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Editorial: Environmental flows in an uncertain future

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Editorial on the Research Topic
Environmental flows in an uncertain future

Introduction

The implementation of comprehensive environmental flow programs for all freshwater ecosystems worldwide, has never been more urgent. Globally, human population growth and activities are placing increasing pressure on freshwater resources, leading to competition for ever scarcer water and overallocation (Tickner et al., 2020; Vanham et al., 2022). Coupled with climate change and increased incidences of drought and flooding, these shifting patterns of water use, and allocation have severely impacted flow magnitudes, durations, and timing in rivers around the world (Estrela et al., 2012; Dettinger et al., 2015; Murgatroyd et al., 2021) and caused widespread degradation of aquatic biodiversity and ecosystem condition (Vörösmarty et al., 2010). These effects are exacerbated by the associated changes in temperature, contaminants, nutrients, and sediments which are modulated by altered flows (Olden and Naiman 2010).

Increasing non-stationary conditions associated with climate change introduce additional uncertainties and complicate challenges in achieving water security under increasing demand, modified environmental conditions and socioeconomic constraints (Arthington et al., 2018a). The combination of uncertainty in downscaled climate predictions, effects of prolonged droughts, and unpredictability in patterns of future water demand for urban, agricultural, and industrial uses makes long-term implementation of environmental flows programs challenging. There also remain considerable challenges in predicting how the ecosystem will respond to streamflow conditions outside those in recent history (Tonkin et al., 2019). Moreover, changing social and political priorities make it difficult to predict which innovative and integrated solutions to water resource management programs aimed reducing water scarcity can be effective, while still protecting the environment (Wineland et al., 2022).

New approaches are needed to assess and manage risk to aquatic environments that balance current needs with predicted future climatic shifts (Poff, 2018; Horne et al., 2019; Tonkin et al., 2019). These approaches must build on our current understanding of managing water resources in water-scarce regions and include consideration of increasing extreme events such as droughts and floods. Risk management, tradeoff analysis, adaptive management, and participatory analysis will become increasingly necessary to translate science into practice (Poff et al., 2016). To address uncertainties associated with the changing biophysical and sociopolitical landscape there is a need to develop consistent approaches to managing environmental flows in a transparent manner with input from a broad range of stakeholders, agencies, affected entities, and community organizations. Environmental flow assessments and implementation must be robust under changing climate, demands, economies, and social values.

In this Research Topic, we provide an integrated, multi-disciplinary compilation of innovative science and policy approaches to developing and implementing environmental flows in water-scarce environments with multiple completing interests, particularly when they apply to large geographic areas. The focus is on approaches that account for heterogeneity across spatial scales and uncertainties associated with changing climate, and which consider additional management drivers, such as increases in water temperature, groundwater pumping and downstream effects on coastal resources. Collectively, these articles provide knowledge and approaches that can be applied and tested in other parts of the world.

Articles in this Research Topic are loosely organized around three major themes. The first of these is the development of new holistic approaches to establishing environmental flow recommendations. Second, are strategies and approaches for addressing system variability and uncertainty associated with climate change. Third are articles that include the consideration of new challenges, that provide opportunities for more integrated approaches for managing river flows to meet multiple management needs.

Advances in environmental flow assessment methodologies

The first ten papers in the Research Topic highlight advances in the development of methods to establish environmental flows that are rigorous, flexible and readily implementable across broad spatial scales. Stein et al. discusses the collaborative development of the California Environmental Flows Framework (CEFF) as an example of a process for developing environmental flow recommendations at a statewide scale. The CEFF uses a tiered functional flows approach, which focuses on protecting a broad suite of ecological, geomorphic, and biogeochemical functions instead of specific species or habitats. It can be applied consistently across diverse stream types and spatial scales. The functional flows approach complements previously developed flow assessments such as ELOHA (Poff et al., 2010) and DRIFT (King et al., 2003), by guiding the selection of metrics to ensure all functional flow components and their associated physical and biological processes are considered in the development and implementation of environmental flow recommendations (Yarnell et al., 2020).

