

Interactive comment on “Continental hydrosystem modelling: the concept of nested stream–aquifer interfaces” by N. Flipo et al.

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Received and published: 10 March 2014

First of all we would like to thank the two reviewers for their detailed and important comments on the manuscript. Although the reviewers recommend certain clarifications, we are pleased to read that both reviewers understand the importance of the paper to achieve a more holistic perspective on stream–aquifer exchanges. We understand from the reviewers’ comments that the paper needs certain revisions, which unfortunately cannot be undertaken before March 11th, the closing date of the opened discussion. However, before the editor takes his decision, we would like to shortly address one major issue pointed out by both reviewers: the difficulty to extract the main message from the paper.

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We actually believe that this drawback of the paper mainly originates in implicit shortcuts and a lack of clarity in the introduction. Based on the comments of reviewer 1 and reviewer 2, we propose to restructure the argumentation line of the introduction as follows:

The emergence of a systemic view of the hydrological cycle led to the concept of continental hydrosystem (Dooge, 1968; Kurtulus et al., 2011), which “is composed of storage components where water flows slowly (e.g. aquifers) and conductive components, where large quantities of water flow relatively quickly (e.g. surface water)” (Flipo et al., 2012, p. 1). This concept merges surface and ground waters into the same hydrological system through the stream–aquifer interface. As a key transitional component characterised by a high spatio-temporal variability in terms of physical and biogeochemical processes (Brunke and Gonser, 1997; Krause et al., 2009b), this interface requires further consideration to better understand the hydrogeological behaviour of basins (Hayashi and Rosenberry, 2002), and therefore continental hydrosystem functioning (Saleh et al., 2011).

The dynamics of water exchanges at the stream–aquifer interface is complex and mainly depends on geomorphological, hydrogeological, and climatological factors (Sophocleous, 2002; Winter, 1998). Recent eco-hydrological publications, dedicated to stream–aquifer interfaces claim the recognition of the complexity of the multi-scale processes taking place in the interface (Ellis et al., 2007; Hancock et al., 2005; Poole et al., 2008; Stonedahl et al., 2012).

A number of published papers address the problem of reactive transport through the stream aquifer interface. These papers imply sophisticated models, which represent the dynamics of pollutant at the local scale (See for instance Frei et al., 2012) fairly well, taking into account the effect of micro-topography and of sharp redox gradients on the exchanged fluxes. Also at the regional scale models are able to simulate pollutants transport at the basin scale (see for instance Seitzinger et al., 2002., or Ledoux et al. 2007). However, these models poorly simulate pollutants removal due to water

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fluxes through the sharp redox gradient of the hyporheic zone. This is due to the tautological nature of these models, which do not account for sub-cell fluxes. These fluxes are driven by finer scale hydrological processes such as upwards or downwards water movements at the stream-aquifer interface. Large scale models therefore lack predictive abilities with regards to climate change issues or the assessment of the implementation of environmental regulatory frameworks, such as the European Water Framework Directive (WFD).

Although, the number of papers concerning stream-aquifer interfaces exponentially increased in the last 15 years (Fleckenstein et al., 2010), they mostly focus on local scale issue, following a classic bottom-up scientific approach (Natfandis et al., 2011). The lack of models aiming at quantifying stream aquifer exchanges at large basins' scale was already alleged by Krause et al., 2011. The current review quantitatively confirms that the larger the scale (scale in the sense of model dimension), the less understood the interfaces. This is one of the major current concerns for large scale river basin managers, who have difficulties to fulfill the requirements of for instance the European WFD, especially for providing guidelines towards a good ecological status of both surface water bodies and subsurface water bodies. State-of-the-art coupled surface-subsurface models nowadays fail to integrate eco-hydrological concepts based on functionalities of morphological units (Bertrand et al., 2012; Dahl et al., 2007), mostly because they are not yet able to integrate the multi-scale nature of the stream–aquifer interfaces within a holistic view of the system.

There is thus a crucial need to develop innovative methodologies for assessing stream–aquifer exchanges at the regional and continental scales, which is a challenging issue for modelers (Graillot et al., 2014). The aim of this paper is therefore to pave the way towards a multi-scale modelling of the stream-aquifer interface, with the ambitious goal of being able to simulate the complexity of the processes occurring at the local scale in larger scale models, i.e. at the regional scale for large basin decision makers, and also at the continental scale, which is the primary scale of interest for the assessment

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of the effect of climate change on hydrosystems. In other words this paper aims at rationalising the modelling of stream–aquifer interface within a consistent framework that fully accounts for the multi-scale nature of the stream–aquifer exchange processes (Marmonier, et al., 2012). This is a necessary primary step before the assessment of the hydrological impact on geochemical fluxes. Following the attempt of Mouhri et al. (2013), who rationalise the design of stream–aquifer interfaces sampling system, we first define the various scales of interest. We also define the concept of nested stream–aquifer interfaces as a key transitional component of continental hydrosystem (section 2). Then in section 3, based on a literature review, we introduce a hierarchical order of the multi-scale controlling factors of stream-aquifer hydrological exchanges, from the larger scale to the finer scale. The stream network is identified as the key component for scaling hydrological processes occurring at the interface. In section 4, the paper focuses on the stream–aquifer interface modelling at various scales, with up-to-date methodologies. After describing the modelling approaches at the two extreme spatial scales, we emphasize which hydrological parameters and variables have to be up and downscaled around the river and also for which models. Finally, we develop the MIM (Measurements-Interpolation-Modelling) methodological framework for the design of multi-scale studies of stream-aquifer exchanges based on a more holistic view of the hydrosystem. MIM is a valuable tool to define strategies for combining field measurements and modelling approaches more easily. Given the usage of the MIM methodology, we show that the scaling of processes from the local to the watershed scale is structured around river reaches of 1-10m. We also analyse the question of how to model stream-aquifer exchanges at the continental scale, and investigate the usage of remote sensing data, which should improve global hydrological budgets. We conclude that further developments in modelling and field measurements have to be performed at the regional scale to be able to model stream-aquifer exchanges from the local to the continental scale properly.

We believe that the message of the paper is now clearer. The main part of the text will be also reworked on to take into account reviewer 2 comments on:

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- Disconnexion issues. The papers indicated by the reviewer will be integrated in section 3.2 and 4.5. It will significantly increase the quality of these two sections. We definitively agree with reviewer 2 that disconnexion issues deserve to be more detailed in the paper. This is totally compatible with the current analysis of up and downscaling issues around the river network.

- section 5.2 about space borne approach: the context was missing and is now presented in the introduction. Satellites coupled with models are valuable tools for assessing climate change impact on hydrosystems functioning. This will become more real with the SWOT mission, which will sample every continental water bodies with a very fine resolution never achieved before. Therefore it is important to start positioning this new product in the MIM framework to design the best coupling strategy with models. It is also clear from this analysis that sampling strategies have to be defined at the regional scale to bridge the gap between the continental scale and the watershed scale. For that we propose to investigate the potential of airborne campaign coupled with in situ sampling system inspired by the LOMOS station of Mouhri et al. 2013.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 451, 2014.

HESSD

11, C339–C343, 2014

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