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Hydrology and Earth System Sciences Discussions

Interactive comment on "Modelling subsurface storm flow with the Representative Elementary Watershed (REW) approach: application to the Alzette River Basin" *by* G. P. Zhang et al.

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We would like to thank the referee, M. Sivapalan, for his critical and valuable comments on our manuscript, which will surely improve the quality of the paper.

The referee pronounced his concerns on the way of conceptualization of the macropore domain, the derivation of the closure relation to the exchange terms associated with the macropore flow, and the necessity of the inclusion of the macropore domain to the REWASH model. We would like to briefly respond to these issues and will address them in the subsequent revision of our manuscript.

Comments: 1) The paper introduces a macropore domain into the REW formulation. I really do not understand the model schematic presented in Figure 1. The macropore domain takes up part of the unsaturated zone - I have a real problem with this. I do not believe the macropores take up such a large surface area - they are almost line segments and I do not see how they can take up so much area. I also do not understand the definition of the variables presented in Eq. 1. In fact I do not understand at all the description in the paragraph that follows Eq. 1. The same comments apply to the paragraph that follows Eq. 4. The macropore description has to be better motivated - it seems very artificial and ad hoc. I have real problems with this type of description.

Figure 1 is a schematic diagram presenting the flux exchange terms and the associated flow domains. The arrows show the flow directions. Same as in the relevant equations, e_{cu} is the flux from the surface (infiltration-excess overland flow domain) to the unsaturated zone (infiltration), e_{cm} is the infiltration flux from the infiltration-excess overland domain to the macropore domain, e_{us} is the flux exchange between the unsaturated and the saturated domains (recharge or capillary rise), e_{ms} is the recharge flux from the macropore domain to the saturated domain, e_{mr} is the lateral flux from the macropore domain to the river domain, e_{sr}, e_{or}, and e_{so} are the flux exchange terms between the saturated and river domains, the saturation-excess overland domain and the river domain, and the saturated and saturation-excess overland domains, respectively.

Indeed, the area of the macropore domain we conceptualised occupies the same area as the unsaturated domain, which is rather large if we associate it with reality. However, what is of our concern is the volume (storage capacity) of the domain, which is the product of the average of the depth of the domain (y_m) and the area of the

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domain (ω_m, assumed to be the same as ω_u), as in Eq. (1). Such conceptualization is motivated by the observation that macropores and other types of large openings are diffusively distributed in the subsurface, although some of such structures are line segments.

Equation (1) describes the volumetric composition of a REW, which takes a similar form as in the previous papers on the REW approach, e.g. Eq. (B1) in Reggiani et al. (2000). This equation explains that the total volume of a REW, represented by the average depth of the soil Z, consists of three parts: the volume of the unsaturated domain ($y_u \cdot \omega_u$), the volume of the macropore domain, represented by $y_m \cdot \omega_u$, and the volume of the saturated domain ($y_s \cdot \omega_s$). There are two assumptions behind this concept: the macropore structures occupy the same area as the unsaturated domain (i.e. ω_m=ω_u), and the saturated domain occupies the total REW area and invariant (i.e. ω_s=1).

In Eq. (4), the left hand side is the storage change of the saturated domain. The storage is represented by multiplication of the porosity of the saturated domain, ϵ_s (which appeared as ϵ_u in the equation due to typo) with the average depth of the domain, y_s, the area fraction ω_s and the surface area of the REW, A. The storage change is balanced by the sum of the fluxes exchanged with the neighbouring domains (sub-regions). These are the infiltration/capillary flux across the unsaturated-saturated boundary, e_{su}; the exfiltration flux across the boundary between the saturated domain and the saturation overland flow domain, e_{so}; the baseflow flux across the river-saturated boundary, e_{sr}; and the recharge flux from the macropore domain to the saturated domain, e_{sm}.

Comments: 2) If they introduce a new flow region, they should include not only new mass balance equation and also a new momentum balance equation. To my

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understanding this is not done - this means the whole formulation may be theoretically flawed. The impact of the new domain on the whole momentum balance must surely be looked at. I need reassurance that this has been done or that the authors have found a way out of this. If not, this is a fundamental problem, in that the physical basis of the REWASH model has been compromised. In fact the paper does not even present the set of momentum balance equations that underlie REWASH.

