Estimation of vertical exchange velocity through sediment–water interface (Case study: Ziarat River in Golestan province)

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Abstract

Precise Estimation of water exchange between surface and subsurface flow in hyporheic zone which is habitat of microorganisms is vital. The temperature can be used as a tracer for estimation of water exchange through sediment water interphase. In this study, an instrument was designed and constructed to make the measurement and recording of sediment temperature in depth of hyporheic zone possible. In this regard, measurements were made in the Ziarat River of Golestan Province by the aforementioned instrument, and vertical exchange velocity through sediment-water interface were calculated using an extended conceptual model of heat transfer. For this purpose, in a 40 m interval of the river, 10 cross sections were selected at 4 m intervals, and at each cross section, temperature of four different depths of the riverbed (just below the bed, 0.25, 0.50, 0.75 m) were recorded during July and December 2018.The results showed that in all seasons there is a continuous vertical exchange through sediment-water interface which can be obtained from the difference of thermal potential between surface and subsurface of the river flow. The average of vertical exchange velocity for July and December was 59.3 mm/day and 284.3 mm/day, respectively.

Keywords: Groundwater, Surface flow, Water exchange, Temperature gradient, Hyporheic region.

Introduction

The hyporheic zone is an active ecotone which connects surface water and groundwater. The characteristics of this zone are determined by the hydrological [3], chemical and biological [1,2] processes. This area of the river can be considered as a shelter for microorganisms which have played an important role in purifying river surface water. In this zone, a part of the surface water enters the underneath part of the riverbed and reenters the surface water by passing the interference path [4]. The exact measurement of the interaction between surface and subsurface water can be effective for surface water quality management. There are many different methods to measure such an interaction through which the way based on the concentration of tracer injected to flow or bed sediment. Regarding the fact that the surface water temperature is less than under bed river water in cold seasons, by the interaction between surface and subsurface water in hyporheic zone , the colder water enters the bed and after transferring the heat, the water temperature is balanced, thus, there will be suitable condition for river creatures especially fishes. While in summer, there is a vice-versa process. Based on the studies, by measuring the temperature of river bed at different depths and by using the temperature as the tracer, the interaction between surface and subsurface can be estimated.

The dynamic recognition of the water phenomenon in hyproheic area regarding hydrological, chemical and biological processes are of importance [4.6]. Normally, this phenomenon is accompanied with heat transfer, solution, and suspended materials in the form of physical and chemical processes [5,7]. This is a basic fact that water movement can redistribute the distribution of temperature under the bed surface [8,9]. The current interaction patterns can be derived from the amount of temperature changes between surface and subsurface water [10]. The temperature can be easily measured by precise and cheap sensors which are accessible [8,11].

Material and Methods

In this study, an instrument has been designed and made in order to measure the temperature of river bed at different depths in Ziarat River. This instrument involves a metal pipe in which the end is sharp and two round metal boards. One board is used as the base to exit water, and the other board to determine a place in the pipe tangent with river bed. The sharp end allows the pipe enter the bed sediment very easily. There are four heat sensors which pass through the pipe and connected to a temperature monitor. The measurement process was done in July and December, 2018. For this purpose, in a 40 m interval of the river, 10 cross sections were selected at 4 m intervals, and at each cross section, temperature of four different depths of the riverbed (just below the bed, 0.25, 0.50, 0.75 m) were recorded. During the measurement the average depth of the water in July and December were 11.7 and 18.1 cm respectively. The average flow velocity in July and December were also 0.2 and 0.35 m/s, respectively.

For assessing the exchange water between surface and subsurface flow across the river bed the following heat transfer equation [12].

$$\frac{k}{\rho c}\frac{\partial^2 T(z)}{\partial z^2}-\frac{\upsilon\rho_0 c_0}{\rho c}\frac{dT(z)}{dz}=\frac{\partial T(z)}{\partial t} \quad (1)$$

Where v is vertical exchange of flow, T(z) is temperature, $\rho_0 c_0$ ($Jm^{-3}k^{-1}$) is heat capacity of saturated sediment and k is thermal conductivity of the solid-fluid system (J s−1 m−1 K−1) [13].

Assuming that $\rho_0 c_0$ for water is 42240 ($Jm^{-3}k^{-1}$) and k equals 1.756 ($Js^{-1}\ m^{-1}\ k^{-1}$), the vertical exchange is obtained based on temperature measured data.

$$\frac{\partial^2 T(z)}{\partial z^2}-\frac{\upsilon\rho_0 c_0}{k}\frac{dT(z)}{dz}=0 \quad (2)$$

In equation (2), the amount of ρ_{0C_0} for water is 42240 ($Jm^{-3}k^{-1}$) and k equals 756/1 ($Js^{-1}\ m^{-1}\ k^{-1}$). Then, by using equation (3), the rate of vertical exchange was calculated.

$$\upsilon=\left|\frac{k}{\rho_0 c_0 z}\ln\frac{T(z)-T_L}{T_0-T_L}\right| \quad (3)$$

Results and Discussion

Figures 1 and 2 show variation of temperature in the depth of river bed sediment. It was found that in July, the temperature is decreased by increasing the depth. The results also showed that in December the temperature is increased by increasing the depth. The average of vertical exchange velocity for July and December was 59.3 mm/day and 284.3 mm/day, respectively. By looking to distribution of temperature it was found that there is an inflection point which can be account as a measure point of mixing the warmer and colder water.

