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Editorial

Fostering water resilience in the Anthropocene

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1. Introduction

Freshwater – the bloodstream of the biosphere (Falkenmark & Biswas, 1995) – is fundamental for Earth system stability and ecosystem health, and profoundly shapes all facets of human societies. However, the accelerating pace of human activities is now exerting a global force, resulting in widespread changes in freshwater flows, stocks, and composition. Extreme pluvials and droughts are becoming more frequent, severe, and long-lasting across many regions of the world (Rodell & Li, 2023), while the probability distribution of freshwater variability may no longer be assumed to remain constant over time (Nie et al., 2024). Water storage on Earth is shifting dramatically, with soil moisture depletion found to be severe and irrecoverable (Seo et al., 2025). Pollution of water, such as plastics, metals, persistent organic pollutants, pesticides, fertilisers, sewage, drugs, pathogens, salts, and industrial cooling (i.e., thermal pollution), poses serious threats to water security and aquatic ecosystems (Jones et al., 2024; Persson et al., 2022; Rose et al., 2024). Altogether, the sheer scale of water cycle impacts on the Earth system suggests that humanity now has transgressed the planetary boundary for freshwater change – a global safe zone defined to safeguard habitability (Porkka et al., 2024; Wang-Erlandsson et al., 2022). In the hyperconnected Anthropocene, these changes and risks in water quantity and quality can further interact with a simplified, homogenous food system and international trade network to amplify global-scale risks (Moore et al., 2024; Nyström et al., 2019; Tamea et al., 2016).

Hence, it is now imperative to foster 'water resilience' – i.e., the capacity of social-ecological freshwater systems to respond to perturbations through persistence, adaptation, and/or transformation. Fostering water resilience involves holistically addressing water's three roles as a *source* of system functions and an *agent* and *victim* of impacts on system resilience (Falkenmark et al., 2019), accounting for social responses, historical legacies, and technological developments. Social-ecological interconnectivity across scales and time means that these three roles of water exist simultaneously and interact dynamically. While many have studied water resilience, a full exploration of the social-ecological intertwinements from the ethical to the technological is needed.

This collection, entitled 'Fostering Water Resilience in the Anthropocene', comprises eight papers, published between 2023 and 2025, that together provide insights into all three aspects of the predicaments of Anthropocene water resilience loss and reflect thoughtfully on possible ways to foster water resilience. Some of the papers shed light on different ways in which the freshwater dynamics for supporting resilient systems are interacting, driving impacts, or becoming possible to modify in new ways, ranging from changes in the anthropogenic capacity to alter precipitation (Keys et al., 2024), flooding interactions with riverine plastic pollution (van Emmerik, 2024), and the contribution of drought and other environmental drivers to contemporary human migration (Wolde et al., 2023). Other papers illustrate how the resilience of water systems is intimately interconnected with the resilience of related systems, such as those between the riverine and connected marine systems (Hansen et al., 2023) and between interlinked groundwater and agricultural systems (Jorgensen et al., 2025). In addition, the Anthropocene destabilisation of the water cycle occurs on top of preexisting human-water relationships, including values and norms, rules and regulations, and other complex societal dynamics. Fostering water resilience can thus involve working with both attitudes (Baird et al., 2023) and perceptions (Krueger et al., 2025), as well as formal institutional change. How to foster water resilience, for whom and by whom, will inevitably have profound ethical implications (Schmidt, 2023). Water challenges cut across society, link individuals, local actors, private sectors, national governments, and global institutions, and extend far beyond the domain of resource managers and engineers. We hope our synthesis of this collection can spur new ideas, thinking, and collaborations to address the emerging Anthropocene water challenges.