Finding appropriate closure relations to the exchange terms of the mass balance equations, as a flux-based approach, is the core of the issues for the REW approach. Therefore, using physical principles by means of the momentum balance, energy balance equations and entropy concept is one of the ways to close the equation systems. Indeed, Reggiani et al. (1998, 1999) have elegantly presented the derivations of the balance equations that potentially serve for guiding the analysis of the REW-scale hydrological processes. However, we have observed that momentum balance analysis does not always or necessarily lead to (proper) functional expressions to close the mass balance equations. Yet, without correct field experiments on the problems at the scale of interest (in this case, the REW scale), it is hard to prove the suggested "physics" (e.g. those forces exchanging across the REW-scale boundaries, which again are not easy to be defined and rather conceptual) are the real physics governing the hydrological processes at such scale. Therefore, in parameterising or closing the mass balance equations, case-by-case (or ad hoc) assumptions are unavoidable in the foreseeable future. A typical example for this is, in Reggiani et al (1999), where they proposed a linearisation approach to quantify the mass exchange terms, which stated that the mass exchange terms are lineally dependent on the superposition of two functions related to potential gradients and average velocities of both sides of the boundary in question, respectively. Actually, even the average velocities are dependent on the potential gradients, i.e. such two functions are interdependent. In the later REW concept applications, this linearisation has been further simplified, such that the mass exchange terms are dependent either on pressure potential gradients or

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on average velocities (e.g. Reggiani et al., 2000). Another example, in the previous publications on the REW application: the mass exchange terms between the saturated domain and the river and overland flow domains are not derived using the general momentum equation of the saturated zone. Moreover, as many authors (e.g. Lee at al. 2005; Zehe et al. 2005; Zhang and Savenije 2005) have discussed, there are a number of approaches to the closure problem, for instance, regression analysis based on detailed numerical experiments, and physical reasoning based on intuitive ground are optional. These types of methods for the closure are conceptual but with some physical background in one way or another. Keeping this in mind in our work of modelling quick subsurface flow for the catchment under study, in introducing a macropore domain to the REW approach, we indeed took a conceptual approach to formulate the new domain and the associated functional relations to close the new mass balance equations, but using a physical background.

Comments: 3) I would like the assurance that the REWASH model without these additions could not predict the observed runoff well with the appropriate choice of parameter values. In particular, I would like the assurance that the incorporation of macropore flow was absolutely essential to reproduce the observations.

In our previous work (e.g. Zhang et al. 2005), we modelled the catchment responses of the Hesperange catchment using our model code WITH and WITHOUT the quick-subsurface-flow component (we call them hereafter the model WITH or the model WITHOUT), although the quick-subsurface-flow component was conceptualised a bit differently from what we have done in this paper. The comparison of the results showed that the model WITH performed better than the model WITHOUT in terms of discharge at the catchment outlet. More importantly, the model WITH simulated the saturated overland flow area more reasonably than the model WITHOUT. In modelling, it is commonly observed that different models may perform equally well in terms of

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discharge but they may not produce the internal states of the system equally well. That is the reason why there have been many debates on "model being right for the wrong/right reasons". Even if the model WITH and WITHOUT would reproduce the observed runoff equally well, considering the catchment characteristics, we think that the addition of the macropore domain into REWASH for this study is necessary because our attempt is to model the phenomenon right for a right reason (taking into account the process observed at the site).

Comments: 4) I have a problem with the authors identification of the macropore flow domain as that of fast subsurface flow domain. I would like better justification of this association.

Terms describing quick subsurface flow are quite subjective. The subsurface runoff processes that significantly contribute to total runoff of a catchment are termed differently in literature, which has been briefly presented in our manuscript. Such processes are very local and take very different pathways underground. They can also coexist in one hillslope or one catchment. The paths of these processes are formed by a variety of large openings in the subsurface where under certain conditions connectivity of such openings is built up. Due to the high conveyance capacity of such connected openings, in contrast to the soil matrix, flows through these structures are fast enough to contribute to the stream hydrograph. As far as the temporal scale is concerned, and due to the difficulty, on the other hand, to specify the dimensions of the domains for each local process at the catchment scale, all the processes occurring in the subsurface that are characterised by a fast time scale are generalised into one category in our study, and thus the domain accommodating this process is named macropore flow domain.

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