A key element to implementing environmental flows across large heterogenous landscapes is the development of parsimonious tools that relate hydrologic (or hydraulic) changes to ecological response, and which are readily accessible to agencies and potentially affected communities. The first step of this analysis requires tools to evaluate hydrologic alteration more readily at ungauged locations. Grantham et al. developed a machine learning model to estimate functional flows for ungauged stream reaches across broad spatial scales. This approach provides a pathway for increasing the pace and scale of establishing initial environmental flow targets. Methods of coupling hydrologic change with ecological responses are demonstrated by Peek et al., who established relationships between specific elements of the annual hydrograph and biological stream condition, based on benthic invertebrates and algae. The results indicate that indices of biological stream condition were most closely associated with flow alteration characterized by metrics of seasonality and timing, such as fall pulse timing, dry-season timing, and wet season timing. Magnitude metrics, such as dry-season baseflow, wet season baseflow, and the size of the fall pulse were also important in influencing biological stream conditions. Consideration of functional flow elements of the annual hydrograph is fundamental to designing flow regimes that can benefit native biota under changing conditions, while still support seasonal human uses.

Implementation of the tools discussed in the first three papers is demonstrated in a pair of companion papers illustrating application of CEFF in a highly altered watershed in CA, United States. Taniguchi-Quan et al. used the California Environmental Flows Framework to develop ecological flow needs based on distinctive components of the natural flow regime in a highly altered watershed (Figure 1). Their approach allowed for consideration of the effects of altered channel morphology and specific life history needs for species of management concern (Figure 1). Effects of channel morphology were also illustrated by Yarnell and Thoms who demonstrated how floodplain reconnection helped achieve functional environmental flows.

Subsequently, Irving et al. applied the approach developed by Taniguchi-Quan et al. to identify high priority sub-basins for implementing flow management actions, in order to optimize

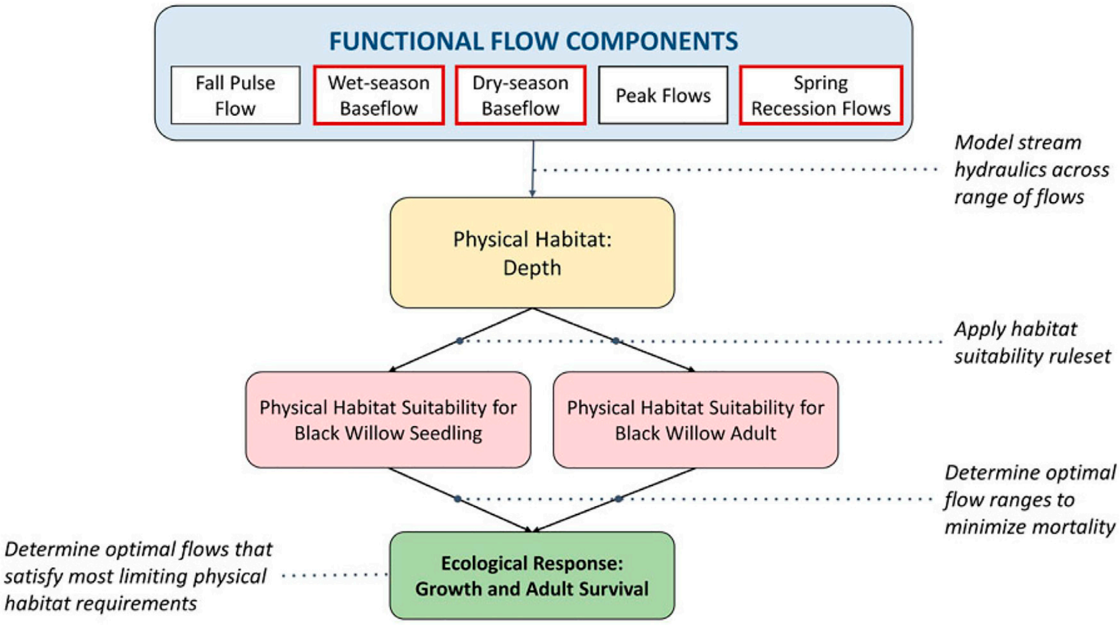

FIGURE 1
Conceptual model for refining ecological flow needs for wet-season and dry-season baseflow and spring recession flow components, based on black willow habitat in the United States (from Taniguchi-Quan et al.)

