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Discussions

Interactive comment on "Detecting groundwater discharge dynamics from point to catchment scale in a lowland stream: combining hydraulic and tracer methods" *by* J. B. Poulsen et al.

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Response to reviewers' comments to the manuscript: Detecting groundwater discharge dynamics from point to catchment scale in a lowland stream: combining hydraulic and tracer methods MS No.: hess-2014-369

by J. R. Poulsen, E. Sebok, C. Duque, D. Tetzlaff, P. K. Engesgaard

The authors wish to thank the two anonymous reviewers for their comments and helpful suggestions to changes and corrections in the manuscript. We have addressed all comments and find that the resulting changes in the manuscript have helped to clarify

several passages and generally improved the manuscript.

Note that references of pages, lines and figures with corrected parts of the manuscript refer to the manuscript version submitted in relation to this response to reviewers' comments.

Response to referee #2

Response to general remarks

Referee comment #1: My main overall issue with this paper is that the information about piezometer sampling and the spatial variability in head gradient are unnecessary to answer the authors' questions and could be removed from the manuscript, including figure 3. While interesting, they do not seem to fit in with the aim of the paper given in the abstract and introduction, which is to compare VTP, DTS, differential gauging, and hydrograph separation. If the authors wish to keep the groundwater head information, they should incorporate it into the abstract and introduction. As the paper currently reads, the head measurements seem to come out of nowhere.

Response #1: We acknowledge the reviewer's concern about the relevance of the groundwater head gradients and the lack of clear explanation of the correlation with the rest of the study. However, we do find that the groundwater head gradients contribute with significant information, especially in terms of supporting the findings of the spatial variability of the catchment runoff sources (as described in section 5.3 in the manuscript). One of the questions that we ask in the introduction is, whether we will see differences in runoff sources in such a groundwater dominated environment as the one investigated. We answer this question primarily based on the results from the hydrograph separations. However, the information about the two different patterns of groundwater head gradients between station 1 and then stations 2 and 4 supports the findings of the hydrograph separations, and the conclusions about the spatial variability. Hence, we would prefer to keep the information about the groundwater head gradients in the manuscript. We therefore hope that we, with the corrections mentioned below, have accommodated some of the reviewer's concerns and made the link between the groundwater head gradients and the other findings of the study sufficiently clear.

Action #1: Sentences have been added to the abstract and the introduction to emphasize the relevance of the groundwater head gradients. In the abstract: 'supported by the groundwater head gradients, where the location of weaker gradients correlated with a stronger response to precipitation events' (p. 2 lines 18-19). In the introduction: 'and groundwater head gradients' (p. 5 line 22).

Response to specific comments

Referee comment #2: The authors cite Sophocleous 2002 multiple times, and given the information about plagiarism in that paper (http://link.springer.com/article/10.1007/s10040-014-1215-0/fulltext.html) I would recommend removing all of those citations.

Action #2: References have been removed from text.

Referee comment #3: Page 13115, lines 28-29 and page 13116, lines 1-2: Are these correlations statistically significant? Please note their p-values.

Response #3: Based on the reviewer's comment we analyzed the correlation between the strength of the groundwater signal and the upward groundwater fluxes further. As the Shapiro-Wilk test showed that the signal strength and the upward groundwater flux data is not normally distributed, instead of the Pearson product-moment correlation, the non-parametric Kendall rank correlation was used for each layout. This correlation coefficient was 0.572, 0.629 and -0.010 for layouts A, B and C respectively, thus showing a moderate/strong correlation between the variables for layouts A and B at the $p<0.01$ and $p<0.05$ significance level, respectively. For layout C there was no significant correlation between the variables.

Action #3: Manuscript text changed to: 'For layout A and B the comparison between estimated upward groundwater fluxes and the strength of the groundwater signal (Eq.

3) at the corresponding DTS locations showed a moderate correlation (significant on the $p<0.01$ and $p<0.05$ level, respectively) (Fig. 5)' (p. 13, line 6).

Referee comment #4: Page 13116, line 24: How are the authors defining 'recovery time'? Is it 90% of prevent water? 95%? This information should be added, and perhaps indicated on the graphs in Figure 7 c-f.

Response #4: Recovery time is defined as the time needed to reach pre-event concentrations in the stream (approximately 100% pre-event water).

Action #4: Sentence added to text: '(recovery time is defined as the time it takes to reach pre-event concentrations).' (p. 13 lines 28-29).

Referee comment #5: Page 13119, lines 7-10: Layout C is 1/3rd of the study, so I believe the authors need to more fully address why there is the discrepancy between signal strength and estimated fluxes in this location. After all, a third of the study does not show that these two methods show a correlation between DTS and VTP flux estimates.

Response #5: We think that the diverse relation between the upward groundwater fluxes and the strength of the groundwater signal in Layout C is due to the reduced temperature differences between the streambed and groundwater. Because of this reduced temperature contrast the signal strength of groundwater discharge is also reduced which we find most likely to be the reason for the less clear relation between signal strength and estimated fluxes in Layout C.

