Hydrol. Earth Syst. Sci. Discuss., 8, C4281–C4287, 2011
www.hydrol-earth-syst-sci-discuss.net/8/C4281/2011/

Hydrology and Earth System Sciences Discussions

Interactive comment on "Sand box experiments to evaluate the influence of subsurface temperature probe design on temperature based water flux calculation" *by* M. Munz et al.

M. Munz et al.

munz@uni-potsdam.de

Received and published: 29 September 2011

We thank the Anonymous Referee #2 for the contribution to and comments on our manuscript. We would like to take this opportunity to answer his questions and explain our points of view.

- Are you sure about the variations of hydraulic conductivity with Temperature? Could you provide one reference showing this kind of effect?

Authors response: We detected daily variations of water fluxes even when no variations (disturbances) of the experimental setup were present. In general: midday fluxes were

higher than those measured in the morning or late in the afternoon. In our point of view the most obvious reason for such variation is the dependence of the hydraulic conductivity on subsurface temperature. The hydraulic conductivity is related to the viscosity and density of the fluid; which are dependent on temperature itself. A decrease in temperature from 20°C to 10°C would cause a decrease of hydraulic conductivity from 19.4 to 14.9 m d-1 and an increase in temperature from 20 to 30°C would cause an increase in hydraulic conductivity from 19.3 to 24.4 m d-1 using sand box permeability and temperature dependent values of fluid density and fluid viscosity. Constantz et al. (1997) demonstrated that the effect of stream temperature on streambed seepage is a major factor contributing to reduced afternoon stream flows. Their explanation is based on the effect of stream temperature on the hydraulic conductivity of the streambed; which can be expected to double within the 0 to 25°C temperature range. Storey et al. (2003) simulated subsurface flow within a single riffle of a low-gradient gravel bed stream and conclude that the hydraulic conductivity of the streambed can vary by up to 40% with season due to changes in water temperature.

The references will be included in the revised version of the manuscript at P 6168-L14: "The effect of stream water temperature on hydraulic conductivity and streambed flux in natural systems is shown by Constantz et al. (1997) and Storey et al. (2003)." The corresponding references will be added to the reference list and the beginning of the following sentence will be adapted.

- You attribute the lack of significance of higher upward fluxes to the oscillating tap water temperature. Did You check this fact? And did You cross check with any probe the temperature of the sediment surrounding the bucket in order to exclude other kind of effects (what about rain)? You should say something more.

Authors response: Measurements of the water temperature at the barrel surface were routinely performed by the MLTS probe and the bucket temperature was checked temporarily. We observed that during high upward fluxes temperature amplitudes at temperature sensors at the depth of 0.365 m were higher than at 0.165 m. In consequence an additional amount of heat was introduced into the system at a depth higher than 0.165 m below the surface. For us, the most obvious explanation of this effect is that heat was introduced into the system by temperature oscillations within the bucket. On the other hand we could not imagine reasonable heat sources within the soil occurring occasionally. In fact, that could have been proven by measurements of deep soil temperature. Missing that information the temperature variations within the bucket were the most obvious reason for the additional amount of heat introduced into the experiment. The amount of heat introduced into the upper water reservoir of the sand box by rain is recognized as it will result in measured temperature variations used in the analytical solution. The bucket was covered and no rain could enter; that is: effects evoked by rain would not influence the analyses of experimental data. We will add this information at P 6169-L21-24 according to the reviewers suggestion.

- At Pag. 6171 You state the utility of some “preliminary calculations for selecting measurements depths and frequencies”. Did you do them? How did you choose the depths for the probes? If possible, justify the choice of the depths.

Authors response: The depth of sensor location was mainly determined by construction of the MLTS having fixed sensor location and fixed sensor spacing. All other setups were designed in the way that equal sensor depth and equal sensor spacing was similar to the MLTS. But in general “the MLTS is constructed in a way that the temperature sensors will be located in the thermally active zone of riverbed sediment; given normally observed hyporheic exchange flux”. This information will be implemented in the description of MLTS probe for the revised version of the manuscript. Generally, the MLTS (temperature lance) could be produced using customer specified dimensions. In advance we prove if expected temperature fluctuation by the given sensor spacing and frequencies of one cycle per day is large enough to be detected by the deep sediment temperature sensors. The damping of temperature amplitude (estimation of thermally active zone of saturated sandbox sediment) was calculated using the Keery et al. (2007) solution (Eq.1) in the forward calculation mode. Note that by ‘frequency’

not the measurement frequency is addressed but the frequency of temperature oscillation. In studies covering larger time scales, seasonal fluctuations could be used for temperature based vertical water flux calculation. Flux results would be yearly averaged values of surface water-groundwater exchange flux.

- You state that the MLTS seems to be the more accurate. But this installation would probably not be effective in presence of horizontal flows. What is then its practical use?

