Study on Heterogeneous Characteristics of Vertical Subsurface Flow Exchange in River Channel Based on Temperature Tracing Method

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Abstract. Through the monitoring of the riverbed temperature in the Xi'an subsurface flow in the Weihe River, Shaanxi Province in the spring and autumn, based on the analytical solution of the one-dimensional steady-state vertical heat transfer problem, the water exchange flux and the surface water temperature are given by the temperature tracer method. Parameters, and explain the distribution of the depth of the submerged zone by the relationship between the groundwater temperature and the depth of the submerged zone. The results show that the distribution of latent flux is 99.61~356.25L/(m²·d), which obeys the normal distribution. There are large differences in the values of different positions in the same section, there is a concentrated discharge area, showing significant spatial heterogeneity, and the river channel. The heterogeneity of the bank is more significant than that of the bank; the depth of the submerged zone is inversely related to the amount of latent flow. The greater the latent flow, the smaller the depth of the submerged zone.

1. Introduction

The submerged zone refers to the area where river water and groundwater exchange with each other. It can penetrate vertically or laterally into the sedimentary zone. The river water enters the riverbed sediment buffer zone or the lateral saturated long-air permeability zone. After a period of time, it is derived in another zone. The formation of regional hydrodynamic processes strongly influences important biogeochemical processes such as river water flow exchange, metabolism, and solute transport (Harvey, J. W. et al, 1996; Sophocleous, M., 2002). Due to the topographic characteristics of the river bank slope, the spatial difference of the permeability coefficient and the effect of river water-groundwater pressure, the river will enter the river bank in the vertical and lateral directions to exchange water with the groundwater to form vertical and lateral subsurface flow exchange (Anderson, M. P., 2005; Daniel O, et al., 2002; Ferguson G, et al., 2011).

This paper selects the Xi'an section of the main stream of the Weihe River in Shaanxi Province as the research section, conducts on-site monitoring of riverbed temperature, analyzes the heterogeneous
characteristics of subsurface flow exchange by thermal tracking, and preliminaries discusses the spatial
distribution of subsurface flow and depth of subsurface flow and mutual mutual relationship.

2. Materials and methods

2.1. Study area
The Weihe River is a vital river of Shaanxi Province, China, belongs to arid and semi-arid regions of
western China, is the largest tributary of the Yellow River. The total basin area is 134,000 km$^2$. The
Weihe river basin in Shaanxi province is mainly the middle and lower reaches of Weihe river area. From
xianyang to tongguan, the entrance of huangkou is downstream, and the length of the river is about
208km. The Weihe River affects the vicissitude of social and economy in Shaanxi Province directly
(Song, 2013). The research of spatial variability of streambed $K_v$ value of the Weihe River is
significantly important to the health of the river system.

2.2. Test points
Based on field investigation and data collection of Weihe river in Shanxi Province analysis, finally
choose the middle and lower reaches of Weihe river in xianyang county typical study area (Fig 1,Table 1). Test point distribution is shown in figure 2.

Fig. 1 Map of study area and tests sites (dots represent test sites, triangles represent gauges stations)

Fig. 2 Sketch map of test points
Table 1 Average stream discharge and stream level in four gauges stations

| Station location | Longitude and Latitude | Mean stream discharge (m³/s) | Mean stream level (m) | Date range       |
|------------------|------------------------|------------------------------|-----------------------|------------------|
| A                | 107.05, 34.38          | 85                           | 493                   | 2004–2016        |
| B                | 107.7, 34.30           | 158                          | 382                   | 2004–2016        |
| C                | 108.7, 34.32           | 234                          | 352                   | 2004–2016        |
| D                | 109.77, 34.58          | 257                          | 336                   | 2004–2016        |

2.3. Temperature test method

The one-dimensional steady-state thermal in out-threaded applications river bed temperature and the potential liquidity of the geographical and time constraints, that is, groundwater and river water temperature difference. Therefore, the amalgamation of the measurement selection of spring and autumn. We take a temperature sensor for different test points at different times in different depth of river sediment measured temperature and record the measurement data.

