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Evidence of water tipping points in the Anthropocene

Malin Falkenmark (1), Lan Wang-Erlandsson (2), and Johan Rockström (1)

(1) Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden, (2) Research Institute for Humanity and Nature, Kyoto, Japan (lan.wang@su.se)

Water is indispensable for Earth resilience and sustainable development. The capacity of socio-ecological systems to deal with shocks, adapting to changing conditions and transforming in situations of crisis are fundamentally dependent on the function of water as state, carrier, supply, climate regulator, feedback mediator, and biomass producer. However, massive human interference such as water withdrawal, dam constructions, and land-use change have significantly disturbed these water functions and induced regime shifts in both ecological and social systems. In many cases, changes in core water functions have pushed systems beyond tipping points and led to fundamental shifts in system feedback. Example of such transgressions are collapse of aquatic systems beyond water quality and quantity thresholds, desertification due to crusting and infiltration loss, and tropical forest dieback from self-amplifying moisture and carbon feedback. While water tipping often occurs at the regional and local scale, modern time hyper-connectivity in terms of e.g., trade and migration can relieve local stress, displace impact, and consequently mask resilience loss at the global scale. Here, we review the evidence of tipping in freshwater systems as well as tipping in systems controlled and driven by water function changes, including the collection of evidence and hypotheses of societal tipping and collapse related to water functioning. Furthermore, we synthesise the current state of human interference of core blue and green water functions at the global scale. We find ample observed evidence of system tipping or non-linear change related to most water functions, although uncertainties still persist with regard to climate related green water functions. Biophysical mechanisms in water related tipping are often well-understood, and understanding of complex interactions with social-economic factors is emerging. Globally, human interference is considerable in all water function categories, calling for better understanding of the cumulative, integrative, and cascading effects on Earth system resilience as a whole.