Authors response: Daily temperature variations will influence the surface water temperature. This fluctuation will propagate into the sediment. Resulting temperature gradients within the streambed occur in vertical direction. All temperature probes are designed as vertical profiles, to analyze these vertical temperature gradients. None of them would be effective in presence of horizontal flow. We assume that the described method could be applied to streams to quantify the general vertical flux condition (gaining or losing). We agree that such installation in not practicable in presence of horizontal flows. We will note that for natural systems, if the focus is on horizontal flows occurring at e.g. pool-riffle sequences temperature will generally not be the best natural tracer to use. We will discuss this limitation more explicitly in section 3.5. in the revised version of the manuscript. For effects of non-vertical flow within streambeds on analytical flux calculations we refer to Lautz (2010) and Schornberg et al. (2010). These references are also given in the introduction (cp. P 6157-L15 and L18). For the practical use of temperature measurement in a vertical profile we refer to the literature cited in the introduction, especially to Anderson (2008) and Constantz and Stonestrom (2003). The advantages of the MLTS in comparison to the other temperature probe designs is its easy installation into the saturated sediment, guaranteeing defined probe distances and data accessibility during operation.

- I am pretty sure that it is possible to simulate your experiment with any numerical solver for the coupled equations of heat and liquid water propagation in porous media (e.g. Hydrus-1D). Did You try to do this? It could be helpful for You for data nterpretation, since You would be able to match your results with an ideal (numerical) case.

Authors response: Yes, we tried the numerical modeling using HydroGeoSphere; a fully coupled, two dimensional groundwater flow and heat transport model. Thereby it could be shown that simulated temperatures match measured temperatures at the depth of 0.065 and 0.165 m. (Measured temperatures of the surface water and at a depth of 0.365 m and measured hydraulic gradients were used as top and bottom model boundary condition. All other boundaries were set to no flow boundaries.) The model results indicate that heat introduced via the side boundary condition (horizontal heat conduction from the unsaturated soil sediment via the barrel sides into the saturated sediment does not affect measured temperatures at temperature probe location (about 0.2 m away from barrel side). Furthermore the model was used to calibrate the hydraulic heads at the bottom boundary condition in order to estimate the vertical water flux, showing comparable results to these arrived by analytical solution presented within the manuscript. As the analytical evaluation; presented within this manuscript; is shown to be an appropriate method to evaluate temperature profiles in order to calculate vertical exchange flux the authors think that an additional incorporation of numerical methods and derived results would go beyond the scope of this manuscript.

- I think also that You can try to correct for the thermal insulation of the piezometer in a rigorous way, applying analytical solutions of the heat equation in presence of a composite medium, with different thermal properties. Look for example in the Carslaw and Jaeger. Since the position of the probes is fixed inside the pipe, the correction could be very effective.

Authors response: A correction of measured temperatures for thermal insulation of the piezometer as suggested by the reviewer would be effective to derive accurate temperatures and time lags. If the study objective is to monitor distributed transient temperature patterns in the streambed a correction of the thermal insulation of the piezometer would be essential. Cardenas (2010) showed that temperature measured inside a pipe buried in sediment is lagged and damped compared to temperature outside of the pipe, violating the assumption that monitored temperatures are representative of the satu-

rated sediment. However, they conclude that methods using amplitude ratios and time lags to derive vertical water fluxes -as presented by Keery et al. (2007) and Hatch et al. (2006)- are not sensitive to effects of thermal insulation. The effect of thermal insulation would be equal for each sensor of the corresponding setup. Accordingly, these effects would cancel out if differences or quotients of sensor pairs are used for interpretation of measured temperatures. We will rephrase the paragraph at P 6172-L1-4 to clarify that statement.

Curiosity: what about using temperature from optical fiber? You could use the fiber as 3D MLTS, accounting for horizontal flows as well.

Authors response: Vogt et al. (2009) showed how DTS wrapped around a 2 inch PVC tube could be used to obtain highly resolved vertical streambed fluxes. They used the analytical solution presented by Keery et al. (2007) to analyze measured temperatures. Their experimental setup is limited to vertical water flow quantification and could not resolve a vertical flow component. The experimental effort to wrap the DTS and to install such measurement devices into natural streambeds is very high. The horizontal distribution of such installation to measure at multiple streambed locations is limited by high costs of DTS devices. The presented MLTS could be distributed independently along rivers to obtain a high vertical resolution of subsurface temperatures at several locations along a river. At any natural, atmosphere-induced temperature variations are not particular sensitive tracers for horizontal flow since the temperature gradients typically develop in vertical direction . A short summary of DTS applications will be presented in the introduction of revised version of the manuscript.

Technical Corrections:

Pag. 6167, Sec. 2.5 line 25: assu"e"med Pag. 6169, Sec. 3.2 lines 19-20: (Fig. 2b) is referred to (Fig.2c) and vice-versa

Authors response: The technical corrections will be changed for the revised version of the manuscript.

Literaure: Constantz, J., Thomas, C. L., and Zellweger, G. (1994). Influence of diurnal variations in stream temperature on stream flow loss and groundwater recharge. Water Resources Research, 30(12):3253-3264

Storey, R. G., Howard, K. W. F., and Williams, D. D. (2003). Factors controlling riffle-scale hyporheic exchange flows and their seasonal changes in a gaining stream: A three-dimensional groundwater flow model. Water Resources Research, 39(2)

Vogt, T., Schneider, P., Hahn-Woernle, L., Cirpka, O.A. (2010). Estimation of seepage rates in a losing stream by means of fiber-optic high-resolution vertical temperature profiling. Journal of Hydrology, 154–164

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 6155, 2011.