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Discussions

Interactive comment on "Contributions of Catchment and In-Stream Processes to Suspended Sediment Transport in a Dominantly Groundwater-Fed Catchment" *by* Yan Liu et al.

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We thank the anonymous reviewer for his/her comments helping us to improve the manuscript.

In the following, the reviewer comments are in normal fonts, and our responses are in italic.

Comments and Responses

The manuscript presents an integrated sediment transport model including hydrological, hydraulic, sediment-generating and an in-stream transport model for the Ammer catchment in Germany. The attempt to assemble a fully integrated model and explain sediment dynamics fits nicely in the recent efforts to support integrated water resources management, the topic is absolutely timely.

I see two significant points that absolutely require improvement.

1. First is the conceptual explanation and model representation of overland sediment transport, where there is a gap between soil mobilisation (erosion) and reaching the streams. Retention during overland transport and its dependence on vegetation cover is generally neglected and not included in any form, except if we consider it to be deeply hidden in the parameters of equations 4-6. This formulation makes sediment loads independent from landcover, which partially violates the Critical Source Area principle (not wholly, because slope and flow depth are still there), and makes the model unable to identify the impact of different cultivation patterns. Although the optimal solution would be to change the non-urban sediment-generating submodel to something more appropriate for such a large and diverse catchment, the absolute minimum is to mention this deficiency in the discussion.

   Response: Several factors may affect overland sediment transport, such as retention, flow path, and the influence of vegetation covers. In our study, we used a simple approach to estimate the amount of surface-runoff generated sediments that can reach the river channel. This approach is adopted from Piro and Carbone (2014), which has shortcomings for explicitly considering all processes on the hillslope scale, but there are several reasons for choosing the simple approach:

(a) *The Ammer catchment is dominantly groundwater-fed. Surface runoff from agricultural areas occurs seldom and is weak, which is caused by the formation of the Ammer catchment, a very wide valley with a small river (the Ammer River) due to rerouting of the former head-water catchment in the early Pleistocene. This geomorphological setup makes the contribution of agricultural sediments generated by surface runoff rather small compared with the contribution of urban particles. We don't think that refining the submodel for rural sediments would have a major impact on the overall behavior.*

(b) *The dominance of urban particles in the catchment has been reported by Rügner et al. (2013, 2014) and other studies performed by the same workgroup who found a surprisingly high load of persistent organic pollutants in River Ammer, which demonstrates the high contribution of urban particles to the total sediment load. Consequently, the contribution of agricultural sediments must be small.*

(c) *Non-irrigated arable land (80.2 %) dominates the total agricultural area in the Ammer catchment, the crop of which is mainly cereals (largely corn, but the farmers perform crop rotation). Unfortunately, crop rotation information is unknown to us, which limits the application of introducing detailed parameters for different vegetation covers. Introducing more parameters to explicitly account for all processes on hillslopes will increase the model complexity and complicate the model calibration process in an unfeasible way.*

(d) *The dominant fraction of non-irrigated land makes it feasible to use one parameter set to estimate average sediment yield from the rural areas. The slope and runoff depth can implicitly reflect some dependence on land covers and they make sediment yields time-variable and different for subcatchments.*

We will explain why we use this simple approach for overland sediment transport, provide evidences from other studies to support our statements, and discuss the

deficiency of this approach in the corresponding paragraphs.

2. The second major issue is the problem of identification and the credibility of model results. TSS concentrations were measured at a single site, the Pfäffingen gauge. All subcatchments and their various landcover classes contributed to this single data series through various transport processes including in-stream retention or resuspension. The identification of the contribution of each class requires specifying contrasting behaviour for all source types a priori, otherwise one cannot decide about the importance of each process from a single aggregate TSS series. Here it was done through the model specification, which one can partially debate, but that's not a principal issue. The problem is that the results, e.g. the importance of processes is finally conditional on the model specification, which is not mentioned here at all. Thus, the identified (and thoroughly analysed) contribution of each source is only true when the model assumptions are correct. This must be explicitly stated in the manuscript, considering that the applied model equations are not obviously the right ones (which is not a real problem, it just reflects the subjective decisions of the authors), and the outcome seems a bit strange (negligible agricultural contribution with 60 % arable land). An additional point to this concern is the imperfect fit of the model to the observed data. While the fit is not worse than what one can usually achieve with TSS modelling, the uncertainty is large enough to make identification of different sources practically impossible.

