Identifying Groundwater Recharge from Huangbizhuang Reservoir Using Distributed Temperature Fiber In North China Plain

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Abstract

Since the 1980s, the distributed optical fiber temperature measurement technology has gradually carried out to be the long-distance, high-precision and long-time temperature measurement, and is more and more used in many fields such as fire warning, leakage monitoring, etc. Since the 21st century, scholars in the field of hydrogeology have used this technology to understand the heat transfer in groundwater, surface water and other media. In this study, the distributed optical fiber temperature measurement technology was used to measure the vertical temperature of groundwater in the downstream of Huangbizhuang Reservoir in North China Plain for 35 sites, and groundwater table has been measured too. On the base of the temperature data, the plane and vertical distribution of the groundwater temperature are obtained. The plane distribution of the groundwater temperature shows that the reservoir water of Huangbizhuang Reservoir recharges the groundwater in the downstream plain area through the seepage at the bottom of the auxiliary dam, and the isotherm is roughly parallel to the groundwater contour, which shows that the conclusion of this technology is reliable. And according to the vertical temperature distribution, the main recharge depth is about 23 and 28 m underground. And the points of seepage are indicated by temperature change inside the dam and the drainage ditch.

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Key Points:

- Groundwater temperature can show that Groundwater in the downstream is recharged by surface water nearby.
- Water temperature can show where the dam is leaking.
- The same tendency of groundwater temperature indicates mainly recharge depth from the reservoir.

Abstract

Since the 1980s, the distributed optical fiber temperature measurement technology has gradually carried out to be the long-distance, high-precision and long-time temperature measurement, and is more and more used in many fields such as fire warning, leakage monitoring, etc. Since the 21st century, scholars in the field of hydrogeology have used this technology to understand the heat transfer in groundwater, surface water and other media. In this study, the distributed optical fiber temperature measurement technology was used to measure the vertical temperature of groundwater in the downstream of Huangbizhuang Reservoir in North China Plain for 35 sites, and groundwater table has been measured too. On the base of the temperature data, the plane and vertical distribution of the groundwater temperature are obtained. The plane distribution of the groundwater temperature shows that the reservoir water of Huangbizhuang Reservoir recharges the groundwater in the downstream plain area through the seepage at the bottom of the auxiliary dam, and the isotherm is roughly parallel to the groundwater contour, which shows that the conclusion of this technology is reliable. And according to the vertical temperature distribution, the main recharge depth is about 23 and 28 m underground. And the points of seepage are indicated by temperature change inside the dam and the drainage ditch.

1 Introduction

Water migration must be accompanied by heat transfer, and it cannot be eliminated((Brunke & Gonser, 1997; Huggenberger et al., 1996). Therefore, studies of groundwater temperature began in 1960s(Suzuki, 1960; Stallman, 1963), however, due to the limitation of temperature measurement, which got data on single points, the attention on groundwater temperature was not very much until Fiber-Optic Distributed Temperature Sensing (DTS) came true in the late 1980s(Schooley, 1982; Constantz, 2001; Taniguchi, 1994, 2003). DTS technology has incomparable advantages in long-distance, high-precision and real-time temperature monitoring(Lane et al., 2008), which is used in more and more fields. In terms of Geology and hydrogeology, scholars have revealed different processes by analyzing groundwater temperature since the 21st century(Selker et al., 2006(a), 2006(b); Tyler et al., 2009), such as geothermal exchange(McDaniel, 2016), groundwater flow in aquifer or fractured rocks(Wroblicky et al., 1998; Read, 2013; Wagner, 2014), discharge of coastal groundwater and seawater intrusion(Abraham, 2003； Michael， 2003， 2005； Taniguchi， 2006), soil moisture(Steele-Dunne, 2010; Striegl, 2012), exchange between groundwater and surface water such as rivers(Constantz， 1998, 2000； Rau, 2010; Mamer, 2012), lakes(Sebok, 2013) and wetlands(Lowry, 2007) etc..

