Exploring the existence of hydrological tipping points at the catchment scale

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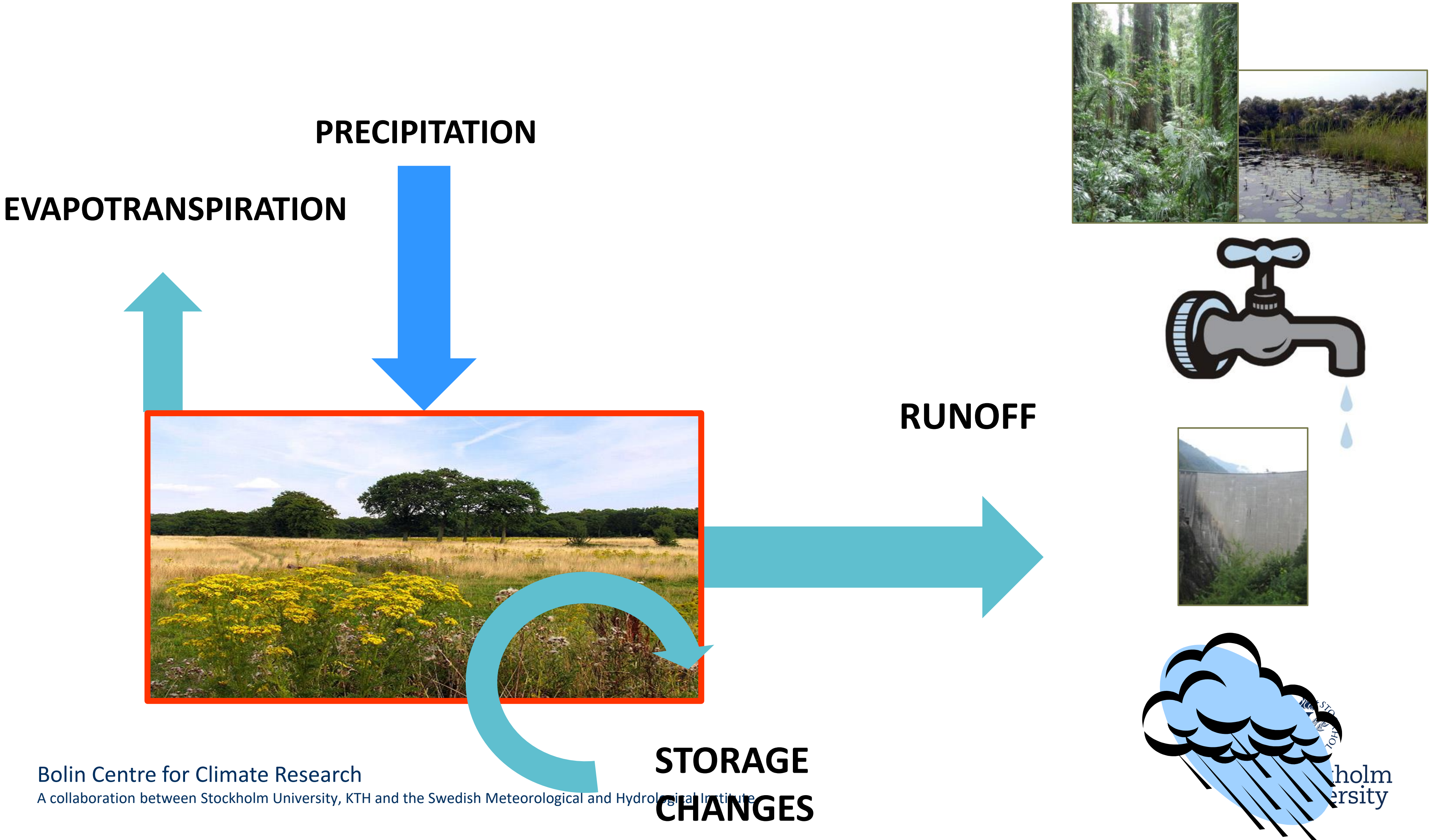
