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Hydrology and Earth System Sciences Discussions

Interactive comment on "A new formulation to compute self-potential signals associated with ground water flow" *by* A. Bolève et al.

A. Bolève et al.

Received and published: 25 September 2007

Dear Sir,

I enclosed a corrected version of our manuscript " A new formulation to compute self-potential signals associated with ground water flow " (the new title is " Forward Modeling and validation of a new formulation to compute self-potential signals associated with ground water flow”) by A. Bolève, A. Revil, F. Janod, J.L. Mattiuzzo, and A. Jardani. A keyed-response to the referees comments follows. We than the Referees and the Associate Editor for the time they have spent on this manuscript.

Sincerely, André Revil

Referee 2, M. Meju

1. The Referee wrote " General comments: While it is well-known that the electrical current flow generated by groundwater flow can be measured using the self-potential (SP) method, evaluating the characteristics of the hydraulic regime and in particular, the microstructure (influence of permeability), remains problematical in SP field investigations. This discussion paper by Boleve, Revil and co-workers presents a much needed synthesis of coupled flow models that explains the interaction of the hydraulic and electrical flow systems for saturated and unsaturated cases. The recently developed models - described in detail and applied to laboratory SP data elsewhere by these workers - are implemented here in 2D using the finite-element method, and their predictive capability are tested using available field measurements of SP anomalies. Importantly, the models predict a decrease in the magnitude of the streaming potential coupling coefficient with permeability consistent with published results by some other workers. Moreover, the SP anomalies computed using the new formulations for realistic estimates of the relevant subsurface physical properties at the adopted field sites, match the field measurements for the three different hydraulic systems that the test sites represent. In this regard, this paper indirectly paves the way for future inverse reconstruction of important hydrological parameters (permeability, flow velocity and aquifer geometry) from collocated SP and electrical conductivity measurements on the ground’s surface. The paper is of high scientific quality and very concise, but the presentation of the methodological developments can be improved further as suggested below. " We thank the Referee for his comments.

2. The Referee wrote "Specific comments: The abstract provides a concise description of the research problem to address (relating streaming current density to groundwater seepage velocity and excess electric charge per unit volume of porous material), work done, result obtained, and the implication for the inverse problem of recovering hydraulic properties from SP measurements. It is justified by the information provided in the main text. In Section 1 (Introduction), the authors present an appropriate review of past work and the drawbacks of the elemental theories of coupled hydroelectrical flow commonly implemented in numerical codes for analyzing the SP response of different

HESSD

4, S1058–S1063, 2007

hydraulic regimes. However, the early 2D finite-element implementation by Wurmstich et al (1991)* of the theory of Sill (1983) is missing here and could be mentioned for the sake of completeness. * Wurmstich, B., Morgan, F.D., Merkler, G.-P. & Lytton, R.,1991. Finite-element modelling of streaming potential due to seepage: study of a dam. Soc. Explor. Geophysicists Technical Program Expanded Abstracts, 10, 542-544. " We agree with the referee and the reference to the work of Wurmstich et al (1991) has been added to the new version of the manuscript.

3. The Referee wrote " In Section 2, the basic theoretical developments by Boleve and co-workers are brought together to provide a coupled model for a saturated case (Section 2.1) and unsaturated case (Section 2.2). The formulations are technically correct but these elegant models are somewhat poorly presented since there is no schematic of the spatial flow domains anywhere in the relevant 5 pages of formulations. Hence, it is not clear whether the saturated case truly represents an unconfined aquifer or a confined aquifer. A sketch of the relevant geohydrological setting will greatly enhance the import of this potential landmark paper. This is particularly so for the unsaturated case where a sketch should be used to define the key parameters (H and z) used in equation (10) and the modified Richards equation; a simple illustration such as used in the Green-Ampt infiltration (wetting front) model will appeal to many hydrologists. In summary, since the major thrust of this discussion paper is to evaluate the formulations (already presented elsewhere) in typical field settings, Section 2 requires some figure(s) to guide the uninitiated. " We agree with the referee and one figure (now Figure 1) has been added to the manuscript.

