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Interactive Comment

# *Interactive comment on* "Extension of the Representative Elementary Watershed approach by incorporating energy balance equations" *by* F. Tian et al.

**F. Tian et al.**

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Answers to the comments by anonymous referee 4

We would like to thank the anonymous Referee 4 for his comments on our manuscript, which will improve the quality of the paper.

**General comments**

The answer to the reviewer's question "what the significantly new results the paper contains" was given in the Redefinition Section (Sect.3) and the Conclusion Section (Sect.7) in the original manuscript. But, it's probably true that the new results of the paper need to be more clarified, and the words "energy balance equations" in the original title may be misleading and need be reformulated, which is already done in the revised manuscript. Here we want to repeat the main contribution of the paper:

**(1) The energy related processes including evaporation/transpiration, melting, freezing, and thawing, could be modeled in a physically reasonable way in our new definition of REW system.** The combined processes of evaporation and transpiration are major components of the hydrological cycle (Ward and Robinson, 1990). It accounts for the disposal of over 90

**(2) The balance equations for each sub-region are re-formulated in a more systematic and consistent way compared with Reggiani *et al.*'s work (1998).** We first derive the general form of time-averaged conservation laws of mass, momentum, energy, and entropy at the spatial scale of REW, which is independent of any zone and any phase. After a series of assumptions aimed at watershed hydrological modeling, the interfaces, which determine the exchange terms arising in the balance equations, are simplified. The general form of conservation laws is then applied to derive the balance equations for each phase in each zone. There are in total 24 balance equations, eight of which are heat balance equations including various energy processes such as heat transfer and phase transition. Readers who are familiar with the REW literature could realize the differences between our formulation and original formulation procedure.

**(3) Our definition and formulation procedure can be more easily applied when it is desired to include new zones and phases into the approach.** This is demonstrated in Appendix B in the revised manuscript by introducing the reservoir zone in order to represent the effect of hydraulic projects on hydrological processes.

**(4) Hillslope is treated with by its flow nature as well as by its evaporation/transpiration nature simultaneously.** In Reggiani *et al.*'s formulation (1998), hillslope is divided into the saturated overland flow zone and the concentrated overland flow zone which does help to represent various flow processes conveniently, but



HESSD

3, S718–S724, 2006

still cannot represent evaporation/transpiration occurring from various kinds of land cover such as water, vegetation, bare soil, snow, and glacier. Hillslopes, which are the primary regions for runoff generation as well as water dissipation, must be treated with by its flow nature and evaporation/transpiration nature simultaneously. Therefore, the original hillslope division scheme containing saturated overland flow zone and concentrated overland flow zone, which is intended to account for various flow processes, is inadequate for hydrological modeling physically. In our new definition, saturated overland flow is no longer separated from infiltration excess flow because their underlying unified mechanism (Rui, 2004), while runoff generation can be modeled physically even without such separation, as in most current physically-based hydrological models such as SHE (Abbott *et al.*, 1986a, b) and GBHM (Yang D. *et al.*, 2000, 2002a, 2002b). The hillslope is divided into various kinds of land covers which presently include bare soil zone, vegetated zone, snow covered zone, and glacier covered zone, and new equations introduced by additional sub-regions when necessary can be easily coupled with the developed equations, as discussed in general comment (3).

**(5) The sub-stream-network is separated from other zones so that the sub-REW-scale runoff routing function can be represented explicitly.** The way that the sub-REW-scale network of channels, rills and gullies is included in the concentrated overland flow zone is somewhat ambiguous in the original REW definition by Reggiani *et al.* (1998). The sub-REW-scale network of channels, rills, gullies, as well as lakes, reservoirs, etc., namely, sub-stream-network, is water body, and its role in hydrological processes is distinct from that of the land surface. The sub-stream-network can serve as not only runoff generation areas but also as runoff routing pathways, and the latter function is by no means less important than the former one, especially in a REW with large area. We cannot represent the sub-REW-scale runoff routing function physically if the sub-stream-network is embedded in other sub-regions. In our extension of the REW approach, the sub-stream-network is separated from other zones which gathers water from the hillslopes and transfers it into the main channel reach.

Besides, the referee questions that how the balance equations together with the rigorous definitions of the flux terms can actually be used to describe a given watershed. The answers lie in the constitutive relationships. One can refer to the literatures by Reggiani and Rientjes (2005), Lee *et al.* (2005), and Tian (2006) for detail.

The authors' answers to the specific comments are listed below:

**Comment 1**

*It would have been useful to define both a watershed and a sub-watershed. I assume one cannot just pick arbitrary areas of the entire watershed and call them subwatersheds? The comment that a REW is a subsystem of the entire watershed is too vague.*

We agree with the referee's option that one cannot just pick arbitrary areas of the entire watershed and call them sub watersheds. The representative area for REW should be pursued with great effort. As a new theory for hydrological modeling, however, one can expect that the research community allow some bugs and leave them for the future research.

**Comment 2**

*The abbreviations for the subregions should be introduced in the main body of the text (in the list on pages 438 and 439) and not only in Table 4.*

The comment is useful for interpretation of manuscript. The abbreviation for each subregion is added in detailed description paragraphs for each sub-region by following the Referee's comment.

**Comment 3**

*Page 441, Line 10: I do not understand the notation K is an element of e|e=1..M Why the vertical bar? In my understanding K represents only one REW. Thus, it should read K = 1, 2, ..., M Similar notation is used throughout the entire paper and should be revisited.*



HESSD

3, S718–S724, 2006

The expression we used is from the set theory, which is one of the mathematical subjects. The expression suggested by the Referee may also be feasible. We prefer the former one.

**Comment 5**

*Equation (23): Should the volume element dV be replaced by the position vector r? Also is this Definition 10, which is missing?*

The reason that we chose dV instead of the position vector r is similar with the answers to the previous comment. And the term of "Definition 10" is missed due to typos and is added in the revised manuscript.

**Comment 6**

*Section 5.2: the authors should carefully introduce the term phase level continuum. Where is it defined, for example?*

The phase level continuum is defined at the beginning of the Sect.4 in the original manuscript as follows: **every type of substance in a sub-region is treated as a subsystem of a sub-region level thermodynamic system, which is called phase-level subsystem. The number of phase level subsystems included in a sub-region level system can be seen in Table 3, and there are in all 23 phase level subsystems in one REW level system.**

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HESSD

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Interactive Comment

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