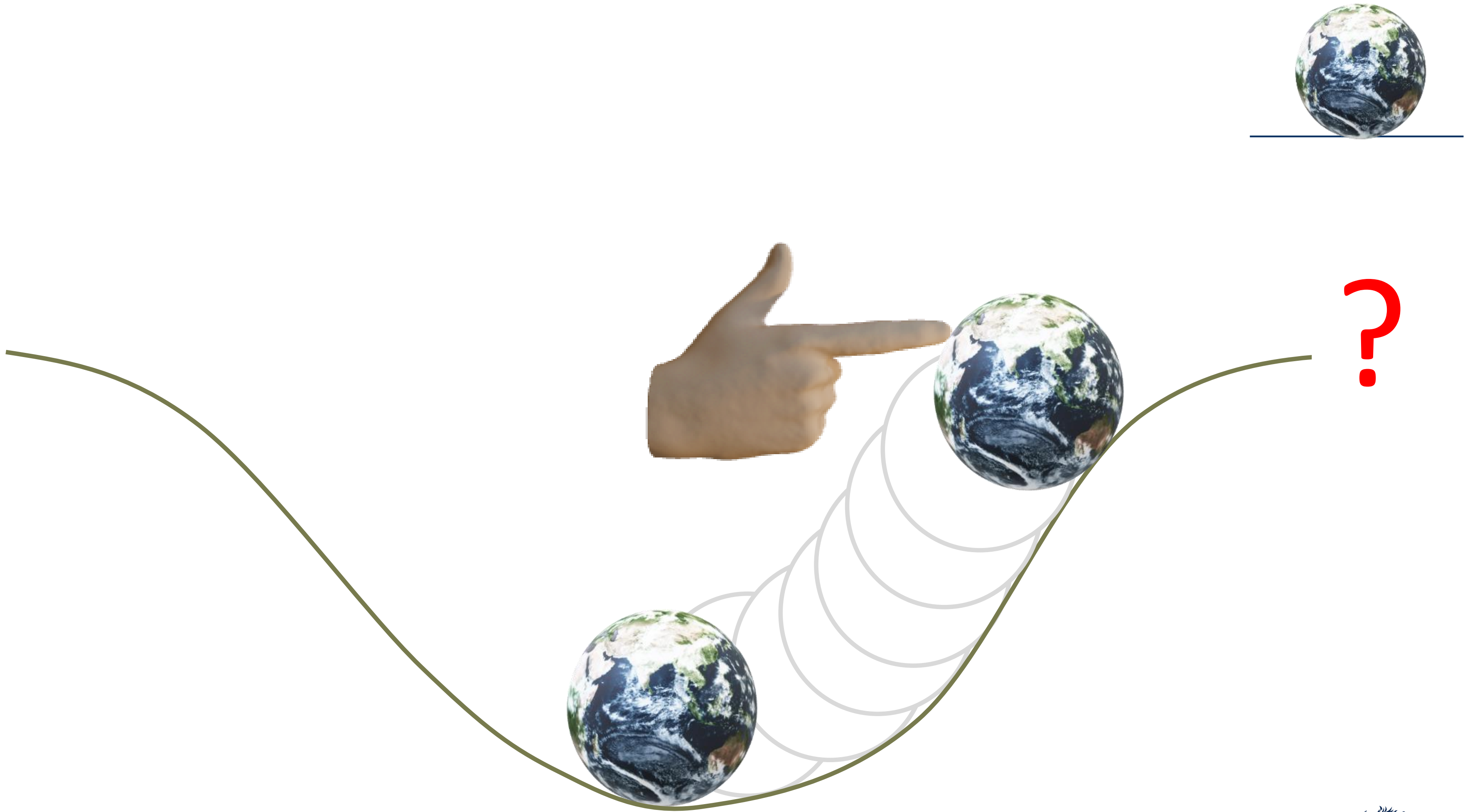
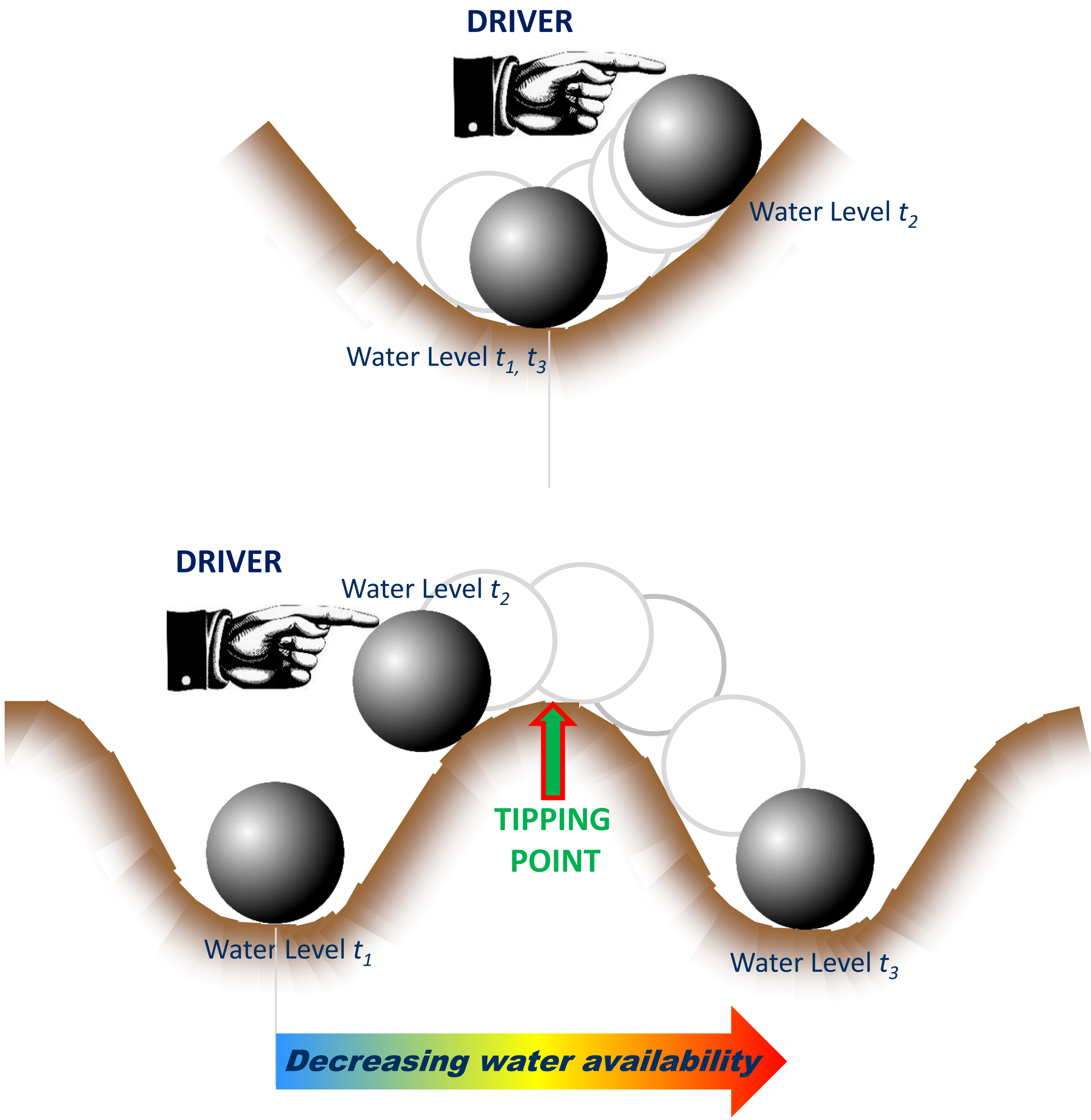
Freshwater changes

