

Interactive comment on “HESS Opinions: A Planetary Boundary on Freshwater Use is Misleading” by Maik Heistermann

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I would like to thank Prof. Rockström for his timely contribution. I will try to respond without repeating too much of what has already been said in the two months since the discussion had started (some of Prof. Rockström's points have already been addressed in my response to RC3).

When I originally wrote the manuscript of the opinion paper, I was indeed kind of concerned. To me, the idea of a planetary boundary on freshwater use appeared so obviously flawed that I suspected I had missed any important aspects. Since then, people (including Prof. Rockström himself, in his comment) have repeatedly been suggesting that I "misunderstood", "misconceived", or "misinterpreted" the concept.

At this point in the interactive discussion, I am confident that this is not the case. That

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confidence is based more on the attempts to argue *in favour* of the PB concept than on the comments that actually shared my reservations. What I'd agree to, however, is that the concept of the freshwater PB in fact holds quite some potential for misunderstanding.

Altogether, Prof. Rockström points out *"two fundamental misunderstandings"* in the opinion paper and the subsequent interactive discussion.

1st misunderstanding

Prof. Rockström reiterates that *"the planetary boundaries define the environmental processes and systems that regulate the stability and resilience [...] of the Earth system"*, and establishes that the water cycle in fact contributes massively to regulate the state of the Earth system (pp. C2-C3). Who would oppose?

The alleged first misconception, as I understand Prof. Rockström, is that I *"wrongly interpreted the planetary boundaries framework as if [there were a planetary tipping point for freshwater]"*, although the PB literature never claimed such a planetary scale tipping point. In fact, that notion was repeatedly emphasized in the PB literature - and it was also explicitly voiced in the opinion paper (p. 3, ll. 13-17). What remains, however, after emphasizing that the water cycle is *"operating across scales"*, is a **planetary boundary on freshwater use**, and the unambiguous statement that *"transgressing one or more planetary boundaries may be deleterious or even catastrophic due to the risk of crossing thresholds that will trigger non-linear, abrupt environmental change within continental- to planetary-scale systems"* and that *"each proposed boundary position assumes that no other boundaries are transgressed"* (Rockström et al. 2009). The inconsistency between these two notions ("planetary boundary, but no planetary tipping point") is symptomatic for the concepts behind the freshwater PB: the "duality" of planetary and basin-scale boundaries, or the idea of having distinct boundaries that should, however, not be viewed in isolation (see also RC3). In my opinion, the common ground of these inconsistencies is a lack of coherent scientific underpinning.

2nd misunderstanding

As for the alleged second misunderstanding, I have to admit that I found the related paragraphs of Prof. Rockström's comment a bit difficult to follow. So before trying to rephrase, I will quote both paragraphs in full (pp. C4-C5):

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"And here comes misunderstanding No 2. We did not choose 'consumptive blue water use' as a control variable for the aggregate global scale water boundary, as an estimate of allowed 'maximum human water use'. We are only interested in the maximum allowed interference with the hydrological cycle, before which we risk seeing non-linear shifts in biome and river basin functioning, which in turn may trigger feedbacks affecting - across scales - the stability of the Earth system. We concluded that the net cumulative and consumptive reductions in runoff water from the global hydrological, is the best parameter we have (so far) in the hydrological cycle, to reflect the stability of water functions in the biosphere. So, it has nothing to do with human water use. It has to do with the maximum level of shifts in the global hydrological cycle beyond which we are likely to see changes in feedbacks, potentially triggering non-linear shifts in other Earth system regulation processes (e.g., carbon sinks, biodiversity, moisture feedback).

Why 'consumptive use of blue water'? Well, because it is a good indicator variable of the final end point of all the changes/dynamics that occur in (i) the partitioning of water in the hydrological cycle, and (ii) the flow of water through landscapes. For example, if rainfall (P) shifts, and/or green water flows as (ET) shifts in the 1st partitioning point in the water balance (e.g., through land use change/increased green water use), this will affect the volumes of surface and sub-surface runoff (R), which in turn are affected by withdrawals of R, generating a net final impact (degree of drying) in river basins, but only after considering 'consumptive use', i.e., factoring in re-

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turn flow of runoff. So, selecting consumptive use of blue water, is solely to find the best possible parameter to reflect the degree of change in the hydrological cycle, i.e., shifts in blue runoff flow to green vapour flows, e.g., changing moisture feedback, which, as Huub Savenije shows clearly in his commentary, has strong evidence not only of affecting rainfall, but also having tele-connections across biomes/regions, i.e., function as a planetary boundary."

As far as I understand, Prof. Rockström tries to make a point that human interference with the water cycle should not be reduced to direct consumptive use of freshwater (e.g. by irrigated agriculture). Instead, he claims that the control variable of the freshwater PB should be interpreted as *"the net cumulative and consumptive reductions in runoff"* (I suppose this implies "natural runoff", although the PB literature lacks the clear definition of a "natural" reference), and implies that these net effects should also include impacts of e.g. land use change on the net water balance. While this interpretation of "consumptive blue water use" appears a bit unusual, it is consistent with the PB literature insofar as it lumps together different processes with different signs.

Prof. Rockström concludes that *"the purpose of the PB framework is to quantify the role of water in sustaining the stability of the Earth system, irrespective of whether changes in the hydrological cycle are caused by natural variability or human interference"*. He (re)defines the planetary freshwater boundary to be about "water" and its "role" - in a more general sense. This is quite convenient since the supposed *"ample evidence of water induced tipping points"* quoted by the PB literature is utterly unrelated to human freshwater consumption. But while, according to Prof. Rockström, *"the freshwater PB has nothing to do with human water use"* (!), it is still referred to, in the PB literature, as the *planetary boundary on freshwater use*, with consumptive blue water use as the control variable. At this point, I am finally lost for words.