   A more objective decomposition of sediment dynamics could have been the analysis of time-dynamics, that is the identification of slow-medium-fast responding components and their precipitation or discharge trigger thresholds, and binding known mechanisms to them afterwards. In the manuscript the same happened in mathematical sense, but it is now stated with high confidence that a certain response pattern is obviously the effect of a certain process, which is simply not proven by fitting a model to the TSS data. Emphasising the subjectiveness of results is therefore advisable.

A logical follow-up study could aim at repeating the same exercise using multiple TSS time-series from different locations possessing different shares of sediment sources. This would strengthen the basis for attributing certain sediment dynamics to specific sources.

Response: Data availability has a large influence on the verification of most hydrological, sediment transport, and pollutant transport models. Especially time-series of spatially variable data are very rare and few. In our study catchment, only one gauge was installed at the outlet of the catchment, where we can obtain time-series of turbidity (which can be converted to suspended sediment concentrations). Then the time-series data were used as the reference to calibrate and validate the combined sediment contributions from different sources. At the time being, we don't have data for sub-catchments, which makes it difficult to verify the sediment dynamics from different sub-catchments. We have started a coordinated project in the catchment last year, which includes installing more measurement stations, so that future data can be used to validate the assumptions regarding the assumed behavior of at least a few sub-catchments.
As suggested in the comment, it is possible and feasible to investigate the importance of different processes given the right knowledge of the catchment (the prior). In the present manuscript, maybe the specification of the model is not sufficient. We will give more detailed model specifications in the revised manuscript to support the assumptions of the model. For example, we will add the formation of the catchment and flow duration curve to indicate why surface runoff occurs seldom in the agricultural areas in order to support the small contribution of agricultural sediments. Secondly, we will search for other studies in the studied regions to support our assumptions and results. Thirdly, we will provide the mass balance calculation of hydrophobic compounds (such as Polycyclic Aromatic Hydrocarbons (PAHs), which is mainly particle-facilitated), which gives evidence for

particles from different sources because the contamination levels of particles with different origins are substantially different. Finally, we will make the code open so that everyone can make further calculation and model development.

Specific Comments

1. P2 L12 and L15: USLE is an empirical model of soil loss on the plot scale, it is not applicable to entire subcatchments, but not because of the lack of in-stream mechanisms. USLE cannot deal with heterogeneities along the transport pathways of soil particles, so it cannot model how much retention will occur during overland transport. So if we don't speak about a homogeneous plot stretching right down to the stream, with the same soil quality, cultivation method, slope, rainfall exposure, USLE will be a bad approximation.

   Response: We will reorganize the statement on USLE to make it more precise and clearer in the revised manuscript.

2. P3 L7: "Towards this ends" sounds strange.

   Response: We will revise it to "In this study" in the revised manuscript.

3. P3 L11-12: Dry weather sediments from a WWTP are much different from "normal" particles due to their different particle size distribution and much higher organic carbon content. Would this spoil the estimation of TSS from turbidity?

   Response: Particle size and composition can affect turbidity and TSS. The sediment transport model computes suspended sediment concentrations. We set suspended-sediment concentrations of WWTP effluent as an input to the model. The TSS—turbidity relationship is obtained at the river gauge, which has already taken different particles from different sources into account. Moreover, because *of the small contribution to total discharge from WWTP and the small suspended-sediment concentrations, the influence of WWTP particles has been smoothed out.*

4. Figure 1: Would "Rural" be a better alternative to "Non-urban"?

   Response: Thanks for the suggestion. We will use "Rural" instead of "Non-urban" in the revised manuscript.

5. P4 L1: It would be reasonable to introduce the Ammer first, as the following sections contain a lot of specific information, which cannot be judged without knowing the basic characteristics of the catchment and river.

   Response: Thanks for the suggestion. We will adjust the corresponding structure: study site first, then model description.

6. P4 L7: When the aquifer is a karst, is "groundwater" the right term? Wouldn't "fracture-water" be a better description? Or is this a mix of karst and non-karst?

   Response: It is a mixture of karst and non-karst, therefore, we will keep using "groundwater". And the water in a karst system is of course groundwater, too.