In China, DTS technology is widely used in fire early warning and monitoring of bridges, tunnels, nuclear power, mines, leakage monitoring of chemical pipelines, leakage monitoring of reservoir dams(Niu, 2009), and water temperature monitoring to study the impact of the ecological environment of the reservoir. The application of DTS in hydrogeology is relatively limited. Only Huang Li (Huang, 2012) carried out distributed temperature measurement work on Heihe River in Hexi Corrido, studied the transformation relationship between Heihe River and groundwater qualitatively, and identified the location of groundwater recharge river according to the temperature anomaly.

In this work, the distributed optical fiber temperature measurement technology is used to measure the temperature of the phreatic aquifer in the Hutuo River alluvial proluvial plain area downstream of Huangbizhuang Reservoir in the North China Plain, and the distribution of the groundwater temperature of the area in the plane and vertical direction is obtained, which provides a new method for the study of the recharge and discharge of groundwater in the area.

2 Materials and Methods

2.1 Study area

Huangbizhuang Reservoir, built in 1958-1960, is located at the Taihang Mountains pass of the main stream of Hutuo River in the west of North China Plain, belonging to the Haihe River Basin(Fig. 1). Its total storage capacity is about 1.21 billion m^3. It is 25km away from Shijiazhuang, the capital of Hebei Province. It is a very important water conservancy project to control flood on the Hutuo River (Huangbizhuang Reservoir Management Bureau, 2015). The dam is built on the ancient river way of Hutuo River, without foundation clearing treatment, and the horizontal blanket is used for anti-seepage(Fei Yuhong, 1999). At present, the variation of groundwater level is not significant.

The phreatic aquifer this area is mainly quaternary alluvial loose rock with a thickness of 7-16m. The bedrock of the main dam is pre-Sinian limestone phyllite interbedding and phyllite marble interbedding. The bedrock of the auxiliary dam is ancient Hutuo group, Sinian system and quaternary system strata, the Quaternary Middle Pleistocene alluvial proluvial ($^{al+pl}Q_2$) is gravel bearing Neogene mudstone is 25.5m thick. The Quaternary upper Pleistocene alluvial proluvial Material ($^{Al+pl}Q_3$) is gravel, sand and sandy soil, less than 50m thick; Sinian siliceous limestone karst cave developed, providing seepage channel for water seepage under the dam.

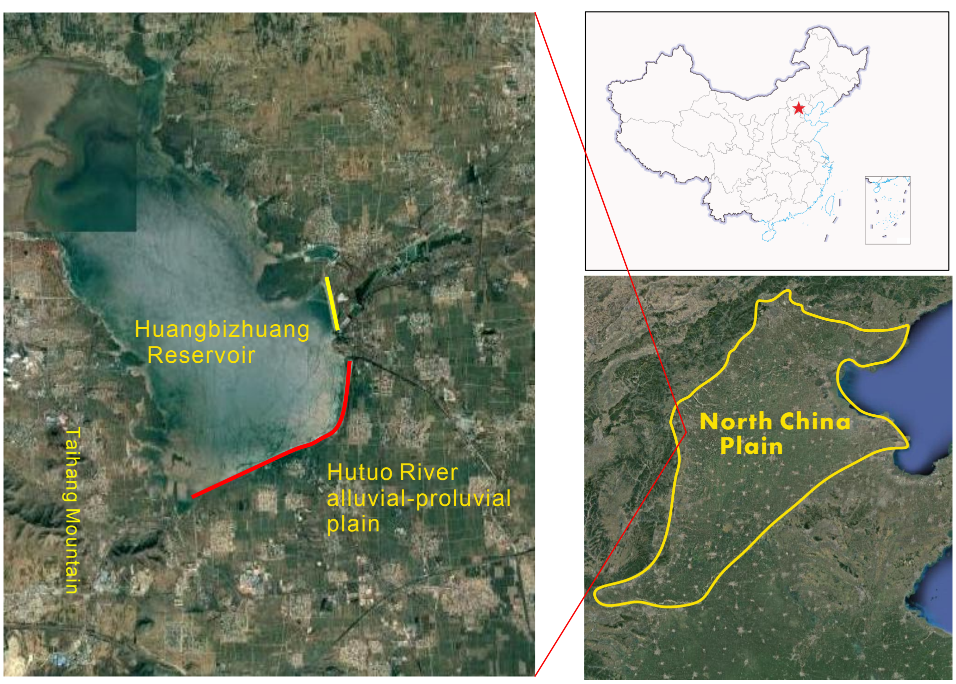


Fig. 1 The location of Huangbizhuang Reservoir

(In the map on the left, the red line means the auxiliary dam, the yellow line means the main dam)

