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Discussions

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

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I appreciate the well articulated planetary boundary critique by Maik Heistermann. The scientific quest for improved definitions and quantifications of the planetary boundaries is a continuous challenge, and constructive critique is key to move the knowledge frontier forward.

Clearing two fundamental misunderstandings

This said, I find it important to clear out misunderstandings that lead to unsubstantiated critique, or worse, is at risk of dismissing important scientific questions.

Two fundamental misconceptions are clearly driving the arguments in Maik's paper. The first relates to what planetary boundaries (PB) are. The planetary boundaries de-

fine the environmental processes and systems that regulate the stability and resilience (the state) of the Earth system (with the inter-glacial Holocene state as the reference state). Earth system science over the past 30 years (driven not least by the Global Environmental Change programs, IGBP, WCRP, IHDP, Diversitas and ESSP including the Global Water System Program, GWSP) clearly shows that the Earth system is a complex self-regulating system where the hydrosphere interacts with the biosphere, atmosphere, cryosphere, geosphere and stratosphere. The global cycles of carbon, nitrogen, phosphorus, and water, interact across scales through the biosphere (oceans and land), atmosphere and stratosphere, to regulate the state of the Earth system. The fundamental role of planetary boundaries is thus to offer an integrated Earth system framework for defining the Earth system processes that regulate the state of the Earth system. Science shows clearly that water forms part of the fundamental fabric of the Earth system, functioning (as Prof. M. Falkenmark has pointed out) as "the bloodstream of the biosphere", through moisture feedbacks (and climate regulation), wettening of landscapes (retaining moisture levels and blue water stocks and flows regulating nutrient and carbon flows and stocks), biomass growth, biodiversity composition, and energy dynamics in the land-ocean interface (Steffen et al., 2004; Bhaduri et al., 2014).

Does this mean that every PB process/system that regulates the state of the Earth system needs to have planetary scale tipping points? Of course not. But Maik wrongly interprets the planetary boundaries framework as if this is the case, despite the fact that this is spelled out time and time again in both 2009 (Rockström et al) and 2015 (Steffen et al) planetary boundaries' papers. As shown in Fig 1. (Steffen et al., 2015), two types of processes/systems qualify as planetary boundaries; (1) those where we have scientific evidence of planetary scale thresholds (the boundaries for the climate system, ozone depletion) and (2) those where we do not (currently) have evidence of planetary scale tipping points but which are processes operating across scales to regulate the direction of Earth system feedbacks (negative or positive). These "slow variables" are identified as the boundaries for water, land, biodiversity and biogeochemical flows (N and P boundary). The point is thus that these boundaries (the slow variables), despite not having clear evidence of planetary scale tipping points (some scholars do question this, e.g., Barnosky et al. 2011, indicating that there very likely is a planetary tipping point for biodiversity), contribute to regulate the state of the Earth system.

The water boundary is a clear case in point. While we do not have evidence of planetary scale water tipping points, there is clear evidence that water contributes to regulate the state of the biosphere and that the global hydrological cycle has entered the Anthropocene, i.e., that human shifts in water flows across scales can affect the functioning of Earth system processes, again, across scales (Vörösmarty et al., 2013). The water boundary is defined in this way. In the 2015 update we proposed a dual definition of the water boundary to reflect the fact that water operates at ecosystem/watershed/basin scale. The key question is, what is the minimum level of wettening (green and blue stocks/flows) of landscapes/river basins required to maintain the functioning of biomes and land systems? Admittedly, as Maik points out, this is a challenging research question. It is a scientific question to provide evidence, for river basins across the Earth system, of the minimum amount of freshwater required - across time and space - to maintain critical Earth system functions intact (e.g., carbon sinks and moisture feedback).

We have chosen, as a proxy, two control variables as our proposed scientific indicators for the water boundary - at the global scale the maximum cumulative volume of consumptive blue water, and at the river basin scale, the minimum volumes of environmental water flow (EWF) that are required for ecosystem stability.

