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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Redressing the balance: quantifying net intercatchment groundwater flows" *by* Laurène Bouaziz et al.

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Dear reviewer,

Thank you for the positive and constructive review of our manuscript. We value the comments and suggestions you have made to improve the manuscript and would like to respond to them below.

"General Comments":

This paper covers a very timely topic and would be a nice addition to HESS. The concept of quantification of Inter-catchment Groundwater Flow (IGF) is still in its infancy, but its relevance to the modeling and process understanding regarding water quality and quantity is obvious. The study summarized in this paper applies a three step ap-

proach to quantify IGF that relies on the (1) comparison and analysis of observed water balance data within the Budyko framework, (2) applying a suite of different conceptual hydrological models and (3) remote sensing based estimates of actual evaporation. Their analyses suggest that IGF varies annually, and at the scale of the headwaters, IGF can make up a relatively large proportion of the water balance. At the same time, as detailed in the comments below, I do have some substantial concerns. After these issues are resolved, I believe this paper will make a nice and impactful contribution to HESS.

"Specific comments"

Introduction

1) The introduction falls short in acknowledging recent research on the quantification of IGF. Gleeson and Manning [2008], Welch and Allen [2012] and Ameli et al. [2018] used physically-based approaches to explicitly quantify IGF. These works also explored factors controlling the IGF. It might also be useful to cite some previous works which used Budyko framework to estimate watershed-scale groundwater recharge/discharge or IGF.

Thank you for pointing out these recent studies on the quantification and controls of IGF. We will acknowledge them in the reviewed version of the manuscript.

2) As it is in the introduction now, the importance of the understanding of IGF is limited to improving conceptual models. In addition to that, IGF impacts (1) water quality in the higher-order streams (2) the fate and biogeochemical alteration of non-point source agricultural pollution (3) the water replenishment in economically important aquifers within arid and semi-arid mountainous regions (4) the generation and migration of petroleum and mineral deposits, and (5) the ecological functioning of the watershed. These points have been discussed in Ameli et al. [2018].

Thank you for this interesting point, indeed the importance of understanding IGF is not limited to improving conceptual models, we will make sure to state this in the revised version of the manuscript.

3) The current introduction did not clearly state how the current paper goes beyond the status quo and why we have to use the proposed approach to quantify IGF. As stated above, recent works explicitly quantified IGF using sophisticated physically-based hydrological models. In my opinion, the advantage of the proposed approach in this paper is to use a simple framework and widely available observations to estimate IGF. While previous approaches used extensive tracer and hydrometric observations, which are rarely available in most landscapes, to explicitly quantify IGF.

Thank you for raising this issue, we agree that this paper provides a simple framework which uses widely available observations to estimate IGF and we will make sure to add this clearly in the introduction of the revised manuscript.

Limitations and Advances

It is good that the author explained some of the limitations of the proposed framework. However, I think this part still should be extended to provide the readers with a better understanding of the applicability and limitation of the proposed framework.

1) Although the proposed framework worked well in the Muse basin with high percentage of steep hillslopes, it ignores surface storage of water in lakes and wetlands. Surface storage of water is an important element of water budget in flat lake/wetlanddominated watersheds. Water retains in these storages for decades without reaching the stream. Ignoring this element when using the proposed approach can lead to a wrong estimation of actual evaporation and IGF.

We thank the referee for raising this interesting point. We agree that the proposed approach can lead to wrong estimations of actual evaporation and IGF in lake/wetland dominated watersheds and we will make sure to state this in the revised version of the manuscript.

2) As the authors acknowledged, the Budyko framework is subject to uncertainties in the data used to calculate long term averages of precipitation, discharge and potential evaporation. In addition, this paper used data from different sources at different watersheds. These uncertainties limit the ability of the framework to compare the estimated IGF between watersheds. This should be clarified in this section. Having said that, the comparison made in figure 9 (lower panel) might not be robust given the different sources of data in different watersheds used in the Budyko analysis. Off course that part of the comparison made using the conceptual model is valid.

If we understand this issue correctly, we should clarify that there are also uncertainties from the fact that precipitation and discharge observations are from different sources (French sources for the French part of the catchment and Belgian sources for the Belgian part). In spite of these differences, we believe that the quality of precipitation and discharge observations is sufficiently high to enable a comparison of estimated IGF between watersheds. The analysis made in Figure 9 only involves watersheds which make use of data provided by the Service Public de Wallonie and we therefore think that the comparison is robust, even in the lower panel of the plot.

