

# Tipping Elements, Planetary Boundaries and Water

The human imprint on the hydrological cycle is now apparent on a global scale. About 40 percent of the total global runoff (“blue water”) is now intercepted by large dams and impounded before it flows to the oceans. In many parts of the world, extraction of water from river systems has become so complete that about 25 percent of the world’s rivers run dry before they reach the ocean. In other parts of the world, such as the central United States and the Chad Basin in Nigeria, extraction of groundwater is occurring at rates much higher than recharge flows, leading to the eventual depletion of the resource.

Humans have also modified water vapour flows (“green water”) from the land to the atmosphere through deforestation and irrigation. Although the net change in vapour flow at the global scale is very small, large regional and seasonal changes have occurred.

## **A global perspective on human water use**

Our growing understanding of the functioning of the Earth System is leading to new insights into the implications of human modification of the global environment. One of the most dramatic features in the Earth System functions is the threshold/abrupt change behaviour associated with “tipping elements” (Figure 1). Tipping elements are defined as sub-systems of the Earth System for which a small change in a forcing factor can trigger an unexpectedly rapid and large response in the system.

The hydrological cycle is involved in several of the tipping elements identified so far. In some cases, human perturbation of the hydrological cycle through modification of blue or green water flows could trigger an abrupt or irreversible change in a tipping element. In other cases, other human pressures on the environment could trigger changes in a tipping element that could have serious consequences for water resources for humans.

A well-known example of a tipping element is the Amazon rainforest, where ongoing conversion of rainforest to cropland or pasture could cause a threshold to be crossed, leading to a rapid, irreversible conversion of the rainforest to a semi-arid savanna. This is a case of human modification of water vapour – or green water – flows through a change in land cover. The reduction in green water flows, which are a critical component of the regional rainfall regime through recycling of water between forest and regional atmosphere, could reach a critical point beyond which the drying forests become more vulnerable to wildfires, triggering the rapid conversion to more arid ecosystems.

An example of a tipping element that could have serious consequences for water resources for a large number of humans is the potential shift in the Asian Monsoon to a drier state. In this case, an indirect human effect – the regional emissions of aerosols – is the trigger for a potentially abrupt shift in monsoon behaviour. A critical change in the regional albedo (ability to reflect incoming solar radiation) could trigger a shift in the monsoon to a drier state, a shift that could

occur in only a year or two. Given that over one billion people are reliant on the wet state of the Asian Monsoon for the water required to produce their food, a sudden switch of the system to a drier state would likely be catastrophic, leading to a significant reduction of available water and a consequent drop in food production. In effect, a shift in the state of the Asian Monsoon would reduce the human carrying capacity of the Indian subcontinent.

The implications of tipping elements for global governance are profound. Recently a new conceptual framework – “planetary boundaries” – has been proposed to guide humanity in dealing with the threats caused by its own modification of Earth System functioning. The goal is to avoid crossing critical thresholds that would trigger abrupt or irreversible environmental changes, which, in turn, would be deleterious for human well-being. In essence, a collection of appropriately positioned planetary boundaries would define a “safe operating space” for the human enterprise to continue to evolve and develop.

Figure 2 presents the conceptual framework for planetary boundaries. For each boundary – whether it relates to a sub-system that can undergo threshold-abrupt change behaviour or whether it is a slow variable that undermines resilience – we identify a control variable. The next step is to identify a boundary along that control variable that humanity should not transgress. Ultimately, the question is a normative one – how much risk is humanity willing to take in approaching, and perhaps inadvertently crossing, one of the thresholds?

*“One of the most dramatic features in the Earth System functions is the abrupt change behaviour associated with “tipping elements”, where a small change in a forcing factor can trigger an unexpectedly rapid and large response in the system.”*