2.2 measurements

In October 2018 and October 2019, the phreatic water table and temperature in 28 civil wells and 7 relief wells of the auxiliary dam of Huangbizhuang Reservoir were measured once a year. Fig. 2 shows the location of wells. The temperature measurement equipment adopts N4385B distributed Raman spectrum analyzer produced by AP Sensing Company of Agilent company of Germany, and the temperature measurement optical fiber adopts Superhawk9900 stainless steel strand waterproof optical cable produced by Beijing Xizhuo Information Technology Co., Ltd. The spatial resolution is 1.0m, the temperature resolution is 0.01 ℃, the time interval is 30s and 60s respectively, and the measurements last 20min and 10min respectively.

In addition, in order to determine the seepage points, water temperature inside and out of the main dam was also measured for 3-5days. Effectively, measurement distance is 760m and 400m.

The measurement was carried out in October when air temperature differs much from day and night, the influence on the water temperature is very small by less rain. Therefore, water temperature change induced by exchange between surface water and groundwater can be identified more easier.

3 Results, or a descriptive heading about the results

3.1 Groundwater flow

According to the measurements of the groundwater table two times, the groundwater contour is drawn, as shown in Fig.2. It can be seen that the groundwater in the downstream of the auxiliary dam of the reservoir generally flows to the southeast, and the groundwater in the downstream of the main dam flows from west to east. The water table on both sides of Shijin irrigation channel is lower. In 2018, the water table is 2.98-27.88m underground, and 2.82-30.85m underground in 2019. Compared with 2018, the phreatic table near the auxiliary dam rises a little in 2019, especially rises more in the western area of the auxiliary dam. The change of phreatic table decreases away from the auxiliary dam in the downstream area.

3.2 Groundwater temperature

With temperature data got through DTF, we protract the temperature contours at the depth of 10m, 15m and 20m in the downstream of Huangbizhuang Reservoir (shown in Fig. 3) . The temperature in western piedmont is lower, especially lower than 12.2 ℃ at the depth of 15 m; there is a higher temperature zone extending from the main dam to the modern river channel in the northeast, the range of the zone is expanded at the depth of 20 m; the temperature decreases away from the auxiliary dam in the southeast. In the whole study area, the tendency of temperature near the auxiliary dam toe is not obvious because of disturbance from recharge from Huangbizhuang Reservoir. That is perfect evidence that Huangbizhuang Reservoir recharge the groundwater.