7. Equation 1: This must assume that it is always restarted at the beginning of the accumulation phases. If this is the case, please mention. Equations 4-6: This formulation ignores that (i) overland flow path lengths have a serious influence on sediment delivery [$>$90 % of the mobilised sediment accumulates during overland transport], and (ii) surface roughness, permeability, flow concentration affect yield. How does landcover quality affect sediment transport here? How would buffer zones work in such a model? Given these shortcomings, please comment whether the landcover conditions in the Ammer catchment make these equations usable.

   Response: Yes, it is restarted at the beginning of every accumulation period considering the remaining particles after the flush period. We will clarify details on

   Equation 1 in the revised manuscript. Equations 4-6 calculate the amount of sediments reaching the river channel. This method and formulation are described in the study of Piro and Carbone (2014). Yes, several factors may affect sediment yield from agricultural land, such as flow path lengths, different land use (reflecting surface roughness), and soil permeability. But in our study, we used a simple method to estimate sediments generated by surface runoff that reach the river channel. Equation 4-6 don't explicitly account for all mentioned processes above, but implicitly consider the dependence of land use and soil property by slope and flow depth in the formulation. Reasons for choosing this approach please refer to the response to Major Comment 1. We will discuss the shortcoming and limitation of this method in the revised manuscript.

8. Figure 2: Given that cross-sections were 100 m away from each other, travel time between cross-sections must have been between 50 to 200 seconds. Then the hourly time step means that this model was solved for a series of quasi steady states. How did the dynamics of sediment sources relate to these times? Wouldn't this mean that some dynamics of the rapidly responding urban sources was lost due to improper numerical resolution?

   Response: The integrated sediment transport model consists of the catchment-hydrological model, the catchment sediment-generating model, and the river sediment-transport model. The time resolution of the catchment hydrological and the sediment generating models is one hour, because we have precipitation data with one-hour resolution. The river hydraulics adapt comparably quick to changing discharge, so that the quasi-steady state mode of HEC-RAS (neglecting in-stream retention of water) with hourly resolution was considered sufficient to calculates river hydraulics. We use ODE23s to solve sediment transport in the river channel, ODE23s includes an adaptive time-step scheme, which uses small steps for rapid changes. We have set the MaxStep in ODE23s 5 minutes. Actually the river sediment transport model can simulate rapid responses. But due to *the hourly input from catchment sediment generating model, the river sediment transport model capture hourly sediment dynamics.*

9. P7 L9: A significant part of TSS and turbidity comes from the wash load, which practically never deposits. So it is a rather significant simplification that all fractions deposit at the same rate. Did this cause problems in the model fits?

   Response: In our model, we simulate particles with average size, the settling velocity of which is the same. But deposition rates are different, which depend on particle size and shear stress. Shear stress varies along the channel and is also affected by flow rates. In the river segments with bottom shear stress greater than a threshold, particles remain in suspension. This approach cannot address the dynamics of different-size particles. If varied particle sizes are considered, additional processes may be needed such as flocculation, which makes the model more complex. That is not the focus of this study.

10. P9 L 11-12: It would be logical to mention the peak NSE value besides the threshold.

    Response: We will calculate peak NSE value and mention that in the revised manuscript. NSE values used in this study is because that the Ammer River is mainly groudwater-fed. The relatively high baseflow affects sediment deposition during low flow conditions. NSE values can reflect the goodness of fit for both high and low flow.

11. Table 2: The applied value of Ch (0.001) is out of the specified range (0.003-0.05).Why?

    Response: The specified range (0.003-0.05) is from a literature (Gilley et al., 1993), which can be used as a reference for parameter estimation. When we use the value of 0.001, the model fit shows a much higher NSE value than that using parameter values greater than 0.003. That is the reason why it is a little smaller than the literature value.

12. Figure 4: Baseflow is perfect (which is a big achievement in a karstic catchment), but discharge peaks are seldom met. What does this mean for the TSS calculations? Most of TSS likes to travel with discharge peaks.