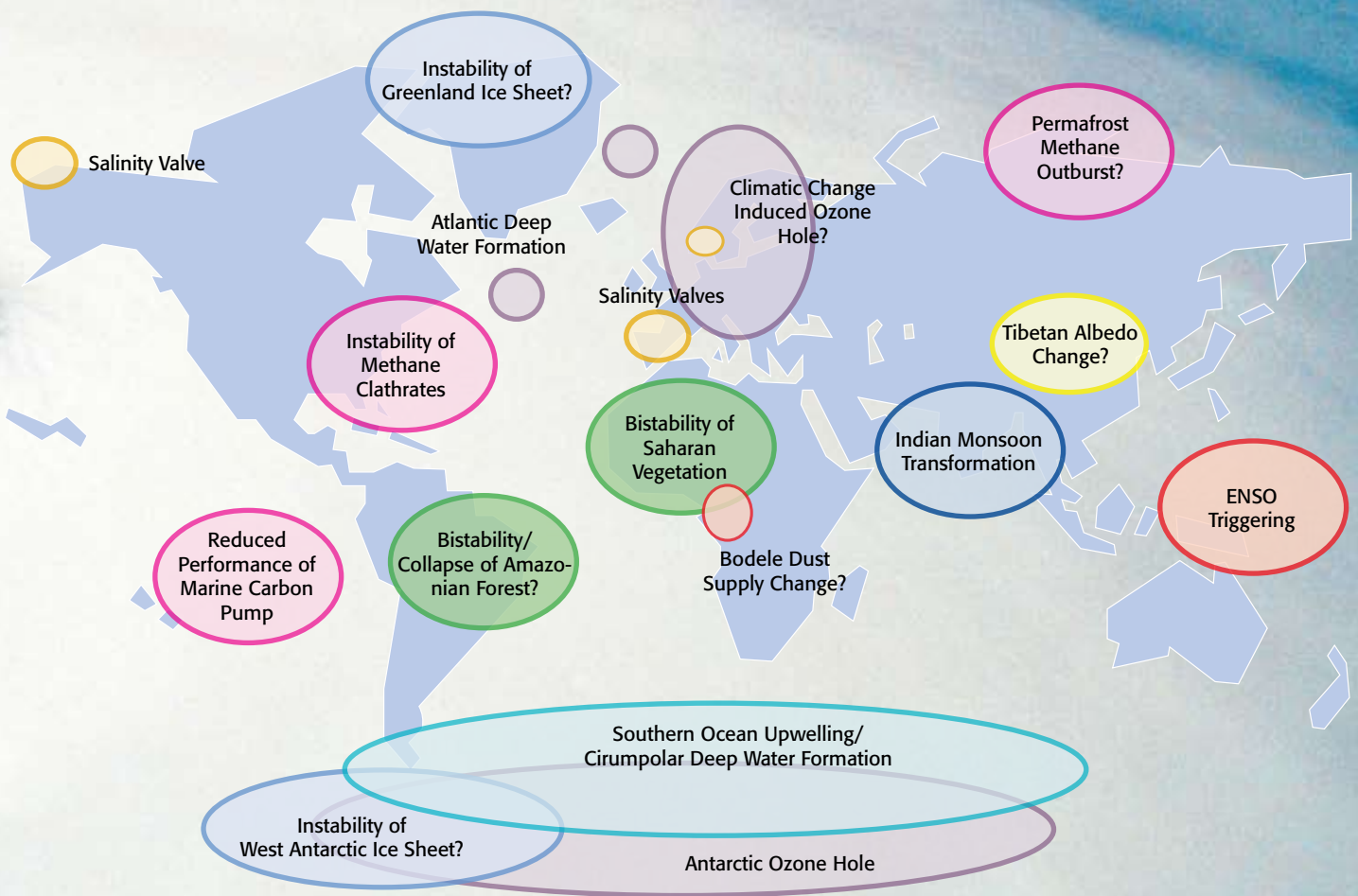


Figure 1. Tipping elements in the Earth System. Subsystems shown could exhibit threshold-type behaviour in response to human forcing, where a small perturbation at a critical point qualitatively alters the future fate of the system (after Lenton et al. 2008).

The initial analysis has identified nine planetary boundaries, one of which is water. The water boundary is perhaps the most complex of the nine, as it acts both as a slow variable that can undermine the resilience of, for example, the climate system, but can itself also show threshold/abrupt change behaviour at the regional scale. The Amazon Basin case cited above is an example of the latter.

Even selecting a control variable for the water system has been difficult. In the end,

we have chosen the amount of blue water co-opted for human use as the control variable, hoping to capture modification of green water flows as an “upstream consequence” of blue water use. Blue water use contributes vapour flow to the atmosphere, later to generate precipitation. But it also depletes river flow, alters the mixing between freshwater and oceans and threatens ecosystems. With this approach, a boundary of about 4,000 km<sup>3</sup> yr<sup>-1</sup> of consumptive blue water use has

been suggested. This compares to a current level of blue water use of 3,000 km<sup>3</sup> yr<sup>-1</sup>, an estimation of 5,000-6,000 km<sup>3</sup> yr<sup>-1</sup> for the onset of physical water scarcity and an upper limit of accessible blue water resources of 12,000-15,000 km<sup>3</sup> yr<sup>-1</sup>.