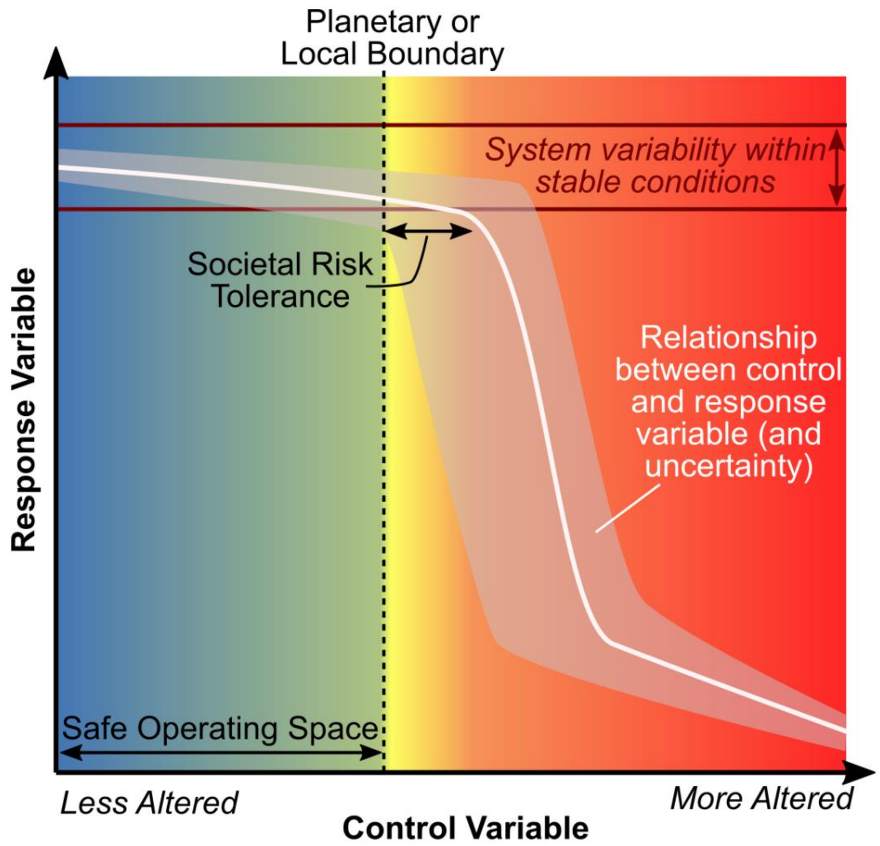



Invemar, 2014

Tipping points of water availability?




DRIVER
Water Level t_2
Water Level t_1, t_3
DRIVER
Water Level t_2
TIPPING
POINT
Water Level t_1
Water Level t_3
Decreasing water availability



Zipper et al., 2020

Objective

- Explore the existence of tipping points in the hydrological state of a hydrological catchment, specifically in the volume of water stored in the catchment-
- Tipping points where the response variable is a hydrological parameter representing water availability and the control variable can be any other socioecohydrological variable.

Methods

- Linear Stability Analysis (LSA; Joulin, 1979; Sole, 2011)
- Causal Loop Diagrams (CLD) and Stock and Flow Diagrams (SFD)
- Potential functions

What is a tipping point?