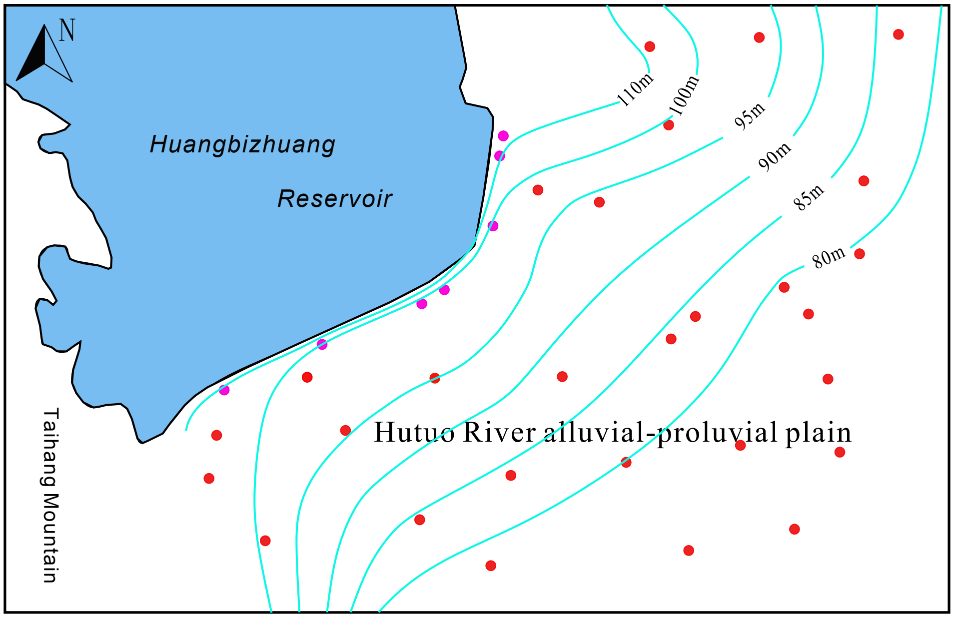


Fig.2 Phreatic water contour in southeast of Huangbizhuang Reservoir(The groundwater in the downstream of the auxiliary dam flows from Western Piedmont to the southeast, and the groundwater in the downstream of the main dam flows from the dam to the east; red points means location of civil wells which installed DTF and measured phreatic table, rose-red points means relief wells)

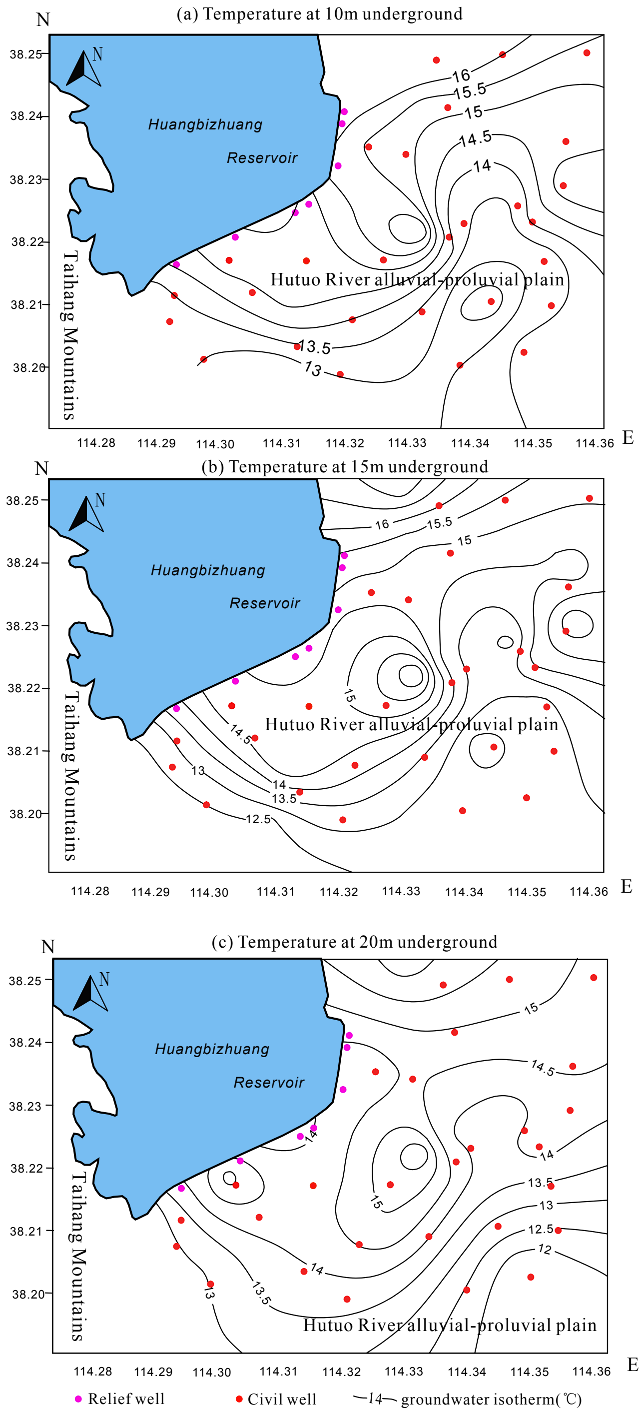


Fig.3 The plane distribution of temperature at different depths underground(Generally, the temperature in Western Piedmont is relatively low, the temperature near the toe of the main dam is relatively high at 10m, 15m and 20m underground)

Figure 3 also shows that in the vertical direction, the higher temperature zone shrinks from the depth of 10 to 15m, and enlarges from 15 to 20m, indicating that the temperature is slightly reduced from 10 to 15m, and increased from 15 to 20m.

