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Hydrology and Earth System Sciences Discussions

Interactive comment on "Subsurface flow mixing in coarse, braided river deposits" *by* E. Huber and P. Huggenberger

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We thank referee #2 for his critical review of our manuscript.

Major comments

Major comment 1. In the revised version, we will (i) replace "mixing" by "advective mixing" to avoid any confusion, and (ii) define advective mixing as the subsurface flow distortions resulting in flow deviation, stream-tube intertwining and stream-tube folding (e.g., Janković et al., 2009). See also our response to referee #1, Major comment 1.

Major comment 2. We agree with referee #2 that the modeled trough fill is rather an idealized than a simplified representation of the local sedimentary structure of the Tagliamento deposits. The main reason for that is the scarcity of knowledge of the (true) three-dimensional sedimentary structure. Therefore, the conceptual model (idealization) constrains the three-dimensional interpolation/fit from the sparse ground-penetrating radar (GPR) data. This aspect will be more discussed in the revised version. However, note that (i) the simplification applies to the conceptual model that simplifies the heterogeneity to regular geometries; (ii) the geometry of the erosional-lower bounding surfaces are clearly identified in the GPR profiles as well as the internal structure (the stereological issue regarding the three-dimensional aspect of the internal structure can be partly solved when combining the information of intersecting GPR profiles close to their intersection); (iii) similar trough fills (erosional lower-bounding surfaces and internal structures) were observed in gravel pit outcrops in Northeast Switzerland (Huggenberger and Regli, 2006); (iv) the sedimentary textures as well as the sand sorting and proportion observed on outcrops close the studied site showed strong similarity with observations made in gravel pits in Northeast Switzerland. Therefore, even if the modeled structure is an idealized representation of the Tagliamento deposits, we can assert that it is a geologically realistic representation of coarse, braided river deposits.

Major comment 3. Fourteen widely spaced GPR profiles were recorded on the active floodplain of the Tagliamento River (spacing between lines is about 20 m, survey area is about 100 m $\times$ 200 m). The objective of the survey was to record many lines over a large area in order to estimate statistical trends and to quantify the proportion of trough fills in the subsurface. Therefore, we do not have a "traditional grid of closely-spaced GPR profile" from which the subsurface structure would be better inferred. This explanation will be added in the Method section. Furthermore, the discussion will be more tightly related to the specific set-up of this study.

Major comment 4. The question if it is "really necessary to resolve the alternating layers of open-framework [...] and bimodal gravel" is interesting but is not directly related to the objective of the study, that is to characterize the impact of a geologically realistic three-dimensional representation of coarse, braided deposits on the advective mixing (i.e., the aim stated in the abstract lines 8-10). To our opinion, this question belongs to the more general framework of model up and downscaling, where the objective is to obtain similar simulation results with a simplified representation of the heterogeneity that can require a coarser grid. Therefore, this question is not relevant to the understanding of advective mixing in the context of the present study but are relevant for other research questions. Admitting that the representation proposed in our study is close to the reality (i.e., a kind of model reference), why should we try to simplify it by merging the open-framework gravel and the bimodal gravel into one single unit with a spatially varying anisotropic hydraulic conductivity tensor derived from the geometry and hydraulic properties of the open-framework and bimodal gravel? In case both the reference and the simplified models give similar results, what conclusions with regard to the advective mixing should be drawn? That the anisotropy modeling was consistent with the reference model? If the results are different, should we conclude that the difference between the reference and the simplified models results from the approximation of the anisotropy in the simplified model? We do not see here a gain of knowledge on advective mixing caused by trough fills. However, such kind of study would be very helpful to define criteria how to coarsen the model resolution without losing to much of the advective mixing characteristics. See also our comments to referee #1, Major comment 6. Referee #2 states that our representation mixes two level of hierarchic heterogeneity. We disagree. The same "level of hierarchy" is used to model the coarse, braided deposits, namely the sedimentary textures as described by Huggenberger and Regli (2006). The matrix consists of an anisotropic uncorrelated hydraulic conductivity field corresponding to horizontal/subhorizontal layers of poorly-sorted gravel. We could have modeled each single layers of poorly-sorted gravel by independently assigning a hydraulic conductivity for each layer. But the interface between the layers of poorly-sorted gravel cannot be (easily) interpreted from GPR data and the thick-

ness of the layers may be smaller than the vertical model resolution. Furthermore, the difference in terms of advective mixing between a layered representation and an anisotropic homogeneous representation corrupted by an uncorrelated noise should be very small. In gravel carry exposures in northeast Switzerland, Huggenberger and coworkers observed in some cases deposits consisting almost only of poorly-sorted gravel in which few trough fills were lying. Therefore, the study set-up is not unrealistic even if thin finite sub-horizontal layers of open-framework can also be found in layers of poorly-sorted gravel (Huggenberger and Regli, 2006). However, we expect that such thin finite layers of open-framework gravel have a negligible contribution to the advective mixing (particularly for vertical advective mixing), because they focus and defocus the streamlines. The degree of details of the different modelled structures reflects our (conceptual) knowledge on the spatial arrangement of the textures.

