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Hydrology and Earth System Sciences Discussions

Interactive comment on "Characterization of spatial heterogeneity of groundwater-stream water interactions using multiple depth streambed temperature measurements at the reach scale" *by* C. Schmidt et al.

C. Schmidt et al.

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We would like to thank the anonymous referee for the thorough review of our initial manuscript. He raised a number of critical points that are worth to be discussed and will help to improve the presented paper.

Specific Comments

1. The work in the present paper incorporates existing methods but combines these methods to a new approach to quantify groundwater-stream water interaction. The pioneering applications in the 1960s (e.g. Suzuki 1960) as well as the work of Lapham

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1989 and the various field studies of the group of Jim Constantz were using only a few temperature profiles (e.g. Stonestrom and Constantz 2003). Our work can be considered an extension of the basic idea of Conant (2004) that relates mapped streambed temperatures to spatial differences in groundwater discharge. We used his idea of "mapping" temperatures meaning measuring temperatures at one time at one location (but in 5 depths) assuming that the observed temperatures are in steady state for the finite time of the mapping campaign. The mapping concept allows to measure hundreds of profiles and therefore groundwater-stream interactions can be assessed with high spatial resolution on a large spatial extend. The use of temperature profiles allows to calculate the water fluxes across the streambed without the need of the installation of streambed piezometers like in Conant (2004). Therefore we do not agree that the approach presented in this paper is a case study that only uses well established methods. We believe that using streambed temperature mapping and the quantification of the water fluxes with a steady-state analytical solution provides a new tool for the characterization of groundwater-stream-interaction.

2. The range of thermal conductivities of saturated sediments is rather small. We want to emphasize that a measurement would not have led to another result than the estimation based on literature values. But nevertheless this is clearly a weak point.

3. In general it is interesting to address the spatio-temporal behaviour of stream and streambed temperatures and water fluxes. The aim of our study was to show that a simple steady state approach can successfully applied to quantify the fluxes across the streambed. We considered a steady-state solution to be the best option. The Stallman (1965) transient solution requires that the average surface water temperatures are equal to the groundwater temperature which is only true on annual scale. Predominantly in losing reaches (i.e. surface water recharging the aquifer) streambed temperatures are significantly influenced by diurnal stream temperature variations (e.g. Lapham 1989). Upward groundwater flow reduces the depth and amplitude of variations. Therefore diurnal temperature changes do not play a major role for temporal

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changes of the effective hydraulic conductivity of the streambed sediments. The investigated reach was dominated by groundwater discharge. We did not expect significant changes in the streambed hydraulic conductivity and the resulting fluxes due to diurnal temperature variations.

4. In our approach, diurnal temperature oscillations in the streambed represent a kind of disturbance. To relate streambed temperatures to water fluxes, it is essential that the spatial differences are higher than diurnal temporal changes during the mapping campaign. Our results show that there was a maximum difference between observed and simulated steady-state temperature profiles of 2.1 K. We will state in a more general way that during a mapping campaign the differences between the ambient groundwater temperature and the average surface water temperature should be higher than possible diurnal streambed temperature fluctuations.

5. Lapham (1989) states if upward fluxes exceed 305 Lm-2d-1 (1 ft/d) the temperature in the streambed would be equal the groundwater temperature and remain unaffected by fluctuations in stream temperature. We observed higher magnitudes of fluxes (up to 455 Lm-2d-1). The constraints depending strongly on the depths in which the measurements were taken. We observed in depth of 0.3 and 0.5 m that streambed temperatures can be essentially equal to groundwater temperatures. This never occurred in depth of 0.15 or 0.1m. With a decreased measurement depth the magnitude of fluxes that can be accurately quantified can be increased.

6. We found that all streambed piezometers indicated upward flow. At a few locations the temperature profiles showed recharge fluxes but with low flow rates (max. 10 Lm-2d-1). We did not consider the downwelling to be a significant process at our site but we have to interpret these findings. We concluded that this might occur due to small streambed topographical features. Explaining the heterogeneity of groundwater discharge is not easy. It is likely that the streambed only is not the major controlling factor. We suppose that high discharge zones are well connected to high conductivity zones in the aquifer. As the reviewer indicates we observed the heterogeneity of groundwa-

ter discharge to a smaller extent than in the study of Conant (2004) in a natural river. But still it was higher than we expected because the streambed appeared to be homogeneous. It is true, the concluding formulation that there is a lot of heterogeneity is misleading in terms of the comparison of Conant (2004). We will reword that.

Technical corrections

All proposed technical corrections will be included in the revised manuscript.

The conduction of heat can be considered a diffusion process. Both terms diffusion and conduction can be justified. For clarification we will use heat advection-conduction equation.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 1419, 2006.