The penetration of surface water into the porous media can be estimated if the position of this point obtained. The position of this point from the river bed is obtained by regression analysis and presented as follows for December (Eq.4) and July (Eq.5):

$$Depth=0.946H+12.82WT+48.3V+12.54295T0-1.9Tw-140.07 \quad (4)$$

$$Depth=-0.55H+7.8WT+68V-61.38156T0+58.8Tw+30.87698 \quad (5)$$

Where Depth= the inflection point, H= depth of water, WT= flow width, V= flow velocity, TW= surface water temperature.

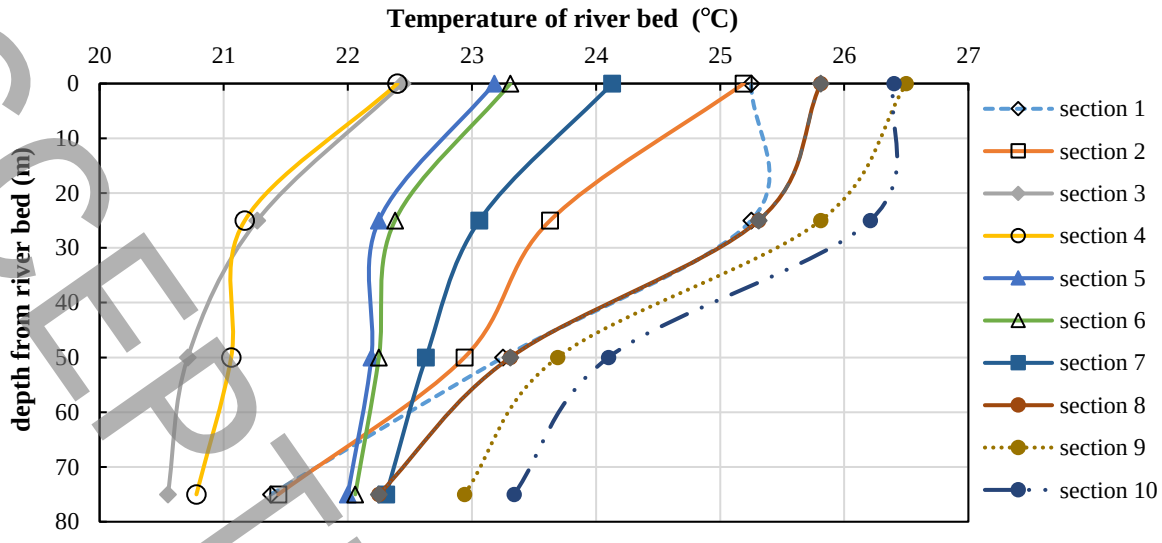

Figure 1: Variation of temperature against of depth from the river bed (July 2018)

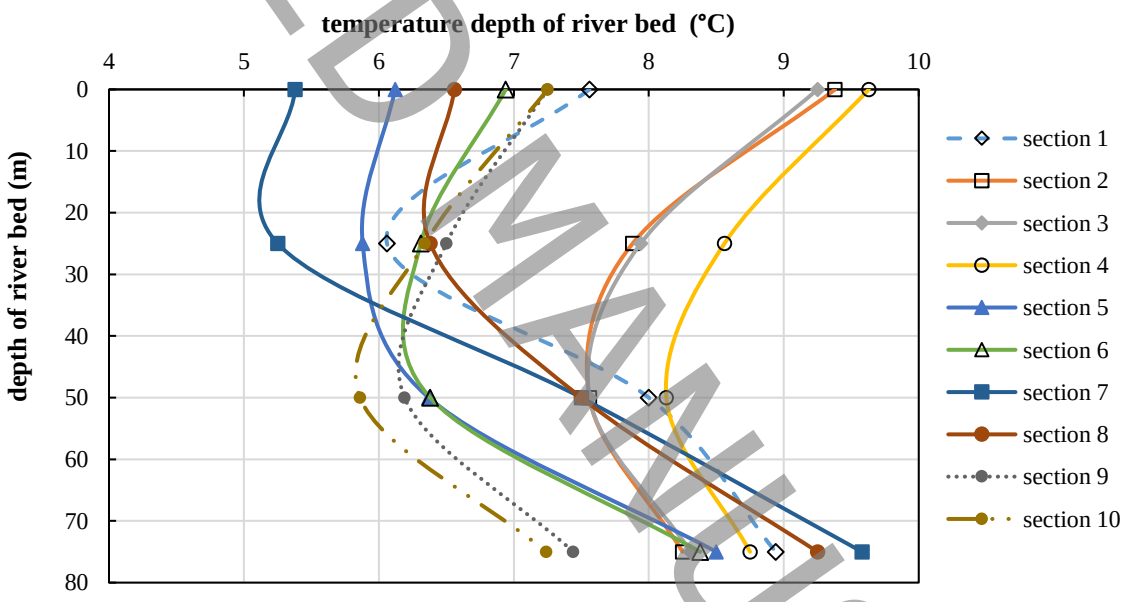

Figure 2: Variation of temperature against of depth from the river bed (December 2018)

Conclusion

In this study, vertical exchange velocity through sediment–water interface is estimated based on measuring the temperature profile below the river bed. The measurements were done during July and December 2018. The results show that the average of vertical exchange velocity for July and December was 59.3 mm/day and 284.3 mm/day, respectively. The results also show that the penetration depth of surface water into the porous media under the river bed can be estimated by correlating to readily available properties such as flow velocity, water depth, and surface water temperature.

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