However, the water temperature of the reservoir is 18-19 ℃, and the vertical temperature near the reservoir is a little higher than that in the downstream, which indicates that the water in the reservoir flows through the auxiliary dam to the downstream, and the seepage mainly happens below 15m. This due to the depth of the constant temperature layer in the North China Plain is generally 30m, and the temperature is about 14-15 ℃ (Zhang Dezhong, 2000). The civil well C10, which is far away from the reservoir, contributes to this result. The vertical temperature near the reservoir receives more heat, so the temperature is higher.

The vertical temperature of groundwater in three civil wells downstream of the main dam shows that the main recharge depth of groundwater in the northeast is about at the depth of 22-23m and 26m underground(Fig. 4) .

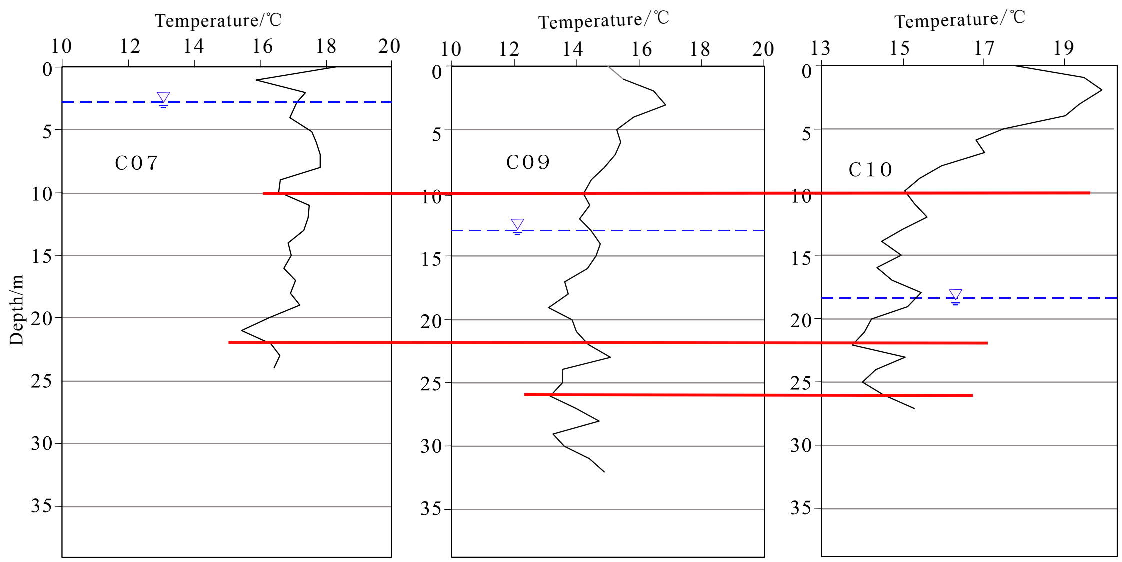
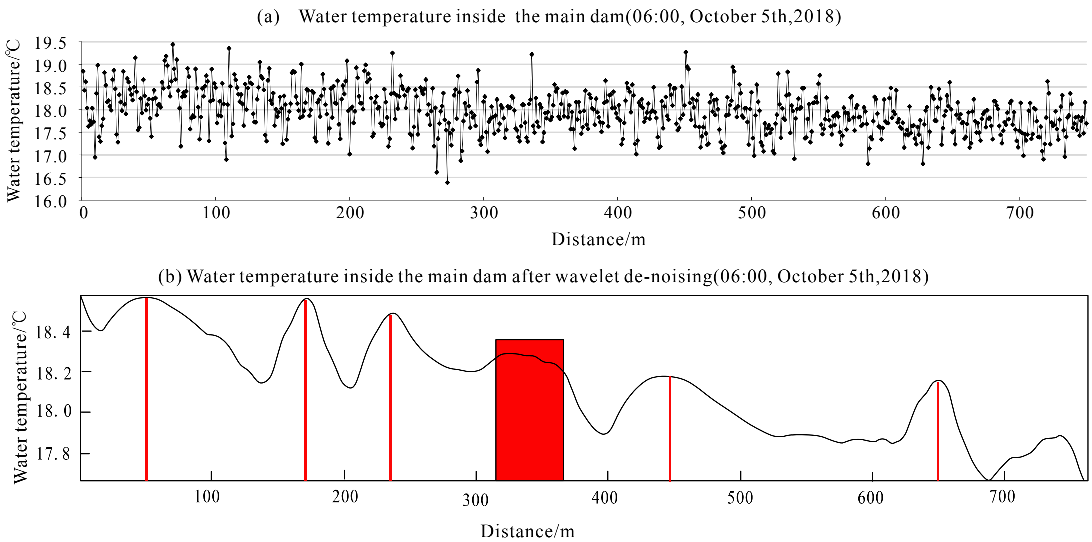
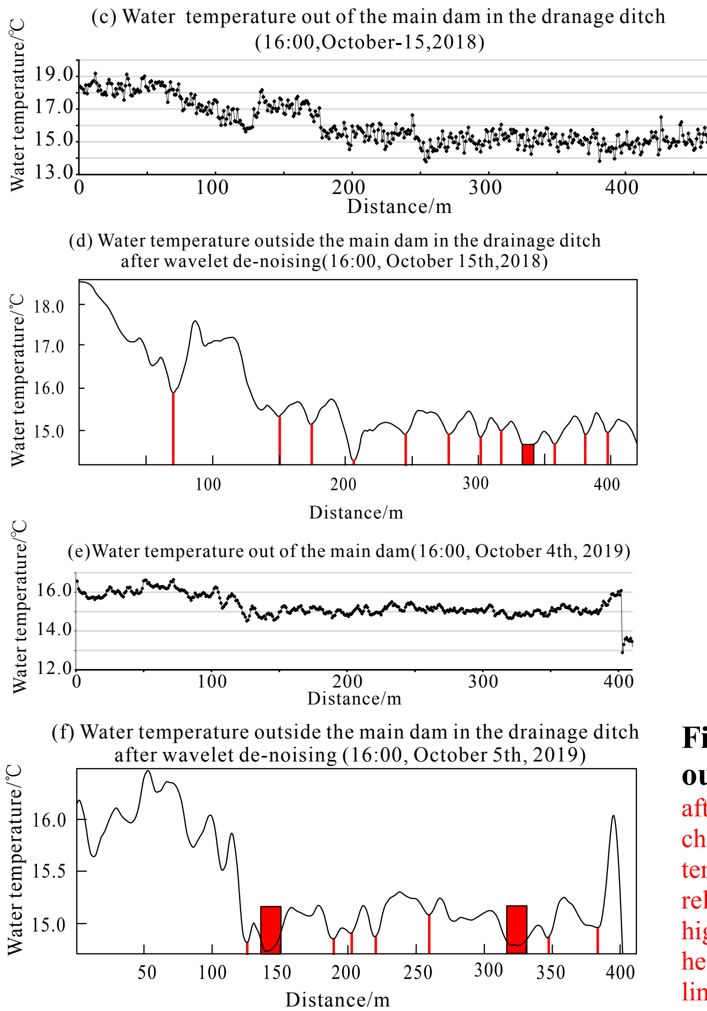


