

Response to reviewers' comments to the manuscript:" The effect of sediment thermal conductivity on vertical groundwater flux estimates, MS number: hess-2018-210

First of all the authors would like to thank the two anonymous reviewers for the encouraging and useful comments! Based on the suggestions we believe that we managed to address all concerns of the reviewers and generally improve the clarity of the manuscript.

Please note that the references to page, line and figure numbers in the corrected manuscript refer to the revised manuscript submitted together with this response.

Response to Referee #2:

General comments: The manuscript "The effect of sediment thermal conductivity on vertical groundwater flux estimates" used measured profiles of sediment temperatures and bulk thermal conductivities (k_e , using a KD2Pro thermal property analyser) with depth in two contrasting environments, and used these data in conjunction with Hydro-GeoSphere (HGS) and PEST to determine upwelling fluxes. The analyses investigated the use of the detailed k_e profiles as well as homogeneous profiles on the resulting fluxes from HGS.

Overall, the manuscript was interesting to read, well written and clearly explained. The figures were also of a high quality.

Specific comments:

The temperature-depth profiles are taken at a specific point in time. Presumably the profiles at a particular site were all taken within a short time frame? At any rate, the use of steady state temperatures is likely an additional source of uncertainty in these analyses. There is an equation presented in Briggs et al. (2014, JoH) that can be used to determine the propagation depth of a diurnal signal. This could be used to determine whether transience is likely to be influencing the temperature profile at each depth. Presumably the upper part of all profiles is not in steady state, especially the lower flux site. An investigation into the implications of this, and comments on the influence of transience in the temperature profiles would be useful.

The temperature profiles were taken within a time interval of a few hours at each measurement site, thus transience in the upper part of the profiles can be expected. At the stream site however, as the majority of stream water is originating from groundwater (thus having a relatively stable temperature) and due to the high velocity water flow, the high upward groundwater fluxes and the thickness of the water column, the transience in the upper part of the sediment profiles is negligible.

In the low-flux, shallow lagoon environment however, transience can be more pronounced. The effect of transience was therefore assessed at the lagoon site using the analytical solution (Goto et al. 2005) reported in Briggs et al. (2014) under the current field settings (see table below), assuming only heat conduction. The results show that the propagation depth of the diurnal signal will be measurable only until a depth of 0.1 m below the sediment bed when assuming extreme boundaries of 5 degree temperature amplitude and a 1h response time (Figure 1, in response). However, such assumptions are unlikely to occur in natural settings. Under natural field conditions upward fluxes can be expected to shift the propagation depth

higher up towards the sediment-water interface. Additionally, lowering the thermal conductivity will minimize the propagation depth and vice versa. Such low thermal conductivities were typically observed in the shallowest parts of the profiles (Fig.2 in the manuscript).

Thus in the timeframe the measurements were taken, the upper part of the sediment temperature profiles can be assumed to be in steady state.

		unit
thermal conductivity:	1.8	[J/m s °C]
fluid heat capacity:	4192	[J/kg °C]
fluid density:	999.73	[kg/m ³]

Table 1: Input parameters for the Stallman model

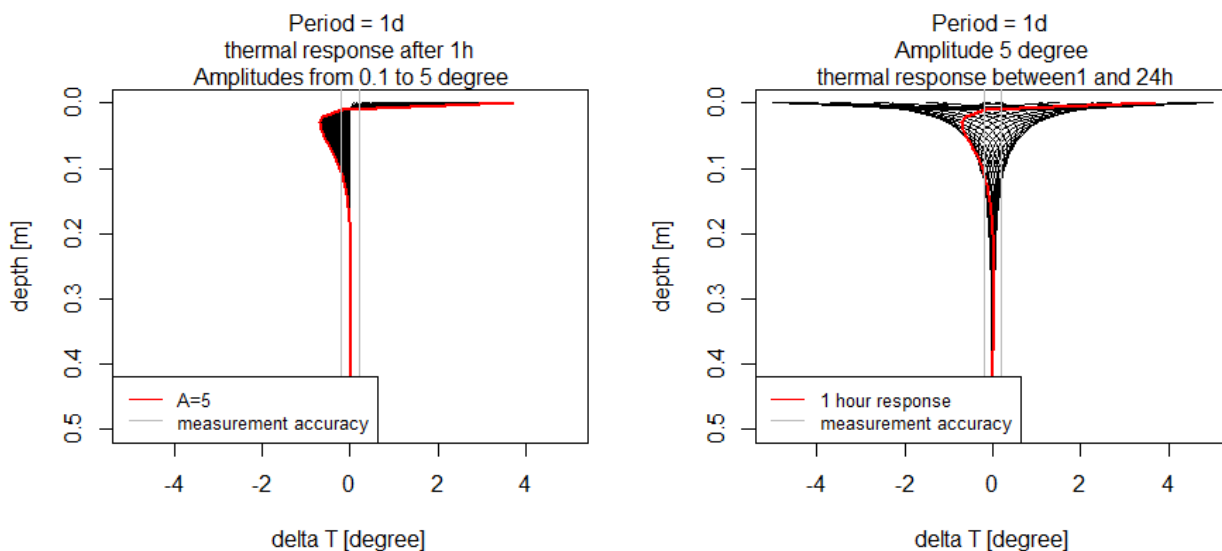


Figure 1: Propagation of the diurnal temperature signal in the lagoon bed, assuming the measured thermal parameters (Table 1, in response) at the lagoon and a temperature amplitude of up to 5 °C (left) and a time interval between 1 and 24 hours (right).

