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Interactive comment

Interactive comment on "Modelling 3D permeability distribution in alluvial fans using facies architecture and geophysical acquisitions" *by* Lin Zhu et al.

Lin Zhu et al.

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Thanks for the constructive comments from Reviewer 2. We carefully revised the texts by incorporating his/her comments one by one. The detailed revision is presented in the response to each comment. Comment 1) What is the novelty of the results presented in this work with respect to the recent publication by the same group of authors (i.e., Zhu et al., 2016b)? This not clear to me, and I think it should appear in the introduction of this paper, together with the motivation for expansion or improvement (if any). Response: The simulation of 3D hydraulic conductivity in Zhu et al. (2016b) was obtained by combing the interpolated resistivity and the stochastic simulated facies through empirical equation (New line 63-66). Moreover, in the previous work only

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VES data was used to get the porosity and the hydraulic conductivity was converted from the porosity data by using an empirical equation. In this paper, we constructed the 3D hydraulic conductivity by coupling the indicator facies simulations and sequential Gaussian conductivity simulations within each facies using the spatial geostatistical parameters deduced from the log conductivity semivariograms of different facies in different zones. The geophysical data are interpreted for computing the hydraulic conductivity distributions at different sampling locations. The novelty of this work is to develop an integrated approach to reconstruct the three-dimensional configuration of conductivity in the alluvial fan by coupling the hydrofacies indicator simulations with conductivity spatial heterogeneity simulations by using the hydrogeological and geophysical measurements or resistivity loggings and electrical soundings. The newly collected geophysical data combining with the sequential Gaussian simulations reduce greatly the uncertainty of the reconstructed three-dimensional conductivity fields. Finally, also the scale of application is very different, with the previous work focused on a small test area and this one to the whole megafan of the Chaobai river. Comment 2) I do not understand how the facies C, FS, MS and G have been defined. Are the names of these units referring to the prevalent grain size value? The reason for this question is that the K values estimated for these units in the three zones show inconsistencies. In table 2, for instance, how do the authors explain that the facies called “Medium-coarse sand” in zone 3 is less conductive (0.81 vs. 1.07) than the facies called “Fine sand” in zone 1? Is the “fine sand” unit in zone 1 the same as the “fine sand” unit in zone 3? If yes, then why the mean K value is about 8 times larger? What I mean is that a deposit consisting largely of fine sand is a “fine sand” regardless of its location with respect to the apex of the alluvial fan. The same applies to all the other units. It is the proportions of these facies that changes with distance from the apex, and these changes are responsible for the non-stationarity of the K distribution. The average K value of the lithofacies (e.g., “fine sand”) should be consistent (plus minus uncertainty) between zones. Please clarify this point because it seems to me a major flaw of the proposed methodology. I also wonder if a different classification with more units would be also more appropriate in this case. In particular, fan deposits especially in the proximal part (your zone 1) are also characterized by debris flow deposits (matrix supported gravel). This type of deposits has been ignored. Response: The hydrofacies (e.g., C, FS, MS and G) are defined qualitatively based on the sedimentary structures, borehole lithological descriptions, and grain sizes, while the conductivity samples are then deduced from geophysical measurements for each facies at each zone. Since the clay contents from zone 1 to zone 3 are increased due to the changes in the sediment transport conditions, for the same facies we also found this trend and the overall hydraulic conductivities are decreased from zone 1 to zone 3. As this reviewer stated, “these changes are responsible for the non-stationarity of the K distribution”. Therefore, we used multi-zone approach to overcome the overall non-stationarity and to assume a local stationary for each zone. Although we still call the similar faces at different zones with the same name, but the structure and statistical parameters for each facies at different zones are quite different. We simulated the facies and the hydraulic conductivity sequentially with the estimated structure and statistical parameters from zone 1 to zone 3 and the final constructed three-dimensional conductivity field can represent the sedimentary and hydrogeological conditions in this alluvial fan. We added a few sentences to explain the statistical parameters listed in Table 2. Comment 3) I think it would vastly improve the impact of this analysis if the authors can include some quantitative assessment of the accuracy of the reconstructed K distribution. For instance, it seems that there is enough data to apply a split sample validation test. A comparison with results in which K is assumed stationary would also be beneficial. Response: The distributions of hydraulic conductivity are obtained through coupling facies indicator simulations and conductivity sequential Gaussian simulations, which represent the spatial features of the sediments including facies lengths and volumetric proportions and the hydraulic conductivity heterogeneity including log10K mean, variance and correlation scales. The simulated three-dimensional conductivity field was validated with the values provided by the Beijing Institute of Hydrogeology and Engineering Geology (2007) based on a number of pumping (Line 318-325). Specific comments 1) Line 34. The ref-

