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Interactive Comment

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

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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.

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 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.

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.

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.

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. 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.

Technical corrections:

Title: needs some modification: e.g., Field evaluation of numerical simulation of SP signals associated with groundwater flow taking into account microstructure.

Abstract: modify the last sentence as: Thus, this formulation could be useful for the inverse mapping of the geometry of groundwater flow from self-potential field measurements.

Page 1431, line 21: replace ‘development’ with ‘improvement’.

Page 1432, line 12: Jouniaux et Pozzi = Jouniaux and Pozzi.

Page 1432, line 25: replace ‘At the opposite of’ with ‘Unlike’.

Page 1433, line 4: provide proper reference for Comsol multiphysics 3.3.

Page 1433, line 25: replace ‘big picture’ with ‘challenge’.

Page 1433, line 15: Jouniaux et Pozzi = Jouniaux and Pozzi.

Page 1435, lines 8&9: Remove redundant statement: ‘This statement is always true’.

Page 1435, line 15: grad symbol missing from Ě ‘and H = .. is the change’ for consistency with equation (5), i.e. Darcy flux.

Page 1435, line 23: They only difference lies in = The only difference lies in.

Page 1435, line 22: If we use this relationship = If we use these relationships.

Page 1435, line 26: does not depends = does not depend.

Page 1435, line 28: Jouniaux et Pozzi = Jouniaux and Pozzi.

Page 1436, line 5: S-alpha; not defined. Be consistent.

Page 1436, line 13: Equation (9) requires a full-stop at the end.

Page 1436, line 16: ..influenced by the conductivity = influenced by the electrical conductivity. (Be specific - hydraulic or electrical?)

Page 1437, line 6: symbol phi(porosity) used but not defined in main text.

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Page 1437, line 19: characterizes = characterize.

Page 1438, line 6: Second Archie's law = Archie's second law.

Page 1438, line 8: elaborated = elaborate.

Page 1438, line 13: Southern part France = southern part of France.

Page 1438, line 25: fresh water were = fresh water was.

Page 1439, line 24: capillarity frange = capillarity fringe ?

Page 1440, line 3: symbol psi; (psi tends to zero) used but not defined.

Page 1440, line 7: measured in = computed in. (confusing use of term 'measured').

Page 1441, line 25: South East = southeast.

Page 1441, line 27: located to North West to = located northwest of.

Page 1442, line 20: equal at = equal to.

Page 1442, line 24: provide proper reference for Comsol multiphysics 3.3.

Page 1443, line8: its account for = it accounts for.

Page 1443, line 13: in the purpose to invert = for the purpose of deducing.

Page 1455, caption for Figure 4: remove the last word (measured) on the first line.

Page 1459, caption for Figure 8 is incomplete. Start with ' Comparison of measured and simulated SP anomalies'. Change error bars to error bar.

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

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