This lab research with long-distance 1.8 m, the scale of the Temperature Test rod for on-the-spot temperature test (Figure 3). The outside of the test device is a metal tube, at the top is a tee fitting, the temperature sensor wiring through the side of the pipe and the external link at the bottom of the tip and install a 7-PT100 temperature sensors are installed on the different height, distance from the end point are 0, 0.1, 0.2, 0.3, 0.45, 0.6 and 0.8m. The sensor consists of a transmission line and is associated with the temperature monitor, you can record the temperature data in real time. The depth of the temperature sensor temperature through the stick into the river below the surface of the water depth can be recorded. During the measurement, the ups and downs due to water and river bed sediment physical patterns, temperature sensor is inserted into the sediment depth measurements in the presence of 0~2cm, temperature test from the river bed surface, temperature control test tube into the sediment depth and record the different test points are different on the depth of the deposition temperature, most of the test point is approximately 0.8m, a deeper test may be tight sand layer blocks or affected by the length of the tool, the lab is about 20 minutes to get a set temperature sensor measured river bed sediment temperature data.

![Fig.3 Schematic diagram of riverbed sediment temperature test process](image)

![Fig.4 Particle grading curve of sediments in the grass bed of Xi'an](image)
3. Result analysis

3.1. Sediment particle size analysis
The test points and test methods are collected according to the above arrangement, and the sediment samples in Guanzhong Basin are collected. The specific process is as follows: first cover the upper end of the pipe with a rubber soft cover to block its contact with the atmosphere, and then pull the pipe out of the riverbed. According to the lengths of L1 and L2, the sediment in the tube was separated and placed in different sample bags, and the collected sediments were subjected to particle size analysis in the soil laboratory. During the particle size analysis, the sediment samples were divided into 17 distinct grades by sieving and the cumulative weight percentage of the deposits was calculated. The smallest particle size is 0.075mm and the maximum particle size is 1.2cm. The particle size <0.075mm is classified as silt and clay, the grain size is 0.075~2mm of sand, and the particle size >2mm is gravel.

The granulation analysis experiment was carried out on the sand samples taken from the test site by sieving method. The gradation curve of the particles, after the average value of each group was taken as showed in Fig. 6. From the particle size analysis results of the riverbed sediment at the sampling point Seen, the sediment particles in the riverbed at Xi’an grassland are dominated by sand (Table 1).

| Test point     | Silt and clay mass percentage | Sand mass percentage | Gravel mass percentage |
|----------------|-------------------------------|----------------------|------------------------|
| Xi’an CaoTan   | 0.51                          | 92.43                | 7.07                   |

3.2. River bed temperature profile
The riverbed temperature profile is a temperature profile derived from measured temperature data. Figure 7 is a test chart of spring (A, C) and autumn (B, D) in two sections of temperature. The position of 0m on the abscissa is the boundary between the water surface and the river bank. The measurement range of the two sections from the shore of the river is 2m, 5m. It can be seen from the figure that the temperature range of the riverbed on the two sections measured in spring is 13.2~19.2°C, the maximum depth is 0.8m, and the minimum is at the top of the measuring point 2 (depth 0m). The average temperature of each test point was 16.8 °C, the maximum temperature difference of each test point was 3.2 °C, and the minimum temperature difference was 1.7 °C. The average temperature difference between the uppermost layer and the lowermost layer of all test points was 2.5 °C. Through different depth-temperature distribution profiles, it can be seen that the test points are represented by groundwater recharge surface water; the temperature of the riverbed in the two sections measured in autumn is in the range of 12.9~18.8°C, and the maximum value is 0.79m in the measuring point. The minimum value is located at The top layer (depth 0m). The average temperature of each test point was 16.2 °C, the maximum temperature difference of each test point was 4.6 °C, and the minimum temperature difference was 2.9 °C. The average temperature difference between the top and bottom of all test points was 3.9 °C. It can be seen from different depth-temperature distribution profiles that the test points are represented by groundwater replenishing surface water.

Comparing the two seasons of experimental data, in autumn, the sediment temperature showed a trend of increasing depth, and the opposite was true in spring. Stratification of sediment temperature was more obvious in both tests. In autumn, the temperature difference of each layer in the sediment is greater than that in spring, but the recharge relationship is expressed as groundwater replenishing surface water; the deeper isothern width in spring and autumn is larger, indicating that the deeper river water and groundwater exchange are more frequent, and the depth of spring water exchange is in the range of 0.2~0.5m, the depth of frequent water exchange in autumn ranges from 0.4 to 0.6m.

In spring, the relatively low temperature of the riverbed is the concentrated discharge area of groundwater. Shallow riverbed sediments have higher temperatures in areas with low latent flows than
those with large potential flows. From Fig. 7, the lower concentrated discharge area is about 0.4m–0.5m, and the second concentrated discharge area is 0.2m–0.3m.