Maik's misconception leads to some quite harsh and unsubstantiated statements, arguing, e.g., that the planetary boundary concept ”suggests that we can globally offset water-related environmental impacts, a notion that defies both common sense and hydrological science.” However, we (Steffen et al., 2015) repeatedly describe freshwater as a regional process, making it clear that “sub-global dynamics are critical” for freshwater use, and that freshwater use is a PB with “strong regional operating scales”. We

furthermore state clearly that “we emphasize that our sub-global-level focus is based on the necessity to consider this level to understand the functioning of the Earth System as a whole. The PB framework is therefore meant to complement, not replace or supersede, efforts to address local and regional environmental issues.” Nowhere do we suggest that water related environmental impacts can be “globally offset”. The differentiated response of ecosystems and climate to hydrological changes as a function of space and time is fully acknowledged. In this case it appears Maik is trying to create an intellectual debate over opposing views that do not exist.

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 estimated 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 return 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.

Are there water thresholds?

A fundamental reason for Maik's critique appears to be his questioning whether there is evidence of water induced tipping points (shifts in feedbacks triggering non-linear dynamics and ultimately state shifts).

To start with, here Maik appears to apply very narrow criteria for scientific evidence of non-linear water dynamics to be accepted as relevant. He seems to imply that it is only non-linear dynamics caused by human water use that is relevant. This is of course incorrect. Just like in climate science, where paleo-climatic data on sea-level rise estimates from the Eemian (last time we had +2 C) is relevant for us to understand what "human climate interference" implies today, hydrological science evidence showing what happens with biomes when water flows shifts, is relevant, irrespective if it is us humans or natural variability causing it!

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.

There is ample evidence of water induced tipping points in ecosystems, references made not least in Rockström et al. (2009) and Steffen et al. (2015). Maik makes a point of lifting Brooks et al. (2013) to the forth, which was an attempt of questioning the core notion of whether there are feedback shifts and biophysical thresholds in the Earth system. What Maik chooses to omit though is the comprehensive response by Hughes et al., (2013), convincingly dismissing Brooks et al's rather unsubstantiated critique, with ample references to the scientific literature.

It is superfluous to run through all the evidence of non-linear water induced dynamics in the Earth system (at different scales) in this commentary. It suffices to refer to papers on water induced transitions in forest to savanna states (Staver et al., 2011; Horita et al., 2011), water related teleconnections across biomes (Snyder et al., 2010), water induced desertification in biomes (Scheffer and Carpenter 2003), major basin transitions such as the Aral sea and lake Chad (Rockström et al., 2014), and critical state transitions in ecosystems related to water (Carpenter et al., 2015).

Human water use affecting feedbacks beyond river basin scale

Furthermore, there is significant research showing that decrease in runoff (caused by increase in consumptive water use), can reduce rainfall, i.e., that landscape "wettening" matters for moisture feedbacks and thus rainfall generation. For example, irrigation can destabilize the monsoon (Guimberteau et al., 2011; Im et al., 2013; Lee et al., 2009; Tuinenburg et al., 2014).

There is a red thread here, where Maik purposefully seems to ignore evidence that shows that interference with the water balance and hydrological cycle can generate [water related] climatic feedback and interactions with other processes. Climate model simulations do show that land surface response can amplify monsoonal shifts – e.g., leading to large scale tipping between an arid and green state of the Sahara (e.g., Tierney et al. 2017).

Finally, on why it is good to have a dual water boundary on both global interference with the hydrological cycle, and maintaining minimum levels of wettening in biomes (as moisture and runoff). In the Anthropocene, with influence across all river basins, we can think of a situation where humans perturb the climate system through water use even if river flows are largely retained. Make the thought experiment that blue water is harvested and released as evaporation at the land-ocean interface everywhere on the planet [this is consumptive water use]. This will in a first step not decrease net flows in blue water stocks, but will add an immense amount of water vapour and latent heat flux to the atmosphere with potential implications for the climate system.

Water - a planetary boundary

Another thought experiment, to elucidate the "proof" of water being a planetary boundary, is to shut down the global hydrological cycle. Clearly, we would then have a fundamental state-shift of the planet, with collapse of the climate system and biosphere. Gradually adding water back to the system, and at a certain point we are bound to see the Earth system kick-in its biogeochemical processes enabling living conditions (as we know them) back on Earth. This thought experiment clearly shows that somewhere - along the water flow line - there is a planetary boundary on water. It is complex, operating across scales, intimately connected with land, ocean and climate. It is a grand scientific quest to continue working towards understanding and defining the safe operating space for water in the Anthropocene. My advice to Maik is therefore, to think more holistically of the Earth System, and not solely focus on incremental decrease/increase of water flows.

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