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2. Features of water resilience loss in the Anthropocene

Anthropocene water-related destabilisation of the water cycle can be challenging to address within current conventional water-management paradigms, among others, due to the characteristics of the water resilience losses that include: Delay, Redistribution, Intertwinements, Permanence, and Scale (DRIPS) (Falkenmark & Wang-Erlandsson, 2021). 'Delay' between resilience loss and resilience impact may occur because system response is slow and/or impacts manifest only when exposed to infrequent disturbances. 'Redistribution' in water cycle dynamics in space and time can lead to surprising effects. For example, infiltration loss may lead to cascading remote impacts on downwind precipitation and downstream water quality. 'Intertwinement' refers to the inherent inseparability of water from every other system that has emerged in co-evolution with water. Water cycle changes, therefore, unavoidably interact with ecological, climatic, biogeochemical, societal, and technological processes, sometimes in unexpected ways. Intertwinements mean that water changes can result in substantial rewiring of system relationships through interactions and co-evolution with, for example, atmospheric teleconnections, weather modification developments (Keys et al., 2024), and migration dynamics (Wolde et al., 2023). 'Permanence' in impacts can occur when the impacts are impossible to undo within relevant time scales. For example, permanent loss of aquifer water storage capacity can be caused by irreversible sediment compaction induced by excessive groundwater withdrawal. Sometimes, apparent permanence can occur, not necessarily because of biophysical impossibility, but because of a lack of societal capacity to intervene. For example, eutrophied lakes may remain in their states due to an absence of pollution control and active measures such as biomanipulation to control algae growth. Lastly, the planetary 'scale' dynamics of water challenges can create new types of risks (Keys et al., 2019). Widespread water cycle changes can now trigger non-linear change and regime shifts across the Earth system, sometimes emerging from teleconnection dynamics. The mismatch in scale and system boundaries between management units and Anthropocene water phenomena also causes new water problems to be overlooked. For example, the conventional focus of water governance on river basins is now presented with new challenges due to the emergence of a suite of 'invisible' water changes (Moore et al., 2024), ranging from human impacts on atmospheric water (te Wierik et al., 2020) to emergent pollution problems (Persson et al., 2022; van Emmerik, 2024).

In this collection, Keys et al. (2024) use science-fiction prototyping to paint imaginative future scenarios of human modifications of the atmospheric water cycle, based on how land-use change, water use, and emerging weather modification technologies could alter precipitation. In fact, Keys et al. (2024) suggest that the redistribution and intertwinements of manipulating land-atmosphere interactions could already signify a potential transition from considering atmospheric water merely as a 'public good' (neither actively consumed nor controlled) to a 'common-pool' good (consumable), with risks posed that certain actors begin to treat it as a 'club' good (controllable), or even a 'private' good (both consumable and controllable).

Another example of a new Anthropocene water-related interaction is the flood-plastic feedback discussed by van Emmerik (2024): heightened flooding risk in densely populated urban areas increases the risk of plastic mobilisation, while at the same time, plastic pollution increases flooding risk through blockages. The novel plastic-flood nexus concept introduced by van Emmerik (2024) implies that water quantity and quality changes interact synergistically to amplify human impacts, which also suggests that improvements in flood resilience, in addition to benefiting local communities, also act to prevent flood-driven plastic mobilisation to oceans. Thus, addressing flooding risks and plastic pollution in small-sized waterways presents itself as a 'low-hanging fruit' where local and global interests coincide, and where proactive measures are far less costly than reactive ones.

Wolde et al. (2023) explore the complexity and changing nature of the relationship between human migration and water resilience. Changing hydrological and hydroclimatic dynamics introduce shocks as well as slower-moving changes that adversely impact the capacity of a community and the ecosystem in which they may be embedded to withstand shocks. Based on meta-analyses of case studies in Sub-Saharan Africa, Wolde et al. (2023) found intra-African migration to be influenced by a complex web of direct and indirect environmental (such as storms and droughts) and non-environmental (such as unemployment and poor infrastructure) factors, where migration is often triggered by individual extreme or slow-onset events such as drought or heavy rainfall. As importantly, though, their review shows the need for more robust analyses to better understand what this means for resilience. Exposure to extreme events may often erode social-ecological resilience and, in turn, lead to forced migrations or displacements. But having the capability to migrate and the agency to mobilise during extreme events, such as the cases where communities practice short-term circular migration, demonstrates social-ecological resilience as well. Disentangling why and which aspects of resilience are being practised in relation to migration patterns is needed to better inform future analyses.

