Hydrology and Earth System Sciences Discussions

Interactive comment on "Quantifying spatial and temporal discharge dynamics of an event in a first order stream, using Distributed Temperature Sensing" *by* M. C. Westhoff et al.

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We would like to thank Dr Wörman for his detailed reading and useful comments. Parts of the comments originate from a lack of clarity in the model description. In the revised manuscript we shall add an appendix describing the model in greater detail, since the article we referred to (Westhoff et al., 2011) is still under review. All other comments are answered just below the issues raised. The reviewer comments are in italic.

Mathematical formulation of the problem
The authors explain that they use the following models

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Interactive Discussion

Discussion Paper

1. A hydraulic routing model
2. A transport model for temperature
3. An energy balance model
The energy balance model "is a sink/source term in the transport model" that is given
in terms of the Equations (1) – (3). Thus, it seems like there is actually only two
models, one for water flow (representing conservation of momentum and continuity)
and one for heat transport given by Equations (2) – (3). Eqn. (1) is part of the hydraulic
model (i.e. the Saint Venants equations) and the two equation systems are solved
uncoupled. Therefore, it is somewhat confusing that the authors discuss three models
and include the continuity equation for water (Eqn. (1)) in the model for heat transport.
The entire model description could be made clearer with regard to the water flow and
heat transport models.

In the revised manuscript, we shall add the momentum equation. We shall also expand
the model describtion, since the article describing this model (Westhoff et al., 2011) is
still under review.

A specific comment regards the formulation of heat exchange with the subsurface.
In Eqn. (3) there are two terms on the right-hand side of the equation that describes
the time rate of change of heat in the subsurface, a diffusive term and a first-order
exchange term. What is the relationship between the temperatures Ts and Thz? My
interpretation is that Thz is a constant temperature of the hyporheic zone and Ts is a
time-variable temperature controlling heat conduction in the rock clasts.

T_{hz} is the same as T_s, but only at the locations where hyporheic exchange occur. In
the revise manuscript we shall make this clearer.

In a comment on p. 2181, the authors claim that the exchange with the rock clasts
(represented by the second term on the right-hand side of Equation (3)) is instanta-
neous. This is not correct. As formulated in Equation (3) the exchange rate due to the

second term on the right-hand side is constant over time, but rate limited.
The second term on the right-hand side of Eq (3) represents hyporheic exchange. Heat exchange with in-stream rock clasts is hidden in the storage term of Eq (2), where A_b represents the cross-sectional area of water plus rock clasts, while ρ_b and c_b are weighted averages of density and heat capacity of water plus rock clasts. This formulation is valid only when heat exchange with in-stream rock clasts is instantaneous. In the revised manuscript we shall better explain this part of the model.

Further, this reviewer doesn't understand how the exchange between the stream water and hyporheic zone can affect the temperature of the rock clasts without a reverse effect on the hyporheic zone temperature from either/or both of the heat of the instream water or rock clasts.
In the model we consider 2 transient storage zones: one represents heat exchange with in stream rock clasts, which is hidden in Eq 2 (as just explained), and the other one represents hyporheic exchange (second term on the right-hand side of Eq 2 and 3). The hyporheic exchange influences the stream water temperature and vice versa, while the rock clasts influences the stream water temperature as well. In the revised manuscript, we shall better explain the model to prevent such misinterpretations.

Model optimization using multi-objective function
The authors introduce an innovative model optimization technique that includes a multiobjective criterion for both heat and discharge. However, it is not clear to this reviewer why some elements of the suggested method is superior to alternative statistical techniques, since no comparisons are made. The authors compare the model performance versus data with different model complexity, but alternative methods are missing.

A more thorough motivation would be needed regarding the splitting of the time series

(first and second discharge peak) to determine different model parameters as well as the range of model uncertainties. For instance, why is the splitting of the time series needed if different model parameters are (really) reflected in distinctly different parts of the data? Wouldn't optimization using the entire time series reflect this automatically? It is difficult to get the overview of the impact on model complexity on model errors.

The aim of this paper is not to automatically optimize the model, but to use the model as a learning tool. We chose to split the time series, because, first of all, it reduces calculation time significantly. And secondly, by splitting the time series, we could first determine the dynamic behaviour of for example stream losses with discharge. By simulating this behaviour during the second peak ("without changing any parameter"), we were able to formulate hypotheses and subsequently test them.

Clearly the model formulation can be discussed in several aspects, such as exact formulation of exchange relationships as well as parameter variability in time and space. Some of these model parameters like flow velocity or cross-sectional width generally vary significantly and can be measured independently (from the applied techniques). Numerous investigations suggest that the hyporheic exchange varies with stream discharge (Wörman and Wachniew, 2007; Schmid et al., 2010). However, the authors acknowledge only a few model scenarios where Qhyp and Pb are spatially variable. Can the authors present specific observations or other findings not included in the current version of the paper that support this limited approach to spatial and temporal dynamics in stream flow generation?

P_b and Q_{hyp} are spatially variable in all scenarios. We measured the cross-section of the stream at 64 locations along the stream using a pin-board, after which we derived for each location the relationship between water depth and cross-sectional area, width, wetted perimeter and the amount of in-stream rock clasts. With the momentum equation we determine the discharge and depth of the stream over space and time and subsequently the wetted perimeter P_b can be determined.

Q_{hyp} is also spatially variable. The spatial variability was calibrated in Westhoff et al.,

(2011). Because this paper is still in review, we shall provide more detail about this study.

The temporal variability of Q_{hyp} is more difficult to determine during a single rain storm. It is correct that numerous investigations suggest that the hyporheic exchange varies with stream discharge, but as we already stated in the introduction, these studies were all done during steady state discharge. This paper shows a first attempt to quantify the temporal dynamics of hyporheic exchange during a single rain storm using this top-down approach. We acknowledge that the chosen relationship between discharge and hyporheic exchange is only one out of several relationships. But since there is only limited information in the temperature signal, it would not make sense to optimize this relationship, because that would introduce another set of extra parameters that could be tuned. Therefore we chose to test only 2 scenarios: no temporal variability in hyporheic exchange, and a linear relation between hyporheic exchange and discharge.

Generality of conclusions
A main conclusion is that groundwater discharge to the stream is constant during the rainstorm event, whereas losses to bypass channels increase with discharge. There is a common understanding that stream flow generation is caused by the increasing groundwater discharge and not the ground surface runoff or precipitation falling directly on the water surface. The authors should develop this conclusion in comparison to previous understanding and/or rephrase it can be misunderstood.

It is correct that this conclusion only holds for this small summer rain storm, while during wetter conditions it may be totally different. We shall make this clearer in the revised manuscript.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 2175, 2011.