

Interactive comment on “Energy states of soil water – a thermodynamic perspective on storage dynamics and the underlying controls” by Erwin Zehe et al.

Anonymous Referee #1

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In a nutshell: This paper has a lot of potential. However, there are important caveats that raise serious concerns. Revision is therefore strongly recommended.

A) General considerations

Overall, I sympathize very much with the good intentions of the research leading to this manuscript, and with the quest to bring more physical rigour and credibility to the hydrologic endeavours and re-discovering the primordial Earth System DNA of hydrology that is often largely absent in engineering hydrology.

From the linguistic side and overall presentation, this manuscript is well-written and moving. Were this an outreach article, I would be delighted to read this paper.

However, in a formal context I see red flags arising when I look at the science beneath the text. I have serious concerns on how physical principles are naïvely invoked and formulation deployed in the manuscript, and how this manuscript follows a misleading line of research promoting problematic thermodynamic considerations as if they were rigorous thermodynamic physics.

While there is some basic mathematical care in the formulations and the argumentations and schematics make heuristic sense, physically the work does not yet meet the high standards that the authors surely intend to pursue, namely in terms of physically consistency.

Even so, admittedly the manuscript provides very nice intuitive explanations about the author's interpretation of hydrologic functioning, at textbook level.

Hydrology has a long history as an Earth System science with strong principles in thermodynamics and complexity and there is nothing new in this study that advances science in that regard. This is a simple nicely written hydrology paper trying to address a highly relevant particular problem with a practical formulation and can only be duly credited as such, without any presumption of building any fundamental "theory". A theory is supposed to be more general, aiming at universality within its scope, quite unlike what is proposed.

B) Perturbation approach

The authors apply a rough reasoning from first-order perturbation theory in analytical mechanics to deploy their work and even to discuss basic nonlinearities. In doing so, their framework unwittingly requires that the Earth System is trivially forced and then released to go back to an idealized equilibrium with the freedom to follow thermodynamic optimality principles.

However, the Earth System is neither forced so simplistically nor in a position to freely relax towards equilibrium. Consequently, in practice thermodynamic optimality aspects

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such as regarding entropy production or free energy decay rates are not allowed to be manifested in the hypothesised manner, which naturally reflects on the inadequacy of the simplistic functional solutions discussed in the paper.

In other words, deviations from storage equilibrium are treated in a perturbative theory setting that is only valid for small perturbations followed by unrestricted return to equilibrium. And that, sorry to say, is neither physically consistent nor useful in a real-world setting.

B) Energy currency

The authors introduce new names for trivially known concepts, like the "Energy state function" for something that is fundamentally not more than a mundane thermodynamic potential routinely used in various applications including in the Earth sciences. I wonder what justification exists for reinventing new names for already existing concepts.

Obviously, when looking at the catchment as with any other system, everything can be characterised around free energy and related thermodynamic potentials. There is nothing fundamentally novel about that and significant sectors of groundwater and broader geophysical hydrology already work in such energy currency.

C) Caveated "principles"

The thermodynamic optimality "principle" of Maximum Entropy Production (MEP) invoked in the text is not well accepted in Physics and Chemistry given that it is valid only under stringent assumptions that are not generally valid, and fundamentally discredited in those fundamental disciplines. Unfortunately though, MEP is mistakenly treated in various applied disciplines as if it were a real general thermodynamic principle.

The Maximum Entropy Production (MEP) approach is only valid as a limiting case of free flow in far from equilibrium macroscale conditions, with instability assumed to fully drive the macroscale dynamics under restrictive conditions such as local equilibrium. This may make some sense at first sight but cannot be guaranteed in complex geo-

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physical flows.

Therefore, when the authors discuss perturbations followed by restoration towards equilibrium and invoke physical reasoning, they should purge the paper from overstating problematic principles, otherwise readers will continue to be misled and the chain of MEP disinformation will further propagate in the literature, further hampering future research in Hydrology and Earth System sciences.