The set of equilibrium points (π_μ) occurring when no change in S takes place in time (t), i.e. dS/dt=0 as

Water mass balance → $f_\mu(S) = \mathrm{d}S/\mathrm{d}t = P - R - E$

$$\pi_\mu = \{S^* \mid f_\mu(S^*) = 0\}$$

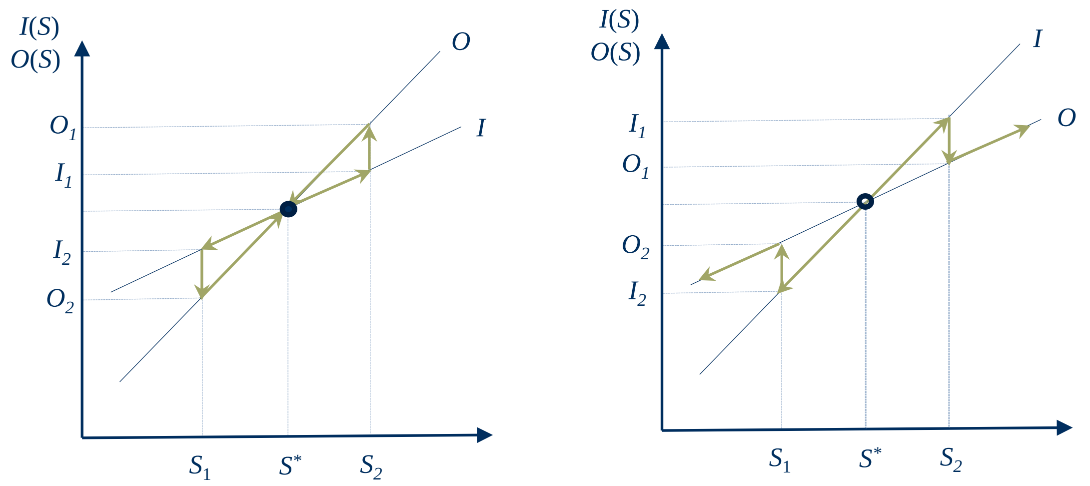
where S* is a value of S when dS/dt = 0 and $\mathrm{d}S^*/\mathrm{d}t = f_\mu(S^*)$

and

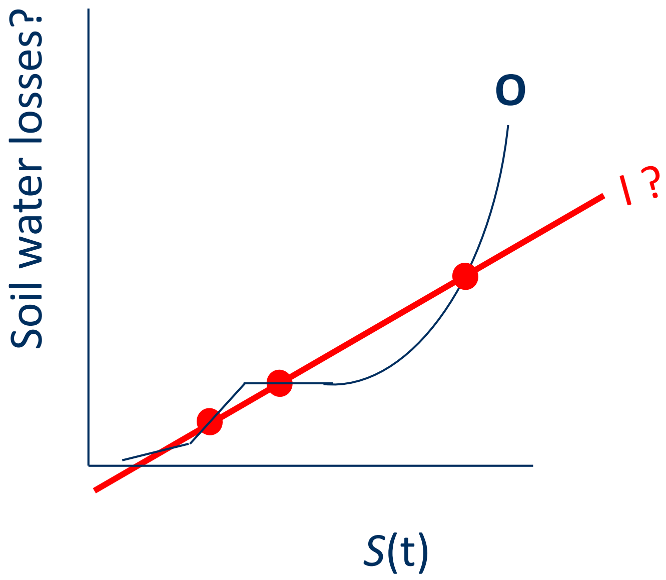
$$\lambda_\mu = \left[\frac{df_\mu}{dS}\right]_{S^*} > 0$$

Stable and Unstable Linear systems

Hydrologic dynamic system of water storage S where the input $I(S)$ and output $O(S)$ of the system are linear functions and the corresponding **a)** stable and **b)** unstable equilibrium points (S*).