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erence Zappa et al. (2006) refers to a different depositional environment. Please use a more specific reference. Response: Suggestion followed. We added a specific reference here as: Weissmann, G.S., S.F. Carle, G.E. Fogg, Three-dimensional hydrofacies modeling based on soil surveys and transition probability geostatistics, Water Resour. Res., 35(6), 1761–1770, 1999. 2) Line 35. I suggest to add “hydraulic”. Response: Changed. 3) Line 65. Insert a period before “The Chaobai”. Response: Added. 4) Line 79. Deposited instead of “laid down” Response: Changed. 5) Line 156. Please specify what you consider as representative grain size diameter. Is it the d10? Response: Changed. d(x,y,z) is the median grain diameter (D50, mm). 6) Lines 161 – 162. Only ranges are provided for the parameters. What specific values have been used? Why? Please explain. Response: ïĄą is equal to 1. In the upper part of the alluvial fan (Zone 1 and Zone) m is set equal to 1.3 because the sand is unconsolidated. In Zone 3. m is set to 1.7 which reflects slightly compressed or cemented sandstones (Niwas et al. 2011). 7) Equations 2 and 3. How do the systematic errors and uncertainty in the parameters associated with these empirical equations affect the uncertainty in the K estimations? Some comment on this would be beneficial. Response: We added a sentence to discuss the parameter uncertainty estimated from this empirical equations as: Note that the parameters associated with equations (2) and (3) are site specific and the application these equations to other sites will need a re-adjustment of the related parameters. 8) Line 169. I suggest to show the histograms of the K values within each facies to justify the lognormality assumption. Response: The histograms of log10K within each facies are given in Figure 5 in our new version paper.

9) Line 172. What information? Grain size analyses? Response: The information is the lithological descriptions and grain size distributions collected from different boreholes. 10) Line 180. Are those data different then the data used in this work? The fact that you say that you found consistency suggests that they are different, but then I wonder why these 694 boreholes were not considered. Please clarify. Response: There are 113 borehole data used in this work which are chosen from the original 694 boreholes. The lithological information in a buffer zone of 200 m

around the VES locations has been used to represent the actual facies distribution in the area surrounding the sites of the geophysical acquisitions (New line 154-155, original line 140-141). 11) Line 217. I understood that the volumetric proportions pk were derived from the borehole data rather than estimated through inversion. Please clarify. Response: The facies transition probability models are calculated on basis of the borehole lithological description data. The analytical equation (Equation 9) of transition probability was used to fit the sample transition probability and to estimate the volumetric proportions and indicator correlation lengths. 12) Line 244. Variance of what? Response: Changed. Variance of the log conductivity. 13) Line 246. "... is highly uncertain" Response: Changed. 14) Line 248 - 249. This sentence does not find correspondence in your analysis. On the other hand it confirms my doubt that the facies classification at the basis of the proposed methodology is not correct (see general comment 2). You rightly write "The deposits consist of wide ranges of sediment categories and grain sizes" to justify the fact that K has higher variance. But this is not the case in this work because the presented analysis is based on the assumption of only four (even three here) units G, FS, MS. So it seems to me that in order to include that variability you are talking about, your units do not actually represent a specific lithology as the names imply but a wider range of lithologies. For instance, your unit called "Fine sand" may actually include deposits that would be classified as fine sands as well as fine gravels. Am I wrong? Response: As we responded to the general comment 2, the hydrofacies (e.g., C, FS, MS and G) are defined qualitatively based on the sedimentary structures, borehole lithological descriptions, and grain sizes, while the conductivity samples are then deduced from geophysical measurements for each facies at each zone. Since the clay contents from zone 1 to zone 3 are increased due to the changes in the sediment transport conditions, for the same facies we also found this trend and the overall hydraulic conductivities are decreased from zone 1 to zone 3. As this reviewer stated, "these changes are responsible for the non-stationarity of the K distribution". Therefore, we used multi-zone approach to overcome the overall non-stationarity and to assume a local stationary for each

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zone. Although we still call the similar faces at different zones with the same name, the structure and statistical parameters for each facies at different zones are quite different. We simulated the facies and the hydraulic conductivity sequentially with the estimated structure and statistical parameters from zone 1 to zone 3 and the final constructed three-dimensional conductivity field can represent the sedimentary and hydrogeological conditions in this alluvial fan. 15) Line 250. Heterogeneity of what? Response: Changed. Heterogeneity of hydraulic conductivity. 16) Line 254. Sorting and grain size are not the same. A poorly sorted sediment can still have a very high K. Response: Yes, we agree. We changed the related terms. 17) Line 263. I suggest to provide the variance also for zone 1. After all, if I understood correctly, there are 102 samples. This is not such a small number. Response: Yes, 102 samples are not a small number. These samples are deduced from eight positions on horizontal plane (Figure 1). When we calculated semivariograms in dip direction using these samples, there are too many zero values and then we ignored the semivariograms and the variances in dip direction in Zone 1. As this reviewer suggested, our next-step study is to collect more hydraulic conductivity to provide the variance in zone 1. 18) Lines 266 – 269. Please revise the sentence. The meaning is not clear. Response: Revised (New line 293-296). 19) Lines 274 - 276. Same comment as #14. Response: We revised the sentences here to incorporate this comment. 20) Lines 280 – 281. Is this conclusion not obvious? I understood that the SGS realizations of K are mapped on the basis of the facies model (Figure 7a). Response: The three-dimensional hydraulic conductivity was obtained by combining the facies model and the sequential Gaussian simulations of hydraulic conductivity for each facies. Detail information on re-constructing the K is given in new line 252-262. 21) Line 281 – 282. This should not be caused by assigning larger average K of three units. This should be the consequence of the fact that coarser units are more frequent in this zone and therefore the average K is larger. The K distribution is the product of the lithological heterogeneity; it is not the opposite as it is implied here and in general in the paper. Response: The sentence is revised (New line 308-309). Coarse units are more frequent in the upper zone, which make the average K is much larger in this zone than that in the lower part of the alluvial fan. 22) Lines 293 – 296. It depends. Are you considering arithmetic or geometric average? Response: The sentences were revised. Arithmetic average of hydraulic conductivity was calculated.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-373/hess-2016-373-AC2-supplement.pdf

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