Reply to comments RC1 on "egusphere-2022-81"

3D hydrogeological parametrization using sparse piezometric data

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Dear Referee, please find below the point by point answers (in blue) to your comments (in black).

Dear authors,

I read carefully your work and I found it a very important contribution in groundwater hydrology.

The methodology is clearly presented, the mathematical background as well. The interpolation part may require some more details but on the other hand it mainly supports the concept

We thank the reviewer for his very positive appreciation of our work.

We agree that the interpolation details are not crucial for the understanding of the methodology. However, we will provide more information about the main ideas embedded in GemPy and the B-splines method in the revised version.

1) The proposed method is only digestive for those who have specialized knowledge of the entire tools presented.

We regret that the description is not as clear as we would like. In the end, the process is relatively straightforward:

1a) Piezometric series are used to invert 2D groundwater flow parameters (i.e. conductivity and effective porosity)

1b) Drilling logs are used to interpolate 3D lithological distribution

2) Flow parameters of each classified lithology is optimized in order to make the final 3D model and the 2D inversion fit locally in terms of transmissivity and porosity.

We'll add further description about each of these steps.

2) Please mention the innovation compared to similar works.

Similar approaches are very few in the literature.

Harp et al. (2008) also used a combination of methods in order to identify aquifer structure, namely a 2D inversion procedure based on minimization of the residuals of hydraulic heads for the flow parameters and a transition probability model for the aquifer structure. Two main points make our study innovative and more advanced compared to it. We tested our method on 5 facies while Harp et al. only designed their aquifer with 2 facies. And speaking of design, their synthetic case is produced with the same tool (T-PROGS) that is then used for reconstructing the aquifer structure. In our case, the initial structure was designed by hand, independently of the interpolation tools used afterwards.

The approach of Viaroli et al. (2019) is less similar to ours. They used a 2D simplification to assess boundary conditions and recharge of an already developed 3D model for a real case application.

We'll integrate these comparisons with the cited literature in the introduction (lines 33-34).

3) Most important the presented methodology is very complex to be reproduced. I am not saying that is bad! but there also similar works in the literature that do the same work with a simpler manner. Maybe it would be good, if possible, to have a comparison with one of them. Your method is more detailed but compared to simpler approach the performance is far more efficient? Otherwise, what is the reason to have such many methodological and sometime complex steps.

First of all, our idea is motivated by the usual way of groundwater calibration which is mostly performed in 2 dimensions. We question the use of the transmissivity field obtained through 2D calibration to build a 3D representation of the aquifer i.e. to estimate the structure of the heterogeneities and their related hydraulic conductivity. Our approach consists in estimating the transmissivity first with a 2D model calibration and then to build the 3D representation of the aquifer using the calibrated transmissivities only. It is quite different from the approaches dealing with 3D representation of an aquifer by joint inversion. We do believe that this approach is simpler than the other ones. It can also take benefit of an existing already calibrated 2D model to build a 3D transport model.

Moreover, the method is not so complex considering what it offers: estimating both 3D flow parameters and aquifer structures, based solely on piezometric series and vertical logs descriptions. Most studies on 3D aquifer modeling use multi-methods/joint inversions based on costly geophysical field data. We do not have experience of those studies that propose 3D modeling in an even simpler way.

4) paragraph 2.4 The optimization part needs more details. It is not clear how optimization works here.

At a given location of the domain, the optimization is performed using:

- A transmissivity value estimated by the calibration of the 2D model;
- A vertical distribution of a given number (n) of different porous materials (facies) with their related thickness obtained by facies interpolation.

The unknowns of the optimization process are the hydraulic parameters (porosity, hydraulic conductivity) for each facies, i.e., 2n unknowns over the all domain. The constraints are the transmissivity values estimated at each selected cell of the 2D groundwater flow model. Estimating the hydraulic properties face an overdetermined problem, the number of unknowns is much less than the number of constraints. We solve this problem through optimization and use only the most relevant values of transmissivity, i.e., the less uncertain. These values of transmissivities are located at wells where measurement exists, either piezometric heads or lithological data. Therefore, uncertainties related to lack of sensitivity for transmissivity values or related to interpolation for lithological data are minimized.

More details following the previous paragraph will be provided in the revised version to make it more understandable.

5)The proposed 3d methodology consist of inversion, interpolation, optimization. All these steps consider parameters. Therefore, an uncertainty analysis is required to study the uncertainty propagation.

We agree that an uncertainty analysis is a critical step in a modelling process. However, in the article, the choice is made to describe a new method through a synthetic case, independently of any data uncertainty. We focused on the effect of data sparsity to assess the method applicability. As uncertainty analysis does not only depend on the methods implemented, but also on the structure of the model, it appears to be more relevant in real case application, where the data is indeed subject to uncertainty and where the resulting level of uncertainty in the model outputs has an operational impact. We plan to implement this kind of analysis in the next development of the tool.

6) How realistic is the upscale of such model to a real case study. I understand the research orientation which is very strong but, this is also a matter of discussion.

A first test in real case was initiated in parallel with the development of the method, showing its applicative potential but also highlighting its dependence to a strong lithological classification (matter already discussed in the conclusion). In addition, the 2D step means that low-permeability facies may be masked by more permeable facies in the transmissivity term, making their parameterization sometimes difficult. And lastly, some other points are not addressed in the study, e.g. the vadose zone and the transport parameters, which require separate estimates.

These points will be added in the conclusion.

7) The fixed parameters of the aquifer model regarding transport it would be good to be accompanied by a sensitivity analysis.

Our choice not to perform a sensitivity analysis follows the same logic as for the uncertainty analysis. In this manuscript, we test the feasibility of this new methodology. We show that it is promising and uncertainties will be addressed in a further paper dedicated to the reliability of 3D transport modelling using this approach to build the 3D model.