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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Modelling the hydrological interactions between a fissured granite aquifer and a valley mire in the Massif Central, France" *by* Arnaud Duranel et al.

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We thank Anonymous Referee #1 for their comments and for suggestions on the original paper. We believe that the paper will be improved by responding to the issues that they raise and by incorporating their suggested revisions.

Summary and Comment 1:

The referee suggests that we "see the main generic contribution of the study as a demonstration of the limits of the "impermeable bedrock paradigm"'. Although our study does indeed contradict this paradigm, we do not see this as its main contribution, nor

its main objective. The "impermeable bedrock paradigm" is only referenced in the Introduction and Conclusion of the paper, to frame our research within the wider context of hydrological research within hard rock regions. It is not central to the aims of the study and the methods employed which, as discussed below, focus on mire hydrology. Nevertheless, we do acknowledge that issues related to hard-rock hydrogeology figure prominently in our introduction. We felt this was necessary to set the scene for our research questions and highlight the novelty of our findings; but we appreciate this may give the reader the impression that our study focuses on this issue. Therefore, in revising the manuscript, we propose to recast the Introduction to focus more explicitly on the central issues related to the hydrology of the type of wetland considered in our study. Given this, reference to the impermeable bedrock paradigm will be maintained but the central focus – i.e. modelling the hydrology of wetlands in such areas – will be much more explicit.

The referee suggests that wetland processes could have been simulated with a multiple model approach, using different and competing conceptualizations of hydrological processes. While we fully agree that such an approach would have been appropriate if our objectives had been to test the "impermeable bedrock paradigm" or to instead investigate the implications and associated uncertainty of using different process descriptions (e.g. Thompson et al., 2009, 2004), we argue the referee proposes a completely different study to that which the paper reports. Instead, our objectives, which are described at the end of the Introduction, clearly focus on the hydrology of the acidic valley mire. Using a case study, we aimed to (1) test the ability of an equivalent porous medium approach, with limited data on the hydrodynamic properties of the granite weathering formations, to reproduce high-resolution spatial and temporal patterns in groundwater seepage and groundwater table depth within the mire, (2) quantify the mire water balance including its dependence on groundwater inflows from granite weathering formations, and (3) investigate the hydrological processes driving groundwater table depth in the mire. To do this we used the best available conceptual understanding of the research catchment and its mire, supported by a large set of field data (further described in Duranel (2015) and, in response to a suggestion from Referee #2, to be expanded upon in the revised paper). We demonstrate that groundwater upwelling can be a quantitatively important and functionally critical element of the water balance of valley mires in granitic headwater catchments.

Whilst our research is a case study and uses established methods, to our knowledge this is the first integrated hydrological modelling study of a mire that accounts for groundwater flow in weathered hard rocks, and shows a close match between spatial patterns of simulated groundwater upwelling and seepage and the observed distribution of mire habitats. Ala-aho et al. (2017) used similar methods in a similar environment, but assumed that the underlying granite bedrock was impermeable. As such, our results are novel and are of interest for a broad international readership since they have important implications for the hydrological understanding, management and conservation of such wetlands, which occur in many regions around the world and provide a large number of important ecosystem services. We hope these results will trigger further research on these systems, including a more theoretical testing of the impermeable bedrock paradigm using a multiple model approach as suggested by the referee.

Response to Comment 2:

Calibration and validation periods covering a total duration of 3 years (and often much less) are the norm rather than the exception in physically-based hydrological modelling studies of wetlands (e.g. Ala-aho et al., 2017; Armandine Les Landes et al., 2014; Haahti et al., 2016; House et al., 2016; Levison et al., 2014; Li et al., 2019; Quillet et al., 2017; Thompson et al., 2004). In many cases this is the result of the unfortunate exclusion of wetland environments from formal hydrometric networks (e.g. Hollis and Thompson, 1998) despite their ecological and socio-economic significance. In revising the paper we will more explicitly refer to the often relatively limited calibration datasets available for wetland environments and that in comparison to many previous studies the data employed in the current study is both more numerous and spatially distributed

(e.g. Ala-aho et al., 2017; Armandine Les Landes et al., 2014; Haahti et al., 2016; Hammersmark et al., 2008; House et al., 2016; Li et al., 2019). The excellent fit of simulated long-term mean groundwater table depth, groundwater upwelling rate and groundwater seepage rate with observed mire boundaries (including along the narrow valley downstream and in the small sub-basins located upstream of and 30m above the main mire extent where no groundwater table depth data were available for calibration) demonstrates that the model satisfactorily reproduces the dominant hydrological characteristics of the mire and its catchment. We therefore conclude the model is suitably robust to quantify the long-term water balance of the mire. Like every model and for practical reasons, our model makes simplifying assumptions, one of which is uniform hydraulic conductivity throughout the fissured zone. We discuss the limitations associated with these simplifying assumptions, but demonstrate that they do not undermine the ability of the model to reproduce the dominant hydrological characteristics of the mire and its catchment and they do not undermine our conclusions.

Response to Comment 3:

We agree with Referee #1 and so when revising the paper will make it clearer that our sensitivity analysis is a local sensitivity analysis around the calibrated parameter values.

Response to Details:

p. 4, line 22: to date, there is still only limited coverage and availability of LiDAR data in France, and none was available for our site. We had no access to UAV equipment. Photogrammetry using the available aerial pictures would have resulted in lower accuracy due to their relatively coarse resolution (a state-of the-art photogrammetric workflow developed by the French Geographic Institute achieved residual mean planimetric and altimetric errors comprised between 1.0 and 3.5m and between 1.4 and 2.0m, respectively; Bris et al., 2018). We used the best technology and data that were available to us at the time to build the most accurate DEM that was possible.

p. 5, line 13: this is correct. This is described in depth in Duranel (2015) which is cited and available online (https://discovery.ucl.ac.uk/id/eprint/1472054/1/Duranel_PhDthesisADuranel2015.pdf) and, in response to a suggestion from Referee #2, to be expanded upon in the revised paper.

p. 7: we agree with Referee #1 and will update the revised paper accordingly.

p. 11, line 27: extensive attempts were made to tighten the convergence criteria, however this resulted in relatively small gains but a substantial increase in computing time. The water balance error is overwhelmingly caused by the MIKE SHE overland flow module within the mire, and so does not affect estimates of overland boundary inflow, stream inflow and groundwater inflow and outflow to and from the mire. Because the mire is saturated most of the time, very little infiltration is simulated within its boundaries. As a result, the overland flow component error mainly affects simulated overland outflow to the river, which is not the main focus of our study.

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