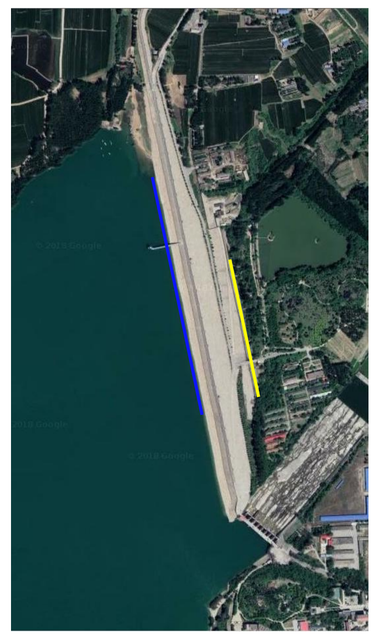
Fig.4 Groundwater recharge depth from Huangbizhuang Reservoir downstream the main dam(The groundwater flow from the main dam to the east, indicated by water table(Blue lines) of civil wells in the downstream of the main dam; At the depth of 22-23m and 26m(Red lines), vertical temperature of civil wells Shows the same change, This can be used as a strong evidence of groundwater recharge depth)

3.3 Temperature evidence of the dam seepage

the location of the seepage can be determined through measuring water temperature inside and out of the main dam. DTF was installed on the dam toe inside the dam to monitor temperature change, and put in the drainage ditch of the dam too. In order to reduce the impact of solar radiation on the water temperature inside the main dam, the temperature at 06:00 on October 5th, 2018 is selected, as shown in Fig. 5 (a), and the signal wavelet de-noising analysis is carried out by MATLAB, and Fig. 5 (b) is obtained. Fig. 5 (a) shows that the water temperature inside the







(g) Installtion of DTF inside(Blue line) and out(Yellow line) of the main dam of the Huangbizhuang Reservoir

Fig.5 Water temperature inside and out of the main dam(temperature curve after wavelet de-nosing show temperature change more clearly such as (b), (d) and (f). temperature on red lines or areas in (b) is reletively higher because the water with higher temperature in the upper layer carries heat downward, but lower temperature on red lines or areas in (d) and (f) due to the seepage water from the dam is cooler than water heated by sunshine and atmosphere elsewhere, all of this indicate where surface water seepage from the main dam to downstream) dam is a little higher at the corresponding part of the main dam and the drainage ditch. This due to the water temperature at the seepage points is higher, the water at the seepage point leaks through the dam, and the water with higher temperature in the upper layer carries heat downward, which makes the temperature near the seepage point higher than that at the non leakage point. In Fig. 5 (b), the temperature in the corresponding part of the main dam and the drainage ditch is obviously increased, the location with red lines or areas are considered as the seepage points.

Otherwise, the same conclusion can be drawn from the temperature analysis of drainage ditch. Figure 5 (c) and (d) show the temperature of the drainage ditch at 16:00 on October 15, 2018. After wavelet de-nosing, the location of the seepage point can be determined; the temperature at 16:00 on October 5, 2019 shows the same characteristics, as shown in Fig. 5 (e) and (f). water temperature is lower at seepage points, because it is cooler than water heated by sunshine and atmosphere elsewhere. Meanwhile, the temperature change from 13:19 on October 2 to 13:00 on October 6, 2019 is shown in Fig. (6). it is clear that water seepages from the main dam near 50m and 150.