local ecological resources. The prioritization process accounts for the appropriate level of sensitivity, provides broad accounts of ecological benefits, and reduces classification errors.

Successful environmental flow approaches must allow for the incorporation of the needs of the environment for water alongside the other multiple demands on the resource and provide transparent mechanisms to consider complementary and competing demands, and the associated benefits and tradeoffs, for all affected parties. Willis et al. demonstrated a process to evaluate tradeoffs between different environmental flow strategies, based on either functional flows or percentage of natural flows. They found that in some cases, functional flows can provide increased ecological benefits in certain circumstances, while still allowing modest increases in hydropower production. Similarly, Serra-Llobet et al. showed that cost-effective multi benefit projects can be designed that both reduce flood risk and restore ecosystems, with the principal barriers often being institutional and regulatory, rather than technical. Maskey et al. provide an example of the importance of considering multiple management needs as part of the inherent tradeoffs of environmental flows. They demonstrate, in a study of reservoir operations in the San Joaquin Basin, CA, United States that the combination of hydropower reservoir operations and climate change can alter hydrology in potentially ecologically detrimental ways, and that reservoir operations have substantially greater affect than climate change effects. They conclude that in the future, modifying reservoir operations has the potential to mitigate some effects of climate change on flows.

The institutional barriers to investigating tradeoffs in water allocation can be partially overcome by an inclusive process that accounts for local knowledge and builds a broad constituency for supporting and implementing environmental flow programs. Mussehl et al. discuss how to fill a critical gap in developing environmental flow recommendations using a participatory governance framework to incorporate diverse stakeholder views and knowledge. They demonstrate how inadequacies in public participation engagement with local communities and Indigenous peoples, can be remedied using a holistic framework for incorporating a diversity of stakeholder views. The proposed framework unifies current participatory engagement approaches into the environmental flows assessment method for a complete engagement strategy.

Addressing uncertainty and change in environmental flow assessments

One of the most challenging aspects of implementing environmental flow programs is addressing uncertainty associated with the non-stationarity of dynamic systems and climate regimes. Judd et al. highlight the need to reassess the foundation of environmental flow assessments and how objectives can be established considering non-stationarity. Judd et al. present a process for developing "climate ready" environmental flow targets that use concepts of persistence, adaptation, and transformation to ensure targets do not become obsolete and are achievable under future hydrologic and ecologic conditions. The paper highlights that consideration of climate change in existing environmental flow assessments is rare. Campbell et al. illustrate how a variable and changing climate can be considered by proposing new indicators that capture the dynamic condition for non-woody vegetation, to better characterize the effects of environmental watering over changing climatic conditions.

Horne et al. examine the complete environmental flows assessment process and call for a rethink of current approaches so that they better meet the needs for managing environmental water under climate change and uncertainty. This process addresses five key considerations of environmental flow assessments under change and uncertainty: 1) acknowledgement of uncertainties, 2) stakeholder engagement, 3) multiple sources of knowledge, 4) modelling that supports tradeoffs and change, and 5) links to monitoring. The suggested approach requires a shift in all aspects of the environmental flows assessment process to actively consider management under conditions of non-stationarity.

Bond et al. examine modelling approaches that better capture ecological response to a changing flow regime. They show that lags in species recovery following major drought may be exacerbated by changing flow conditions, but that there is considerable variability and uncertainty. They conclude that state-and-transition simulation models may provide a parsimonious approach to evaluating changes in stream communities by overcoming many of the data challenges associated with more complex mechanistic models.