3. Fostering water resilience in the Anthropocene

Addressing the Anthropocene destabilisation of the water cycle requires transformative change, which values, norms, institutions, and human-water relationships premeditate. Baird et al. (2023) investigated the general public's attitude toward water resilience in six countries and identified some parts of the population to have a higher potential for greater endorsements, including younger people, parents, and urban dwellers. The study suggests that engagement with the public or interventions aimed at strengthening water resilience can be adapted accordingly to be more effective.

Likewise, the study of Krueger et al. (2025) suggests that urban water resilience can be enhanced by integrating different stakeholder perspectives in the development of water management strategies. Krueger et al. (2025) conceptualised the urban water system of Amman in Jordan, which is simultaneously facing water scarcity and low adaptive capacity, as a complex social-ecological-technological system. Based on surveys and interviews, Krueger et al. (2025) found that different stakeholder groups tend to focus on different system components and interactions. Households, moreover, tended to undertake adaptive actions to compensate for system deficiencies, which went unrecognised by experts, leading to uncertainties when evaluating intervention outcomes. Thus, independent of the factual truth of the perceptions, they shape social responses and adaptive capacity, which need to be accounted for when designing effective management strategies.

Further, both Hansen et al. (2023) and Jorgensen et al. (2025) show that resilience stewardship needs to account for interlinkages across typical system boundaries. Hansen et al. (2023) highlight ten areas where measures to enhance riverine and ocean resilience carry mutual benefits, such as addressing the regulation of river flows, sustainably managing freshwater aquaculture, and reducing

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nutrient and plastic pollution in waterways. Jorgensen et al. (2025) similarly demonstrate how nature-based solutions – in particular, overlooked social infrastructures – can carry mutual benefits for addressing groundwater depletion and agricultural resilience.

A pluralised approach to water resilience is also the recommendation of Schmidt (2023), but in a way that challenges other framings of resilience even within this collection. The scientific advances in the understanding of the global-scale water resilience challenges in the Anthropocene call for transformation and Earth stewardship. However, Schmidt (2023) argues that the call for Earth stewardship, transformation, and water resilience itself is not a value-neutral process and can unwittingly oppress other ways of practice and knowing. Instead, Schmidt (2023) calls for the articulation of 'an ethic in which specialised knowledge of water risks arises from plural ecologies of practice and combines in a duty of care and reparation.' In a similar spirit, Jorgensen et al. (2025) find that Indigenous practices of groundwater harvesting that have been in place for centuries tend to imply higher recharge, more effectively counteracting groundwater over-extraction and enhancing agricultural resilience. Integrative and pluralistic recognition of different practices, perspectives, and knowledge systems across ethics, science, and management recur as a running theme for enhancing inclusive resilience (Jorgensen et al., 2025; Krueger et al., 2025; Baird et al., 2023; Schmidt, 2023).

4. Concluding remarks

The advent of the Anthropocene presents unprecedented pressure on the life support system of Planet Earth and threatens to destabilise social-ecological systems across scales. Given that social-ecological system disturbances are already widespread, governance will have to focus on resilience stewardship and resilience building. The contributions to this themed collection addressed risks of water resilience loss and opportunities for fostering water resilience in the Anthropocene across scales, systems, and disciplines. Three takeaways emerge from the articles in this collection: first, new or hidden interactions are emerging in the Anthropocene (such as new ways of atmospheric water manipulation, or flood-plastic pollution nexus); second, enhancing resilience can create synergies across multiple social-ecological systems (such as riverine and marine systems resilience); and third, pluralistic recognition of perspectives, practices, and knowledge systems is important for defining what it means to have water resilience and for fostering a just and resilient water future for all. Moving forward, continued inter- and transdisciplinary collaborations for fostering water resilience need to embrace this diversity without losing sight of the global Anthropocene dynamic interactions and teleconnections.

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