D) Caveated quotes and claims

The insight from Aristotle had already been widely mentioned in various scientific fields, including Ecology and Hydrology, long before the authors and their reference did so. However, neither the authors nor their mentioned reference invoke the expression with appropriate scientific and technical rigour.

In fact, treating a system in a holistic manner as a meta-organism does not qualify for being more than the sum of the parts, i.e. system holism does not guarantee that the whole is more than the sum of the parts. The Aristotle quote is only valid in specific system categories and embarrasses the paper in the prominent way that it is presented right at the start. No extra beyond the sum of the parts is rigorously analysed or computed anywhere in this paper.

Another problem pertains the general presentation style of the manuscript with unfair claims and hype. There is an unjustified sense of self-importance in the manuscript as it addresses the state of the art about having brought Thermodynamics into Hydrology. The paper makes such allegations whilst ignoring a vast body of literature in fluvial geomorphology and ecohydrology where hydrologic problems have been treated in a sound thermodynamic manner for decades and even taught in hydrology classes for earth science degrees, and long perceived and treated as a complex system or a meta-organism as in the Gaia hypothesis and exhibiting emerging features at system level.

The classical literature came long before recent literature such as Savenije and Hrac

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(2017) cited in the paper. The aforementioned opinion paper essentially reinvented the wheel with well-known generalities about Hydrology in the broader Earth System. While such unscientific hype can be digestible in tabloid-style opinion papers, it should not be admissible here where the authors worked hard to make real science. My stern advice is not to ridicule an otherwise fine work with such unscientific hype.

E) Summary and way ahead

Overall, there is merit of this manuscript in raising further awareness among engineering and statistical sectors within hydrology that hydrologic science is more than a naïve data science, and that it is fundamental to actually think about how the system is physically structured and operates like hydrology geoscientists have been doing for a long time.

I just wish that the physical arguments for the particular problem under consideration would be more consistent - hence my disappointment with this paper and my call for a thoughtful, sober revision.

As a way ahead, and this can be easily done in a sober revision:

First, please play out the cards as they are. When introducing concepts and quantities, they should be framed in a clean manner for what they really entail, rather than giving the illusion of fundamental novelty and using hypothesis that lack the validity and generality that is claimed.

When invoking "principles", it should be extensively explained to the readers what the domain of applicability, the underlying conditions, caveats and open questions are. Overall, all the assumptions and technical options, along with their limitations, need to be thoroughly justified, so that readers can approach "principles" for their real value.

Second, please eliminate the exaggeration and hype reminiscent of the literature upon which many of your arguments are based. This is supposed to be a rigorous scientific article, not a buzz-worded paper mixing technical science with rebranding old concepts

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yielding the illusion of novelty, out-of-context or unjustified quotes that look good but make no sense in this paper (e.g. Aristotle), perpetuating mistakes such as misuse of ill-posed thermodynamic optimality principles and perturbation theory, and further misinformation that otherwise propagates downstream in the chain of knowledge as has been happening to the related literature. Just because mistakes are published and highly cited, that does not make them correct.

The authors have the opportunity to amend their work in a scientific-technical sense, or at least to plainly explain the limitations and caveats of their formulation so that nobody is being misled anymore.

I will trust in the authors' willingness and ability to take my concerns into consideration in producing a revised version of their manuscript. For these reasons, and notwithstanding my skepticism about the work, I see value in a modest, cool-minded version focusing on the real science which has merits.

Therefore, I would not outright dismiss this paper but rather give a second opportunity that can be achieved through reflection and revision. The authors should be given a chance to amend their work and strengthen the scientific merit of their message.

It is clear that the authors have good hydrologic insights and there is a lot to be learnt by many readers in that regard. What is critically needed now is to correct the physics, which are fundamentally flawed, or at least make the limitations straight and clear to the readers. And for that, it is crucial to look beyond.

Thank you and good luck.

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