John et al. apply "stress testing methods" to evaluate the feasibility of establishing environmental flows under future non-stationary climate conditions. They address many of the previous technical challenges of applying stress testing methodologies at a larger spatial scale and across multiple interconnected objectives as required to assess environmental flow objectives. Stress testing results showed that increasing environmental entitlements yielded the largest benefits in drier climate futures, whereas relaxing river capacity constraints (allowing more targeted delivery of environmental water) offered more benefits for current and wetter climates. Ultimately, there was a degree of plausible climate change beyond which none of the adaptation options considered were effective at improving ecological outcomes and transformative options would need to be considered.

Emerging issues for environmental flow assessments

Environmental flow programs must continue to evolve and adapt to better accommodate emerging needs and management issues beyond the effects of surface flow regimes on stream and river ecology (Arthington et al., 2018b). This Research Topic includes four articles that provide examples of emerging issues that require some enhancement of environmental flow efforts. These include management needs related to groundwater effects, flow induced changes in temperature and its effect on instream biological communities, and the effects of flow management on downstream estuaries and other coastal resources.

Yarnell et al. applied the California Environmental Flows Framework (CEFF) to evaluate the relative contribution of groundwater inputs to streamflow and how surface-groundwater interactions should be accounted for in environmental flow assessments and management actions. The outcomes created opportunities for integrated surface-groundwater management strategies that support the recovery and protection of streamflow in groundwater-influenced streams. The Research Topic of confounded stressors was also evaluated by Abdi et al., who modeled the effect of water reuse on temperature to illustrate the combined effects on sensitive species and habitats. They demonstrated that managing flow along with substrate modification and shading could reduce water temperatures to within thermal tolerance ranges necessary to support steelhead migration in the highly urbanized Los Angeles River, United States.

The outcomes of environmental flow programs also extend beyond the riverine environment. Brookes et al. quantified how environmental flows improved outcomes for a coastal lagoon system by preventing the ingress of saline water. The fresher conditions created by environmental water provision supported a considerable expansion of suitable fish habitat area. This is a less commonly encountered example of assessing the effect of environmental flow management on estuarine systems. Similarly, Chilton et al. reviewed environmental flow requirements of estuaries to: 1) identify the key ecosystem processes (hydrodynamics, salinity regulation, sediment dynamics, nutrient cycling and trophic transfer, and connectivity) modulated by freshwater flow regimes, 2) identify key drivers (rainfall, runoff, temperature, sea level rise and direct anthropogenic impacts) that generate changes to the magnitude, quality and timing of flows, and 3) propose mitigation strategies (e.g., modification of dam operations and habitat restoration) to buffer against the risks of altered freshwater flows and build resilience to direct and indirect anthropogenic disturbances.

The nineteen articles included in this Research Topic provide examples of technical tools, participatory approaches, modeling and tradeoff analysis and implementation strategies that advance the concepts, knowledge, and practice of managing environmental flows under uncertain conditions. The findings and innovative approaches presented will be instructive for the advancement of environmental flows globally, helping contribute to the roadmap needed for the protection and restoration of aquatic ecosystems well into the future. The Research Topic of articles also highlights technical advances necessary to continue improving environmental flow management, including: 1) the need for models that can better simulate and be used to evaluate competing water needs under future hydroclimatic scenarios and in consideration of multiple ecosystem needs (Chen and Olden 2017); 2) the need to consider species dispersal across catchments in response to climate change and shifting water use practices; and 3) the need to evaluate the resilience of environmental flow approaches to multiple compounding stressors to improve our ability to adaptively manage systems in light of increasing demands and uncertainty (Tonkin, 2022).

Author contributions

ES: primary writing. AH, RT, and JT: writing contribution, review, and edits.

Conflict of interest

Author RT was employed by the company Riverfutures.

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