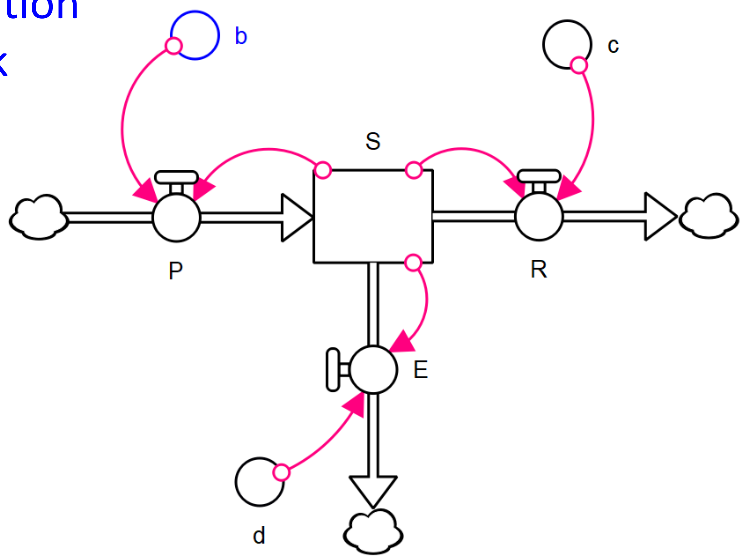
Tipping points?