Transgressing the boundary for global freshwater use could lead to the crossing of water-related thresholds, such as the collapse of freshwater ecosystems or the collapse of regional lake systems (e.g., the Aral Sea). At the

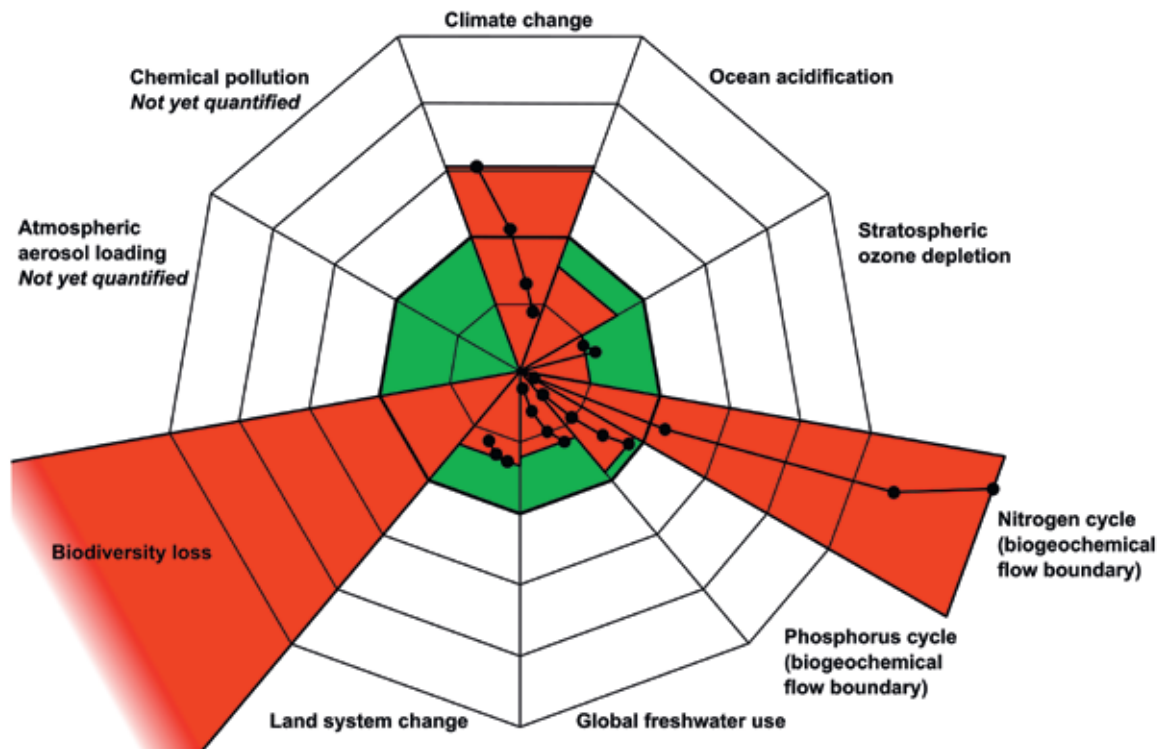


Figure 2. Conceptual definition of a planetary boundary. The boundary is designed to avoid the crossing of a critical threshold in an Earth System process. Insufficient knowledge and the dynamic nature of the threshold generate a zone of uncertainty about its precise position, which informs the determination of where to place the boundary. The inner green shaded area represents the safe operating space with proposed boundary levels and the points show the estimated course of the variable in 20 year intervals, between 1950-present. Reprinted with permission from the author(s). Source: Rockström, J. et al. 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society* 14(2): 32. [online] URL: <http://www.ecologyandsociety.org/vol14/iss2/art32/>.



Photo: Jakob Granit, SWI

planetary scale, it is more likely that global freshwater use acts as a slowly changing variable that undermines resilience through indirect changes to green water flows, impacts on the provision of terrestrial ecosystem services and through the alteration of the balances between vapour flows and runoff.

The planetary boundaries framework is not the last word in defining the relationship between humanity and our own life support system. Rather, it should be viewed as the opening of a deep, profound conversation on the future of homo sapiens on this finite planet. Perhaps nothing is more central to this conversation than water, simultaneously the lifeblood of the Earth System and the most fundamental resource for human well-being.

By Prof. Will Steffen, Executive Director, the Australian National University Climate Change Institute

### Further Reading

- Rockström J, Steffen W, Noone K, Persson Å, Chapin S, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber J, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Liverman D, Richardson K, Crutzen P and Foley J (2009) Planetary boundaries: Exploring the safe operating space for humanity. *Nature*.  
 Lenton TM, Held H, Kriegler E, Hall JW, Lucht W, Rahmstorf S, Schellnhuber HJ Tipping elements in the Earth's climate system. *Proc Natl Acad Sci (USA)* 2008; 105:1786-1793  
 Steffen W, Sanderson A, Tyson PD, Jäger J, Matson P, Moore III B, Oldfield F, Richardson K, Schellnhuber H-J, Turner II BL, Wasson RJ Global Change and the Earth System: A Planet Under Pressure. (2004) The IGBP Book Series, Springer-Verlag, Berlin, Heidelberg, New York, 336 pp.