

## ***Interactive comment on “Transient analysis of fluctuations of electrical conductivity as tracer in the streambed” by C. Schmidt et al.***

**C. Schmidt et al.**

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Received and published: 24 August 2012

Reply to Referee#1

We are grateful for the constructive comments and suggestions of Referee #1. We have carefully considered all comments. Detailed responses to all individual comments by Referee #1 are given below.

**SUBSECTION 2.1. FLUCTUATIONS OF ELECTRICAL CONDUCTIVITY** At the end of this subsection, you mentioned a variety of factors that may affect EC fluctuations in stream. Could you explain why the effects of evapotranspiration, changes in groundwater discharge, and uptake of CO<sub>2</sub> are neglected?

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Section 2.1. does not claim to include all possible mechanisms influencing the EC of stream water. We wanted to show that a variety of factors may influence the actual EC and cause significant variability which in turn can be used as a natural tracer. However, on page 6349 in lines 23-26 we state that groundwater discharge, evapotranspiration and the uptake of CO<sub>2</sub> have an influence on EC. These factors have thus not been neglected.

**SUBSECTION 3.2. EXPERIMENTAL SETUP AND DATA COLLECTION** Adding a picture or a figure with the sketch of the screened tube containing the EC sensor could be very helpful to the reader.

A new figure showing the screened tubes will be added to the revised manuscript.

Introduction Page 6346, lines 21-23. Please, add a citation to support this sentence.

We will add appropriate references and rephrase the sentence to: Spatial pattern of water fluxes are controlled by the heterogeneity of streambed sediments and the resulting hydraulic conductivity distribution (Sawyer and Cardenas, 2009, Salehin et al. 2004), streambed and stream morphology that cause pressure gradients across the streambed (Stonedahl et al. 2010) as well as the spatial connectivity to the adjoining groundwater system (Storey et al. 2003). Temporal variations of flow are a result of varying hydraulic conditions in both the stream and the aquifer (Schmidt et al. 2011).

These additional references will be included in the revised manuscript:

Salehin, M., Packman, A., Zaramella, M., 2004. Hyporheic exchange with gravel beds: Basic hydrodynamic interactions and bedform-induced advective flows. *Journal of Hydraulic Engineering-Asce* 130, 647–656.

Sawyer, A.H., Cardenas, M.B., 2009. Hyporheic flow and residence time distributions in heterogeneous cross-bedded sediment. *Water Resour. Res.* 45.

Stonedahl, S.H., Harvey, J.W., Wörman, A., Salehin, M., Packman, A.I., 2010. A multiscale model for integrating hyporheic exchange from ripples to meanders. *Water Resour. Res.* 46, W05501.

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sour. Res. 46, 14 PP.

Storey, R.G., Howard, K.W.F., 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.

Page 6346, line 25. Replace 'direction flow' with 'flow direction'.

We will change the sentence to: Changes of flow velocity and flow direction in the streambed can be induced by flood events...

Page 6347, line 22. It would be appropriate to cite other works in this paragraph that supports your text, see for example Constantz J.: Heat as a tracer to determine streambed water exchanges. *Water Resour. Res.* 44, W00D10, doi:10.1029/2008WR006996, 2008.

The sentence on Page 6347, line 22 is intended to introduce the works on heat as a tracer and a number of references is provided in the following lines. We agree that including a reference giving a general overview of this topic is helpful. We will add the proposed paper by Constantz, 2008:

Constantz, J., 2008. Heat as a tracer to determine streambed water exchanges. *Water Resources Research* 44, 20.

Page 6348, lines 2-4. I am confused about how this sentence help the reader to understand why EC is practically a conservative tracer. Please, reformulate it.

Indeed, this was not clearly formulated. We will rephrase the sentence to:

Temperature variations at the surface are strongly attenuated with depth since heat is conducted through both the solids and the water of the bulk sediment. In contrast solute transport is realized by fluid flow and diffusion in the pore spaces. Therefore fluctuations of solute concentrations (expressed by EC) are typically attenuated less and can propagate further into the sediment than temperature variations (Vogt et al.

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2010 b, in the reference list) .

Page 6349, lines 5-8. Please, improve/remove this statement and clearly outline the paper objectives.