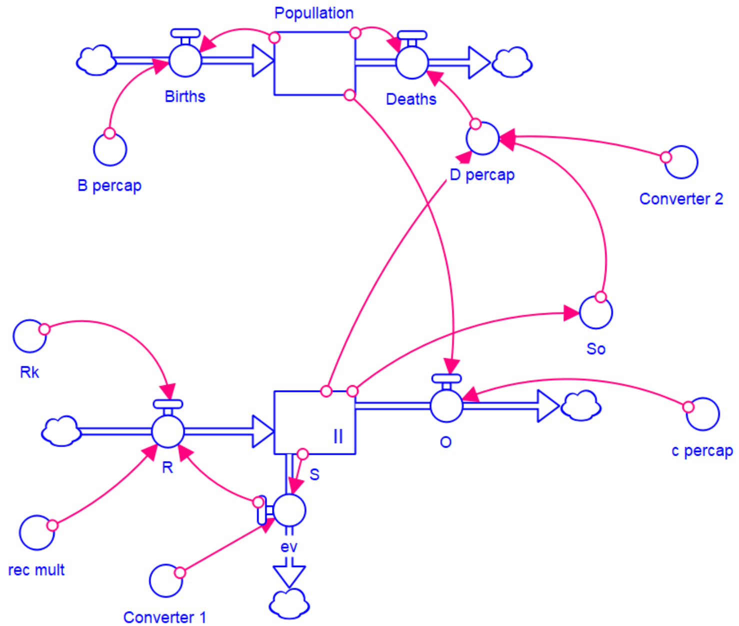
Adjusted from
Laio et al., AWR, 2001

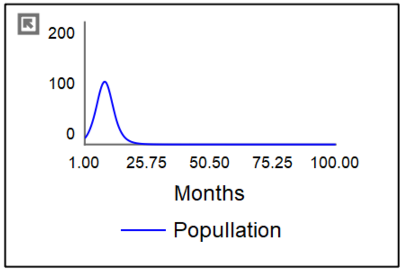
Causal Loop Diagram of the water budget

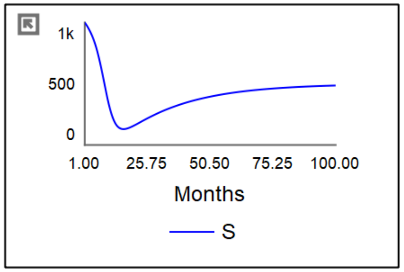
Important precipitation feedback



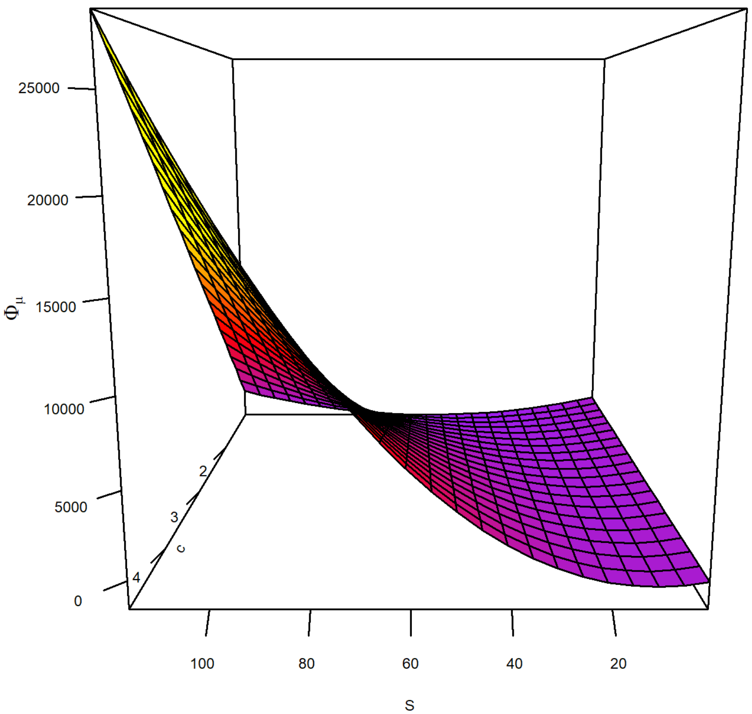
Tipping point in sociohydrological systems?

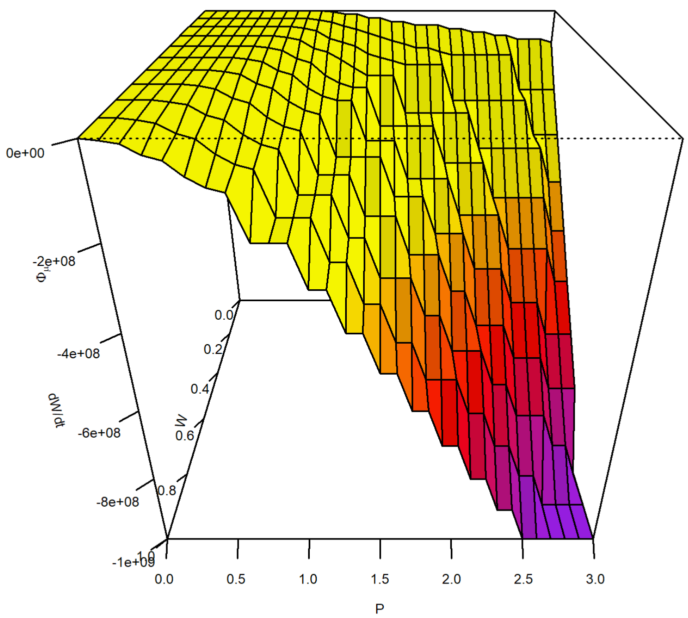






Potential functions





References

- Joulin, G., 1979. Linear Stability Analysis of Nonadiabatic Flames: Diffusional-Thermal Model. Combust. Flame 35, 139–153.
- Laio, F., Porporato, A., Ridolfi, L., Rodriguez-Iturbe, I., 2001. Plants in water-controlled ecosystems: active role in hydrologic processes and response to water stress: II. Probabilistic soil moisture dynamics. Adv. Water Resour. 24, 707–723. https://doi.org/10.1016/S0309-1708(01)00005-7
- Solé, R., 2011. Phase Transitions. Princeton University Press.
- Zipper, S.C., Jaramillo, F., Wang-Erlandsson, L., Cornell, S.E., Gleeson, T., Porkka, M., Häyhä, T., Crépin, A.-S., Fetzer, I., Gerten, D., Hoff, H., Matthews, N., Ricaurte-Villota, C., Kummu, M., Wada, Y., Gordon, L., 2020. Integrating the Water Planetary Boundary With Water Management From Local to Global Scales. Earths Future 8, e2019EF001377. https://doi.org/10.1029/2019EF001377

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