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Unsustainable Groundwater Exploitation and Stochastic Regime Shifts: Converging Management Constraints

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Increasing water security concerns arise from projected increases in competing freshwater demands, resulting from rapid urbanization, growing affluent population, and the need for increased production of food and bio-energy. These global trends in concert with the convergence of three groups of threats are likely to exacerbate freshwater security issues: (1) increasing dependency on effectively non-renewable groundwater ("peak water"); (2) increasing groundwater quality impairment("land-use intensification") from larger contaminant loads delivered from the vadose zone and surface water; and (3) increasing uncertainties in groundwater demand/supply from climate change ("stochastic risks"). Here, we present a conceptual framework for exploring water security threats, with a consideration of aquifers as complex hydrological systems with two stable states. Regime shifts in groundwater pumping – from "sufficient" to "insufficient" – result from changes in both internal system dynamics and external forcing from stochastic divers (non-stationary demands, hydro-climatic patterns). Examples from recent related work, in groundwater and surface water systems and ecosystems, are briefly reviewed as a prelude to presentation of model simulations of hypothetical scenarios of regime-shifts (tipping points) involving groundwater quantity and quality constraints. In addition to three types of widely recognized tipping points, we introduce a new type, stochastic tipping, that contributes to unexpected, undesirable regime shifts, resulting in inability to meet groundwater pumping needs, even when the perceived precariousness is small and the system is far from bifurcation point (deterministic tipping). Implications to sustainable groundwater management are discussed.