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What now?

I think the essence of Prof. Rockström's comment is that water is of paramount importance for the functioning of the Earth system, and that such importance must be reflected in a water-related planetary boundary. In my view, that is a fallacy. The water cycle is an inherent part of the climate system, and a key agent to mediate transport and conversion of matter and energy. The importance of water cannot be highlighted by putting it into an isolated PB. While PB proponents continue to argue that "the fresh-water PB should not be viewed in isolation" (see RC3), it merely demonstrates that the boundary is ill-defined: neither does it highlight the functional relevance of water in the Earth system, nor does it demonstrate, as an indicator, the urgency of sustainable water resources management.

So does the water cycle contribute to "regulate the stability and resilience [...] of the Earth system"? Of course! Does the planetary boundary on freshwater use reflect that role of the water cycle in the Earth system? I don't think so, and it is convenient for me to disagree. This is because the burden of proof is not mine: to prove that "consumptive blue water use" or "global reduction of runoff" beyond whatever limit is an adequate proxy to indicate the risk of system collapse. If you argue, however, that water-induced changes will act regionally (or "accross scales"), you should understand and quantify the specific causal chains or loops.

Prof. Rockström gave me the advice *"to think more holistically of the Earth System"*. If I were to return the favour, my constructive advice would be to take a glance at the "Zen of Python" (Peters, 2004), an aphoristic collection of Pythonic design principles that, in my view, are surprisingly relevant to the matter, and which I hereby selectively quote:

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[...]

Explicit is better than implicit.

Simple is better than complex.

Complex is better than complicated.

[...]

Readability counts.

Special cases aren't special enough to break the rules.

Although practicality beats purity.

Errors should never pass silently.

Unless explicitly silenced.

In the face of ambiguity, refuse the temptation to guess.

[...]

If the implementation is hard to explain, it's a bad idea.

If the implementation is easy to explain, it may be a good idea.

[...]

I would like to let these principles speak for themselves, and let the reader decide if he or she finds analogies to the issue under discussion. Just that much: "explicit is better than implicit" - example: if you think that human freshwater consumption affected terrestrial moisture recycling or atmospheric circulation patterns to a level that destabilizes the entire Earth system, then follow that thought and collect the evidence.

In fact, Prof. Rockström has provided a good starting point: after all, he presents four papers that demonstrate how irrigation might affect the climate system (Guimberteau et al., 2011; Im et al., 2014; Lee et al., 2009; Tuinenburg et al., 2014). Excellent!

These are the first references quoted in this discussion that establish a link between consumptive freshwater use (irrigation) and regional climate systems. Instead of accusing me to *"purposefully ignore evidence"*, it might have been a good idea to include these references in the Steffen et al. (2015) update of the PB framework. Why was none of these papers cited as evidence to support the existence or quantification of a freshwater PB? I will certainly not speculate about the reasons. These are all interesting papers, and they demonstrate that the functional relationships between irrigation and (monsoonal) rainfall patterns are highly complex. Guimberteau et al. (2011) compare *"a 30-year simulation which takes into account irrigation [...] with a simulation which does not."* They find that *"differences are usually not significant on average over all land surfaces but hydrological variables are significantly affected by irrigation over some of the main irrigated river basins."* Im et al. (2014), Lee et al. (2009) and Tuinenburg et al. (2014) find that the irrigation-induced cooling effect appears to be a dominant process as it tends to decrease atmospheric moisture convergence under specific constellations. All papers demonstrate that a decrease in precipitation in one region is typically tied to an increase in another region. What **none** of these papers demonstrates, yet, is a mechanism for the collapse of regional hydrological cycles, induced by consumptive water use. From that, we should neither draw the conclusion that such a collapse is impossible or inconceivable, nor should we start guessing numbers at which level of water withdrawal or consumption that collapse might still occur. What we *should* do is to follow up on that research, and I encourage the PB community to do so. I thus vigorously reject Prof. Rockström's allegation that fundamentally challenging the concept of a freshwater PB created the *"risk of dismissing important scientific questions"*. I merely suggest to replace speculation by a continued quest for scientific evidence.

While simulation experiments such as the ones discussed in the previous paragraph can be very useful to understand the mechanisms that govern system dynamics, I fail to see how the "thought experiments" provided by Prof. Rockström can be of help. Mental models (or thought experiments) are of limited value in understanding emergent

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properties of non-linear systems.

And finally, about the controversial issue of "water offsetting" - as this has, for obvious reasons, raised some emotions: Prof. Rockström argues that *"nowhere do we suggest that water related environmental impacts can be 'globally offset'"*. He is right. Neither Rockström et al. (2009) nor Steffen et al. (2015) suggested such an idea, and it is also fair to assume that it was not their intention to imply anything like it. Still, I insist that it is way too convenient to back out saying that such interpretation was unintended and that there is no way to prevent misuse of the concept. Why? Because a **planetary boundary on freshwater use** is a point-blank invitation to legitimate concepts such as "water-neutrality" or "water offsetting".

Concluding remarks

I have the feeling that the tone of the discussion has become increasingly bitter, and I honestly regret that. I guess the occasionally provocative style of the opinion paper has contributed its share, and an alleged "lack of evidence" might sound, in one scientist's ear, similarly harsh as "purposefully ignoring evidence" in another's. This is why I would like to use the opportunity, again, to particularly thank Prof. Gerten and Prof. Rockström for taking a stand to defend the freshwater PB. Those readers of HESS who had the perseverance to follow through the discussion might have learned a few things that they had not been aware of. That certainly holds true for myself, and I am grateful for that opportunity. While my position towards the freshwater PB is still crystal clear, I will certainly make use of these insights in a potential revision of the manuscript in order to make the message clearer and avoid misunderstandings.

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