11-11. The water sample with high concentration tracer was first found in $3^\#$ borehole 22 hours after the tracer injection, which showed that the $3^\#$ and $5^\#$ boreholes were in the main leakage pathway. The injected tracers of low concentrations were detected in $1^\#$ and $2^\#$ boreholes 26~27 hours after the tracer injection, which showed the two boreholes didn't locate in the main leakage pathway. The injected tracers of different concentrations were detected in L106-155 drainage holes in no.30 drainage gallery 48 hours after the tracer injection, which were showed in Fig. 4. So the interconnection experiments confirmed that a deep leakage pathway located in the bedrock of left abutment.



(a)



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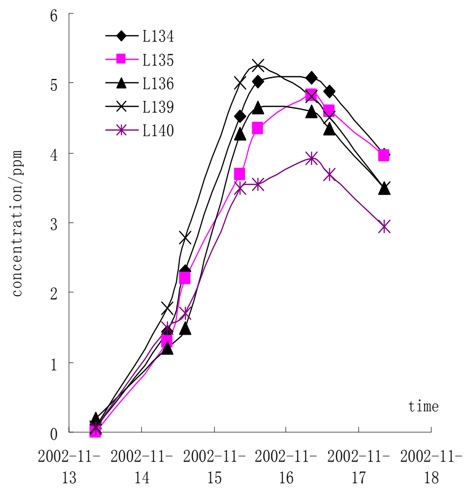

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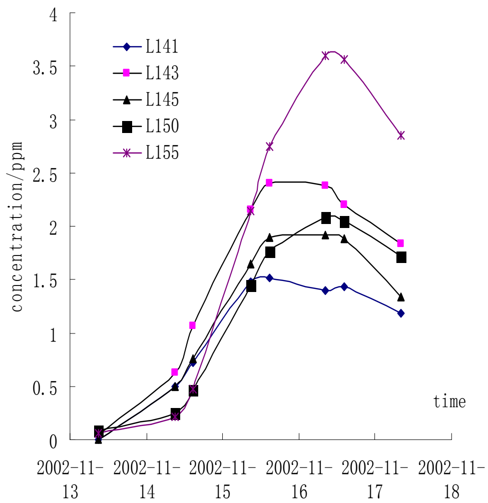

(d)

Fig. 4: Injected tracer detected in 1#-3# boreholes and part drainage holes in no.30 drainage gallery

CONCLUSION

In the latest decades, lots of progress had been made on using the tracing methods of environmental isotopes to study the leakage from dam in China. In the paper the tracing methods of environment isotopes, chemical composition and temperature were used to study the drainage water in the north of no.30 drainage gallery at left abutment of Xiaolangdi hydropower station. The drainage water mainly came from the reservoir water that passed the F28 fault zone and went through permeable T_1^{3-1} stratum around the dam, which was confirmed by the interconnection experiments. The study about the drainage water in the north of no.30 drainage gallery would eventually play a guiding role in reinforcement of the curtain at the left abutment.

Acknowledgments

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