3) Similarly, the proposed framework has limited ability to estimate IGF for different scenarios of land use and climate change. IGF is a slow process with transit time of over hundreds of years (cf [Ameli et al., 2018]), and is not rapidly sensitive to most environmental changes. So it takes long time that the changes in climate and land use impact the amount of IGF (but the Budyko framework may suggest in a different manner as Q/P changes).

Thank you for raising this point, indeed, Ameli et al. (2018) state that regional groundwater flows can have mean transit time of hundreds of years, however the distinction should be made between the mean transit time through the catchment and the mean response time of the catchment. The mean transit time characterizes the hundreds of years a water particle may need to travel from the surface where it arrives as a raindrop to the catchment outlet through deep subsurface flow paths. This process is driven by the advective velocity of a particle. On the other side, rainfall events initiate the propagation of pressure waves through the system and enable the catchment to release water with a much faster response time. This process is driven by the celerity of the propagation of the pressure wave. The very long mean transit time of water molecules and the rapid rainfall-runoff response time imply that very old water can be released by the catchment in weeks, days or hours. As we are interested in the fast response of the propagation wave through the catchment, we believe that the framework should still be applicable to assess the impact of future land use and climate change scenarios on IGF. We will make sure to address this in the revised version.

4) Also please clarify that the Budyko framework is only able to estimate long-term IGF and not annual IGF.

We will clarify this in the revised manuscript.

"Minor comments"

P2-L15. Delete extra period.

Thank you for seeing this, we will delete the extra period.

P2L33. It is true for some but not all types of solutes. Ameli et al. [2017] compared the degree to which the residence time and concentration of different solutes are corresponded.

Thank you for raising this point, we will be more specific in the revised version of the manuscript.

P3L1. Gleeson and Manning [2008] used water budget analyses to calculate the actual rates of intercatchment groundwater exchanges

Thank you for pointing this out, we will include this reference in the revised version.

P3L6. Provide examples of these models and their citations

We will add examples and citations of these models in the revised manuscript.

P5L2. Perhaps this last sentence could come earlier in the paragraph

We will change this in the revised manuscript.

P6L24. Explain the Turc-Pike framework and its assumptions

We will add this in the revised manuscript.

P10L24. But previous research showed different conclusions (see Ameli et al. [2018] and Gleeson and Manning [2008]). As the watershed slope increases, the water table depth increases on average, leading to more regional GW and thus more intercatchment GF.

Thank you for raising this point, however, in their study, Gleeson and Manning [2008] assume a homogeneous subsurface because their objective is to explore the general behavior of groundwater flows on a regional scale rather than to study specific groundwater flows in a particular geological setting. In the Meuse basin, the studied flatter catchments are mainly underlain by high-permeability (potentially karstified) geological features which might be a stronger control than the watershed slope.

P13L19 Use annually in the entire paper and figure labels/captions

We will make sure 'annually' is used consistently throughout the paper.

P14L33. This is too general statement. This value may be significantly larger or smaller for different types of geological settings and watershed slope.

Thank you for raising this point, we agree that different types of geological settings and watershed slope may be more important controls than the size of the watershed, however, we show that evidence for IGF is largest in small catchments and less pronounced in larger downstream catchments, even though there are also small catchments with little evidence for it. We will make sure to make the statement more specific in the revised version.

Reference Cited

Ameli, A. A., C. P. Gabrielli, U. Morgenstern, and J. McDonnell (2018), Groundwater subsidy from headwaters to their parent water watershed: A combined field-modeling approach, Water Resources Research, 54.

Ameli, A. A., K. Beven, M. Erlandsson, I. Creed, J. McDonnell, and K. Bishop (2017), Primary weathering rates, water transit times and concentration-discharge relations: A theoretical analysis for the critical zone, Water Resources Research, 52.

Gleeson, T., and A. H. Manning (2008), Regional groundwater flow in mountainous terrain: Three-dimensional simulations of topographic and hydrogeologic controls Water Resources Research, 44(10).

Welch, L., and D. Allen (2012), Consistency of groundwater flow patterns in mountainous topography: Implications for valley bottom water replenishment and for defining groundwater flow boundaries, Water Resources Research, 48(5).

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