Action: Results of test calculating the penetration depth was added to the manuscript text:
‘Using the solution presented by Briggs et al. (2004) with the thermal parameters measured in the lagoon assuming 5° C diurnal amplitude and only heat conduction, the penetration depth of the diurnal signal was found to be 0.1 m under the lagoon bed. Due to the upward fluxes at the lagoon this penetration depth is even shallower, thus it is assumed that transience in the temperature profiles does not affect results significantly.’ Page 9 lines 1-4

There are a number of numerical modelling programs that are custom made to fit temperature data to determine fluxes (e.g. Munz and Schmidt, 2017 HP, Koch et al. 2015, GW). Is there any particular reason why HGS was used over these other approaches?

HydroGeoSphere was selected as a modelling program as a similar code coupled with PEST was already available to the authors from a previous study.

No action

I think that the selected boundary conditions in the HGS simulations are also a major source of uncertainty/error. Rather than setting the water temperature at $z = 0$ and a deeper groundwater temperature, why not use the measured temperatures at the top and bottom of the profile as the boundary conditions? This would dramatically improve the fits on some of these profiles (e.g. P4, upper part of S4, P1, S7, H4). This will likely significantly change the resulting flux estimates. The large mismatch between observed and modelled data look to be a major source of uncertainty.

The reviewer is referred to the response given to the comment of Referee# 1 on Section 4.2 and Figure 3.

It would also be useful to see the T-z profiles from all (or more) of the sites. In particular, the low flux environments. Alternatively, a way to show the RMSE that goes with the values in Fig3 and Fig4 would help show whether poor fits are a major source of error or not.

Our intention with including Figure 3 in the manuscript was to visualize the T-z profiles and provide an opportunity to the readers to assess the fit between the measured and simulated data. For this reason for each measurement site we selected the profile with best and worst fit between observed and simulated data and also included in the manuscript text the best and worst RMSE values for the five cases (page 6, line 27-31). As each measurement profile would have 6 datasets on the T-z figure (measured data and the five cases) we believe that a separate figure would be needed for each individual profile in order to maintain the readability of the figure. Furthermore as the included profiles are typical for the measurement sites we feel that providing an extra figure would not give any additional value to our manuscript.

No action

Page 2 lines 6-7, there are also time series based methods for mapping fluxes (e.g. Lautz and Ribaudo 2012, HJ, Irvine and Lautz 2015 JoH).

Action: Reference to the study of Lautz and Ribaudo (2012) added to the manuscript: “*The temperature distribution at the bed of surface water bodies can be used for qualitative mapping of potential discharge sites (Conant, 2004; Sebok et al., 2013; Briggs et al., 2011) or supplemented by heat transport modelling also for obtaining flux estimates over larger areas (Lautz and Ribaudo, 2012).*” Page 2 line 7-10

Page 2, lines 24-25: The McCallum/Luce methods do not require thermal conductivity to estimate fluxes. They can also be used to determine thermal conductivity. i.e. these are two separate approaches. It is not immediately clear if this is what is meant in the first two sentences here.

Action: The manuscript text was changed to clarify this misunderstanding: ‘*For some approaches sediment thermal conductivity (ke) is not required to estimate groundwater flux and in a separate approach sediment temperature time series can be used to estimate sediment thermal diffusivity (McCallum et al., 2012; Luce et al., 2013).*’ Page 2 line 25-27

Technical corrections: Page 9, lines 23-25: In the sentence about the paper from Duque et al, is this depth supposed to be 0 m?

Action: Sentence was rephrased to: "*Previously, Duque et al. (2016) also measured thermal conductivities between 0.62-2.19 W/m°C at the surface of the lagoon bed at 0 m depth, while in our study values between 0.65 and 1.99 W/m°C were found at 0 m depth at the lagoon surface.*"
Page 9 line 25-27

References:

- Briggs, M. A., Lautz, L. K., Buckley, S. F., and Lane J. W.: Practical limitations on the use of diurnal temperature signals to quantify groundwater upwelling, *J. Hydrol.*, 519, 2014.
- Goto, S., Yamano, M. and Kinoshita M.: Thermal response of sediment with vertical fluid flow to periodic temperature variation at the surface, *J. Geophys. Res.*, 110, 2005.