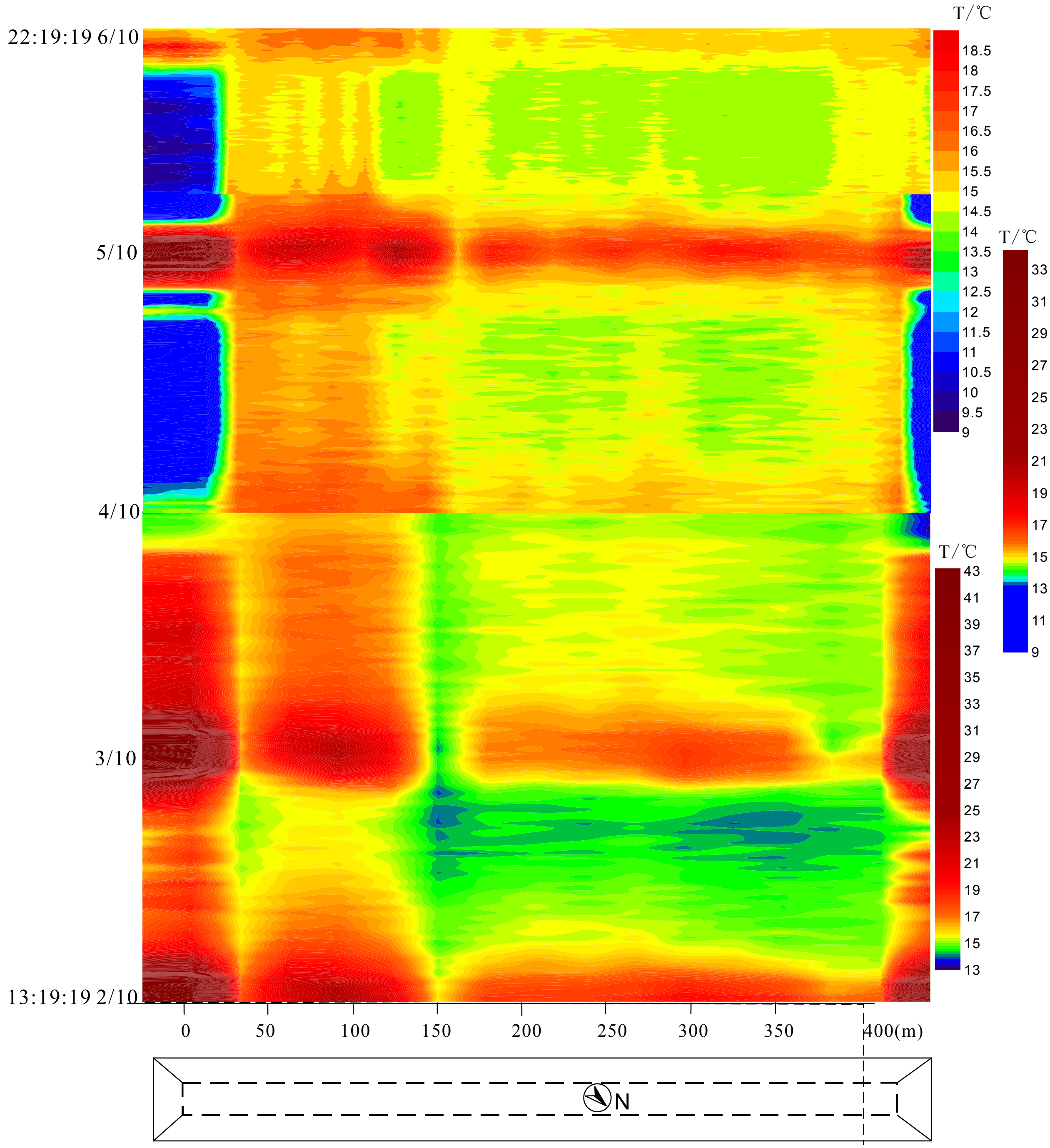


Fig.6 Water temperature in the drainage ditch of Huangbizhuang Reservoir dam
(From 13:19:00 on October 2th to 22:19:00 on October 6th,2019)
(the lower temperature shows that the main seepage points is about 45-50m and 150m)

4 Conclusions

By analyzing the plane distribution characteristics of groundwater temperature, it can be concluded that the groundwater in the downstream of Huangbizhuang Reservoir is recharged by the reservoir water, which is consistent with the direction of groundwater flow reflected by the groundwater water table contour; at the same time, the vertical temperature distribution also reflects the main depth of groundwater recharge from the reservoir. And the points of exchange between surface water and groundwater can be indicated by temperature change along the drainage ditch.

Compared with the traditional water level measurement, survey visit and hydrogeological drilling, Temperature measurement has the advantages of more accurate, more economical and less time-consuming. Therefore, the vertical temperature will be included together with water level, hydrochemistry, isotope and other indicators to describe the regional water cycle more precisely in the future hydrogeological survey.

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