Action #5: The manuscript text has been modified to explain the discrepancy observed at Layout C: 'There is a discrepancy of estimated fluxes and groundwater signal strength in the case of layout C which can be most likely attributed to the reduced difference between the streambed temperatures and groundwater temperature (Fig. 4a).' (p. 15 lines 24-27) Referee comment #6: Page 13120, line 1: this is exactly why you need to add error bars to figure 4 (see note below on figure 4)

Response #6: During the campaign the ADCP measurements were expected to have an uncertainty less than or equal 5% (se response to comment #10 below). A pilot study was conducted during a low flow period in early spring 2012, to determine the approximate distances needed between discharge measurements, in order obtain an increase in discharge of more than 5%. The study showed that for the investigated stretch of the stream, at least 150 m (and for some stretches 200 m) were necessary between measurements.

Action #6: A sentence has been added in the text: 'The distances of 150 and 200 m between ADCP discharge measurements were chosen, based on a pilot study conducted in early spring 2012. The pilot study showed that at least 150 m between measurements were needed to obtain discharge increases larger than 5%.' (p. 8 lines 32-35).

Referee comment #7: Page 13120, lines 23-27: I would also cite Vidon and Cuadra, 2010, Impact of precipitation characteristics on soil hydrology in tile-drained landscapes, Hydrologic Processes 24.

Response #7: We agree that this is a highly relevant paper which should be cited.

Action #7: Reference added in the text and in the reference list.

Referee comment #8: Figure 2: The authors should combine these two graphs into one and help the reader to better visually assess the stream response to rainfall events.

Action #8: We agree and the figure has been changed.

Referee comment #9: Figure 4: The caption does not tell the reader where the vertical flux measurements are coming from. I'm assuming they are from VTP measurements, but that information should be added.

Action #9: Note added to the figure caption: 'Vertical fluxesare estimated based on VTP measurements.' (p. 32 line 9).

Referee comment #10: Figure 4: Error bars should be added to part b, or if they are too small to see because of the symbol size, that should be indicated in the caption.

Response #10: We are not entirely sure how to interpret the reviewer's comment about the error bars on VTPs. It would generally be possible to fit a temperature profile on the observed data by inverse modeling, thus giving the confidence intervals on the flux estimates. In the meanwhile we used a trial-and error approach when estimating the upward fluxes. In our opinion this approach works better in this high-flux environment where significant temperature changes occur over very short distances below the streambed. Based on our experience, the numerical solutions may provide a good fit to the observed temperature data minimizing the difference between the observed and modeled temperatures, but are also sometimes incapable of capturing the sharp temperature changes in the vertical profiles rather providing a general good fit where the differences average out. The trial-and-error optimization process allows for both the minimization of the RMSE between the observed and modeled temperatures while also ensuring a good visual fit of the modeled temperature data in the critical areas of the temperature profile.

In the meanwhile we calculated the RMSE for the fit of the observed and modeled temperature data for each profile. The average RMSE for the temperature profiles was 0.126°C between the measured and the modeled temperatures (minimum RMSE: 0.016°C, maximum RMSE: 0.304°C). Considering that the accuracy of the temperature measurements is 0.2°C, the RMSE between the measured and modeled temperatures represent a good fit, thus the uncertainty in the calculated temperature profiles is assumed to be small.

Teledyne Instruments recommend conducting enough ADCP measurements to obtain at least 4-5 measurements which deviate within 5% of each other. With this procedure the deviation between measurements are considered to represent the minimum uncertainty of the measurements. In a pilot study in Holtum stream it was investigated, how many repeated measurements were needed, to reach a steady average discharge value. The results showed that more than 10 repeated measurements did not significantly change the average discharge value. Hence, for the campaign sampling in the present study, ADCP measurements were repeated at each location, until 10 measurements were achieved which deviated less than 5% from each other. Hence, the uncertainty of the discharge measurements depicted in Figure 4 is expected to be below 5%, and are thus too small to depict on the figure.

Action #10: Data about the RMSE of the temperature profiles was added to the manuscript: 'The average RMSE for the fitted temperature profiles was 0.126°C between the measured and the modeled temperatures (minimum RMSE: 0.016°C, maximum RMSE: 0.304°C).' (p. 12 lines 23-25) and about ADCP uncertainty: 'Uncertainties of the ADCP stream discharge measurements were all below 5% (not shown).' (p. 32 lines 8-9).

Referee comment #11: Figure 4: The authors should indicate in part a and b of this figure where the tributary joins the main channel.

Response #11: We agree that it is confusing with the label "station 3" as the station is located in the tributary.

Action #11: The figure has been changed so that it is indicated where the tributary joins the main channel.

Referee comment #12: Figure 5. Error bars should be added.

Response #12: Please refer to response for comment about Figure 4.

Action #12: No action.

Referee comment #13: Figure 8: The authors should show the uncertainties in the figure.

Response #13: As stated in the figure legend to Figure 8, the uncertainties of the calculated pre-event fractions were all below 10%. As the data points mostly plot close

to each other, adding the error bars to each point significantly reduces the visual impression of the differences between stations and between pre-event and sub-surface fractions. Hence, we prefer to mention the uncertainties in the figure caption and not with error bars on the figure.

Action #13: No action.

Response to technical corrections

Referee comment #14: Page 13105, line 14: I would change 'wrong' to 'incorrect'

Action #14: Has been changed in the text.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 13101, 2014.