4. The Referee wrote " The title of this paper implies the development or presentation of a new formulation; however, much of what is presented in Section 2 appear in recent papers by these authors. It is appropriate that the title be modified to indicate work actually done - refinement (or adaptation) and validation of concepts developed recently and presented elsewhere. A suggested title is : Field evaluation of numerical simulation of SP signals associated with groundwater flow taking into account microstructure

HESSD

4, S1058–S1063, 2007

". We agree with the Referee and the following new title is now used for this manuscript " Forward modeling and validation of a new formulation to compute self-potential signals associated with ground water flow”.

5. The Referee wrote " In Section 3, illustrative case studies are provided. This section is well presented. However, the code COMSOL Multiphysics 3.3 is mentioned a number of times without any reference to the authorship and product date. It should be referenced as appropriate in scientific writing. " The web address is now provided in the references.

6. The Referee wrote " Also, the electrode types used for measuring the SP anomalies are clearly stated for the three case studies but nowhere did the authors mention the actual equipment used to record the SP data (high impedance voltmeter?). The authors should specify the type of voltmeter used in these measurements to guide the reader who might be interested in testing these new developments. " We agree with the referee and the type of instrumentation used to perform the measurements is now described for the three field cases discussed in the manuscript.

Technical corrections: All the technical corrections have been taken into account.

Referee1 Anonymous

1. The Referee wrote " General Comments: This paper represents a significant contribution to the emerging field of self-potential (SP) modeling. Given the inherent non-uniqueness in the intrepretation of SP source generating mechanisms, the robust yet realistic modeling approach offered by the authors should allow subsequent researchers to rapidly assess a number of realistic source models. Confidence is inspired through testing of three field examples, indicating the extent to which their approach can be applied to a wide variety of streaming potential related investigations. While the approach is elaborated within the context of the constuitive equations, it is not entirely clear how such a modeling approach might be undertaken by the uninitiated. " We thank the referee for his comments. This modeling approach can be

HESSD

4, S1058–S1063, 2007

easily reproduced by any reseacher interested by the subject since (1) we used a very classical formulation for the hydrogeological approach (the Richards equation with the van Genuchten parametrization), and (2) the coupling with the current density can be performed very easily with the commercial finite element sofware Comsol Multiphysics 3.3.

2. The Referee wrote " Furthermore, while the resultant subsurface SP images are presented, it would be useful to present the actual current distribution. As one might use their model to expand upon other possible SP source generating mechanisms, it would be useful to assess the valiidity of the proposed (i.e, model generated) current flow patterns. Specific Comments: It would be worthtwhile to include (e.g. as a supplementary figure) a plot of the proposed subsurface current distribution pattern. Similarly, it would be useful to present the current flow densities that yield the modeled SP anomlaies. Current densities may be particualrly diagnostc of certain subsurface phenomena and their presentation might be of value to the interested reader. " We think that such figures showing the current density distribution into the ground is not very informative. The papers contains already 13 figures and 3 tables. However, if the editor feels that such a figure is needed, we could provide it.

3. The Referee wrote " In their concluding remarks, the authors speculate on ability to jointly invert temper- ature data, something that is presented hastily and does not tie directly to the presented work. " We agree with the referee and the last sentence of the conclusion has been removed.

********** Dear Dr Revil,

I am the associate editor handling your paper that you submitted to Hydrology and Earth System Science - Discussion A new formulation to compute self-potential signals associated with ground water flow” by A. Bolève et al.. Attached please find two reviews that were posted on the web. Both reviews are positive and I would like to recommend your paper be published in HESS after revisions suggested by the

HESSD

4, S1058–S1063, 2007

two reviewers which are technical and of editorial nature. The paper is a significant contribution which we really would like to publish.

Could you please let us know what your intention is as you have not posted any author comments on this paper.

Regards,

Christoph Hinz

Associate Editor - Hydrology and Earth System Sciences

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 4, 1429, 2007.