Specific remarks

1. Abstract. We will add a few lines to describe the impact of the modeled trough fill on advective mixing.

2. Line 7: "drawn (instead of draw)?". We will do as suggested by reviewer 2.

3. Page 9297, lines 3-5. The following references will be added in the Introduction: Anderson et al. (1989), Lunt et al. (2004) and Bridge and Lunt (2006).

Page 9297, lines 7-9. The sentence line 6-9 (page 9297) does not exclude other depositional elements. Nevertheless, we propose to modify this sentence as follows to make it clear that Fig. 1 illustrates the two main depositional elements and not the heterogeneity of coarse, braided river deposits:

Coarse, braided river deposits are characterised by two main depositional elements (Fig. 1), namely horizontal to sub-horizontal layers of poorly-sorted gravel and trough *fills characterised by clear-cut erosional lower-bounding surfaces.*

To clearly not exclude other forms of heterogeneity we will add the following sentence:

Additional sedimentary structures as well as depositional elements are described in the references above.

Note that the layers of poorly-sorted gravel are not isotropic but anisotropic (vertical anisotropy because of the layering structure, see Table 1). Furthermore, Regli et al. (2003) showed that the horizontal anisotropy can vary depending of the orientation of the sediment deposition. We agree that the open-framework texture is also observed in the layers of poorly sorted gravel.

4. Page 9298, line 24. The profiles are not very close to each other because we were surveying a large area within a limited period of time. We agree that a denser sampling of the area of interest would have significantly reduced the conceptual bias in the representation of the sedimentary heterogeneity.

5. Page 9299, lines 14-16. The velocity data will be added to Fig. 2 of the manuscript.

6. Page 9300, lines 8-20. We will stress that the flow and transport model is run through a conceptual analogue model, separating the real features derived from the Tagliamento setting (the size and shape of the scour pools) from the conceptual inputs.

7. Page 9300, lines 26 and following. The local sedimentary characteristics of the Tagliamento deposits are very similar to the sedimentary characteristics observed in gravel carries in northeast Switzerland (Siegenthaler and Huggenberger, 1993; Huggenberger and Regli, 2006) as shown by (i) the sedimentary textures inferred from outcrops close to the studied site and from the interpretation of the GPR data and by (ii) the proportion and sorting of sand (that determines the hydraulic properties of the poorly-sorted and bimodal gravel). Therefore, the hydraulic properties in this study were taken from hydraulic measurement made on disturbed and undisturbed samples in Quaternary coarse gravel deposits in northeast Switzerland (Jussel et al., 1994). We

will clarify this point in the revised version.

7. Page 9301, lines 4 and 5. Unclear what referee #2 means. Is it unnecessary to draw uncorrelated hydraulic conductivity values? It simply add more noise. See also our response to referee #1, Major comment 7.

8. Page 9303, Lines 10-13. We completely agree with referee #2 that "this observation holds for the synthetic conceptual model that is under investigation". That is exactly why we used the phrase *modelled trough fills* to clearly state that the conclusion only holds for the modelled trough fills. This point will be clarified in the revised version.

9. Page 9303, line 11. We will do as suggested by referee #2.

10. Page 9304, lines 13-15. In this context, the whole geological fabric means the whole hydraulic conductivity field *of the model*. The phrase geological fabric refers to the model (all the voxel), not to the true geological units.

11. Figure. The coordinates of the survey field are provided. A simple map showing the survey location would not add any useful information.

12. Fig. 2. Good idea. Some arrows will be added on Fig. 2, 3 and 4 to show the strike of the GPR profiles.

13. Fig. 4. A scale will be added to the photos.

14. Fig. 5. This figure will be modified as we will use particle tracking instead of advective solute transport to investigate the effect of through fills on the advective mixing.

15. Fig. 5, 6 and 7. We suggest to show the x, y and z coordinates/axes on these figures. That will greatly help the reader to better understand the orientation of the figures.

16. Fig.7. We will do as suggested by referee #2.

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