![Image](image_url)

**Figure 5.** Temperature profile of spring and autumn

### 3.3. Latent liquidity

The water flow in the formula (1) is the case that the groundwater is replenished to the surface water vertically. The calculation results in this study are all positive values, indicating that groundwater recharges surfaces water, and both are greater than 12L/(m².d). When latent flux in the study is less than 12L/(m².d), the surface will occur. The conclusion that water is recharged to groundwater is consistent. Fig. 8 is a contour diagram of different depth-temperature distribution, and the magnitude of the latent flow is obtained by curve fitting according to the measured temperature of the vertical line. It can be seen that the greater the latent flow, the faster the convergence of the surface of the riverbed in the depth direction, that is, the greater the latent flow, the closer the temperature stable position is to the surface of the riverbed.

![Image](image_url)

**Figure 6.** measured temperature and fitted temperature curve

The statistical characteristics of the latent flow are shown in Table 2. The range of all sample changes is 99.61–356.25L/(m².d). The maximum amount of latent flow in the measurement range is
356.25L/(m².d), which is generated at 5m from the shore in autumn; the minimum amount of latent flow is 99.61L/(m².d), which is generated at 5m from the shore in spring. The median value of the latent flow in the section of the spring and autumn sections at a distance of 5 m from the shore is 2 m above the shore. From the frequency histogram (Table 2), we can see the concentrated distribution range of the latest flow of each section in spring and autumn. In general, 50% of the latent circulation in spring is distributed between 140 and 180 L/(m².d), and in the autumn, it is distributed between 190 and 230 L/(m².d). By non-parametric single-sample KS test and normal curve, we can find the normal distribution of all samples and the potential flux of each profile.

### Table 3. Statistics on the distribution law of latent circulation

| q_r/L/(m².d) | Spring | Autumn |
|--------------|--------|--------|
| Profile 1(2m) | Profile 2(5m) | Profile 1(2m) | Profile 2(5m) |
| Maximum value | 213.21 | 220.51 | 334.56 | 356.25 |
| Minimum value | 127.23 | 99.61 | 104.95 | 161.22 |
| Average value | 182.06 | 162.65 | 295.25 | 273.17 |

Figure 7 shows that the latent flow distribution is uneven, and the latent flow generated along the length of about 37% of the profile accounts for about 50% of the total latent flow in the test range; about 64% of the total latent flow comes from 50% of the total Section length. Figure 8 is a distribution diagram of the latent flow rate on each section. Along the section of 0.2~0.3m and 0.4~0.5m, there are three high-value areas with latent flow, which is in good agreement with the above-mentioned concentrated groundwater discharge are determined according to the measured riverbed temperature profile. Submerged flux increased slightly from the river bank to the river channel, and the variation range was larger. The 2m curve from the shore in autumn was more significant than the other three curves, which confirmed the spatial variability of the submerged flux. Subsurface flow changes with flow, gradient, riverbed morphology, sediment permeability, and river water surface slope. Under the condition that the river bed is less undulating and the water flow is stable at the same test point, the spatial variability of the latent flow is mainly impacted by the non-uniformity of the medium in the submerged zone. Because the medium is consistent, the preferential flow channel in the riverbed is
reduced, and the local area is larger. The possibility of latent flow is decreased, so the more heterogeneous the sediment in the riverbed, the greater the potential flow. The calculation results are shown that the closer to the shore (the area near 0m in Figure 100), the smaller the latent flow, indicating that the heterogeneity of the latent flow in the riverbed near the shore has a weakening trend. The above results and analysis confirms the validity of calculating the latent flux and quantitatively characterizing its heterogeneous features by the thermal tracking calculation method.

4. Discussion of results
(1) In this test, the heat trace method is utilized to select the one-dimensional steady heat transfer equation of groundwater vertically replenished surface water to calculate the latent flow, and its distribution range is 99.61~356.25L/(m²·d). The submerged circulation obeys the normal distribution, and the numerical difference is very different at different positions of the same section. There is a concentrated discharge area, which shows significant spatial heterogeneity, and the channel is more expressive than the shore heterogeneity, which confirms the tracking through heat. Methods The validity of the heterogeneous characteristics of latent flux is studied.

(2) The temperature fluctuation of the measured riverbed profile is small, and the surface water and groundwater temperature obtained by the formula is also relatively stable, and the amplitude is not large. According to the low temperature zone of the riverbed temperature profile, the high groundwater discharge zone is consistent with the high value of the potential flow obtained by the analytical solution.

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