    Response: Honestly some peaks are missing in the model. Several factors can affect prediction of flow rates, the most important is precipitation. The model reproduced many events, however, some thunderstorms in summer months cannot be well captured due to insufficient representation of precipitation data. This is a very common problem. Baseflow also has a big influence on sediment transport in our study catchment. Because 65 % of discharge is less than the annual mean discharge (1 $m^3 s^{-1}$) and only 1.5 % of discharge is greater than 2 $m^3 s^{-1}$, which makes the contribution of suspended sediments under low flow conditions a relevant fraction to the total sediment transport (around 25 %).

13. Figure 5: Please use log scale for TSS, this linear scale isn't very informative, the reader can't figure out if the model was right or wrong.

    Response: We will present the log plot in the revised manuscript.

14. P14 L4-5: Urban and karstic dominance in TSS loads would be exceptional with 60 % arable land (which - with its barren soil surface in certain months - is generally considered as the most erosion-prone land use class, besides construction sites). Can you find specific reasons for this?

    Response: There are several reasons that the contribution of agricultural sediments is small for the simulation period (2014-2016):

    (a) The formation of the Ammer catchment results in a very wide valley and a small river (the Ammer River) due to rerouting of the former head-water catchment in the early Pleistocene. The catchment has a large water storage capacity due to the karst and the slope of this catchment is mild. These characteristics make the surface runoff from the agricultural areas very small, which explains the small sediment production.

(b) *The infiltration rates of loamy soil and clay loamy soil are 10–20 mm h^{-1} and 5–10 mm h^{-1} (http://www.fao.org/docrep/S8684E/s8684e0a.htm), respectively. But for the Ammer catchment, very few events have precipitation intensity greater than 10 mm h^{-1} during the simulation period of 2014–2016. Thus, very few and small surface runoff can occur in the agriculture land, which limits sediment generation and transport from agricultural areas to the river channel.*

(c) *We will add the flow duration curve in the supplementary material. It can be seen that only 0.04 per cent of the discharge is greater than 12 $m^3\ s^{-1}$ (2-year return period level), totally 3 events for the entire simulation period, which indicates a very small proportion of big events. During big events, it is possible to generate surface runoff in the agricultural areas.*

(d) *The previous study of Rügner et al. (2013) has compared the turbidity measurements of the same event (30. Nov. 2012) for the Ammer catchment and the Steinlach catchment, which is a southerly tributary to River Neckar, the confluence of which is also in Tübingen. The two catchments have a similar size. The population density of the Ammer catchment is higher than that of the Steinlach catchment (but in the same order of magnitude). The difference lies in the topography of the catchments. The measurements of that event show that the peak turbidity of the Steinlach River is 7.4 times higher than that of the Ammer River. This observation indirectly indicates that the sediment generation of agricultural land in the Ammer catchment is much smaller than in the paired Steinlach catchment.*

(e) *Rügner et al. (2013, 2014) and other studies performed by the same workgroup found a surprisingly high load of PAH in River Ammer, which could be interpreted by the high contribution of urban particles to the total sediment load. It confirms the dominance of urban particles in the catchment.*

15. P14 L9: These infiltration rates seem to be a bit high. Design values (for

example: https://stormwater.pca.state.mn.us/index.php?title=Design_infiltration_rates) for loam are around 8 mm/hr, for clay loam around 1-5 mm/hr, which would change the runoff picture significantly. Can you bring up a reference in support of these high rates?

Response: We will give the reference in the revised manuscript, which is from FAO website (Food and Agriculture Organization of the United Nations). http://www.fao.org/docrep/S8684E/s8684e0a.htm. These values are used as a reference to indicate why not too much surface runoff occurs in the agricultural areas.

16. Figure 10: Would be better to show the NET rate and slope along the river, because the present legend is confusing. Where can one see "NET EROSION"?

Response: We want to show detailed length profile of deposition and erosion in Fig. 10 so that we can see different reasons for net deposition/erosion for different slopes. The net erosion is too small and sporadic in the simulation period, thus it may be confusing in the present figure. We will find a way to make it clearer in the revised manuscript such as adding a subplot to show the net rate and slope along the river as suggested.

17. P22 L5-9: This paragraph is speculative. First it should be shown with further measurements that the model was right.

Response: As responded to the previous questions, we will show more evidences and compare with other studies (Rügner et al., 2013, 2014; Schwientek et al., 2017) in our study region to prove that the model is right in the manuscript. Furthermore, we will make the code open so that other people can test it. After doing so, we hope this paragraph would be reasonable.

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