We rephrased the sentences to better clarify the objective of the paper. We also add some lines to better specify the novelty of the paper with respect to the comment below

In this study we introduce a modified DTW algorithm with a sliding window to evaluate the variability of advective travel times between the stream and the streambed based on time series of EC. We provide the general theory and an application of the method. The underlying idea of our approach is to create a distance matrix similar to conventional DTW but instead of an element by element alignment, subsequences of the time-series are aligned. This reduces the sensitivity of the method to noisy data. To our best knowledge, a DTW approach based the alignment of subsequences has not been published. We show how this transient analysis and interpretation of EC time series can provide deeper insight into flow processes in the streambed and the hyporheic zone.

Theory Page 6349, lines 14-16. Please, add a reference to support this statement "However, diurnal temperature signals: : :".

The work of Vogt et al. 2010b (*Advances in Water Resources*) will be added here (already in our reference list)

Page 6351, lines 15-16. I think that this really needs a clearer explanation. Reading the sentence and the successive paragraphs it seems that the author develop a new modified DTW approach. Please, specify the novelty of the approach that you use.

We do not claim that our method is a new modified DTW approach. However, we are not aware of any publication using DTW in the way we have proposed (please find our specific reply to the suggested references). We would be grateful for a reference on DTW as we applied it. The main goal of our study is to introduce a DTW based

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technique to for the transient analysis of time series. We refer to an earlier comment which shows how we will modify the text to better explain the novelty of our approach.

In literature there are other works that use the sliding window where the distance matrix use the Pearson sample correlation coefficient (see for example A. Webb, *Statistical Pattern Recognition*, 2nd ed, 2002, or M. H. Ko, G. West, S. Venkatesh, M. Kumar, *Using dynamic time warping for online temporal fusion in multisensor systems*, *Information Fusion*, Volume 9, Issue 3, July 2008, Pages 370-388, ISSN 1566-2535, 10.1016/j.inffus.2006.08.002).

The reviewer suggested two references.

The book "Statistical Pattern Recognition" is not related to our work. We could not find information on dynamic time warping or cross correlation or related methods. Please correct us here if we are wrong.

We analyzed the paper of Ko et al. 2002 in detail. They analyzed data streams from multiple sensors. They used a sliding window to extract vectors from continuous streaming data and then further processed the selected vector. The use of a sliding window is a preprocessing step and not part of the DTW algorithm itself. In our application the window is used to create the distance matrix itself and replaces the element by element distances. We find that the suggested reference does not directly relate to our work.

Results Page 6534, line 12. Replace "for" with "of".

We replace the "for" with "of" at page 6354

Page 6534, line 22. Add "was" after "and". An "was" is added at page 6354

Page 6355, lines 7-8. This sentence is quite confused, please reformulate it. Do you mean that because of high frequency components in the stream, EC signals are partially damped in the streambed both at downstream and upstream location? In the introduction section, you state that EC propagate deeper in the sediment and therefore

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you can consider EC a better conservative tracer than temperature; but here you say that at a streambed depth of 44 cm the EC signal present some dumping. So, can you explain why EC is better than temperature?

The EC signal is subject to dispersion, as the concentration of a solute would be during flow in porous media. Thus, a pulse like input of solutes (measured as EC) will spread and will not be detectable after a sufficiently long flow distance. For periodic (or quasi periodic) signals the damping is also dependent on the frequency. High frequencies (short fluctuations) are subject to higher damping. In Figure 4c in both streambed signals the double peak in the stream EC is not resolved. We assume that this short term variation did not propagate sufficiently deep into the sediments. The damping of temperature fluctuations is even higher because heat has a much higher diffusivity than solutes (EC)

To make this section more concise we will rephrase the sentence to: However, we have detected a period with low correlation between the stream and the streambed EC around July 24th and 25th (Fig. 4c, Fig.5). The short term fluctuations (double peak) of EC do not propagate sufficiently deep into the sediment to be detected by the streambed sensors (Fig. 4c). The damping of the varying EC signal depends not only on dispersion and diffusion but also on the frequency.

Discussion Page 6357, lines 4-14. This paragraph discuss particulars that are not directly related with the EC measurements and therefore it should come earlier in the "Study Site" section.

The paragraph compares the vertical velocities estimated from the time lag of the EC signal and the depth of the EC sensors with independent Darcy based flow velocities. It shows that the results are comparable with Darcy based estimates and EC might be even the better choice for short term variations of water levels.

Since the paragraph seems unclear we decided to remove it from the paper since it is not essentially needed. Please also see our reply to Referee#2

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Page 6357, line 29. Add “along” after “locations”.

Instead of "along" we will add an "in"

Page 6357, line 26. Replace “out” with “output”.

We will change this on page 6358 line 6

References The references have several spelling mistakes, please take a closer look.

All references will be checked in the revised manuscript

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 6345, 2012.