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SPECIAL ISSUE

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Evaluating and managing environmental water regimes in a water-scarce and uncertain future

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Abstract

1. While the number of environmental flows and water science programmes continues to grow across the globe, there remains a critical need to better balance water availability in support of human and ecological needs and to recognise the environment as a legitimate user of water. In water-stressed areas, this recognition has resulted in friction between water users in the public and private sectors. An opportunity exists for practitioners to be on the forefront of the science determining best practices for supporting environmental water regimes.
2. This Special Issue brings together a collection of environmental flows science and water management papers organised around three major themes: (1) method development and testing; (2) application case studies; and (3) efficacy evaluation. Contents of this Special Issue are intended to foster collaboration and broaden transferability of the information, technical tools, models and methods needed to support environmental water management programmes.
3. The technical sophistication of methods and modelling tools, while important to the advancement of environmental water science, may come at the expense of easily interpretable outcomes that positively influence management decisions. Researchers need to be more proactive in translating the results of advanced modelling methodologies into user-friendly tools and methods. This will allow stakeholders and water managers to proactively test alternative water allocation scenarios to help address growing human water demands in the face of droughts and changes in climatic patterns.
4. The application of environmental flows science and water management strategies cannot be done in isolation. Implementation involves a complex decision-making process that integrates ecological, hydrologic and social science across diverse multifaceted governance systems and requires active stakeholder involvement. Scientists and managers must strengthen partnerships at multiple scales to develop sensible science investment strategies so that collective knowledge can be translated into wise environmental water management decisions.

KEYWORDS
case studies, ecohydrological investigations, environmental flows science, environmental water management, modelling

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1 | INTRODUCTION

The tension between consumptive water use and ecological needs of rivers and estuaries has been a mainstay in the freshwater science literature for nearly 30 years. Over the years, there have been synthesis articles, journal special issues and books devoted to various aspects of the science, implementation and management of environmental flows to sustain species and ecosystems (Acreman et al., 2014; Annear et al., 2004; Arthington, 2012; Arthington, Naiman, McClain, & Nilsson, 2010; Hirji & Davis, 2012; Horne, Webb, Stewardson, Richter, & Acreman, 2017; Kendy, Apse, Blann, Smith, & Richardson, 2012; Novak et al., 2016; Poff & Zimmerman, 2010; Richter, 2014; Webb, Watts, Allan, & Conallin, 2018; Webb et al., 2013). Despite this attention, growing water demands, coupled with recent droughts and changes in climatic patterns, have produced increasingly widespread water scarcity in many regions throughout the world (Dettinger, Udall, & Georgakakos, 2015; Estrela, Pérez-Martin, & Vargas, 2012; Famiglietti et al., 2011; Meybeck, 2003; Trenberth, Overpeck, & Solomon, 2004; Veldkamp, Eisner, Wada, Aerts, & Ward, 2015; Vörösmarty et al., 2010; Williams et al., 2015). These shortages emphasise that there are critical limits on the amount of water available to support human and ecological needs. These shortages have motivated many federal and provincial governments (Figure 1a) to establish environmental flow rules and criteria (e.g. instream or minimum flow requirements) for the protection of biological resources and ecosystem integrity (Hart, 2016; Le Quesne, Kendy, & Weston, 2010; Novak et al., 2016). The cumulative number of programmes establishing environmental flows and water management criteria in the U.S.A. and across the globe has risen substantially just in the last decade (Figure 1b), emphasising the importance of retaining water in streams, rivers, estuaries and lentic systems for ecological use and ecosystem services. However, recognition of "the environment" as a legitimate user of water has led to legal confrontations among water users in the public and private sectors (Capon & Capon, 2017; Poff et al., 2003) and increased scrutiny of the methods used to determine, implement and evaluate environmental water regimes.

Various approaches for assessing environmental flows and water regimes have been developed over the past two and half decades, including those based on species life-history requirements (e.g. instream flow incremental methods; Bovee et al., 1998), flows that determine requisite habitats (e.g. physical habitat simulations; Milhous, Updike, & Schneider, 1989), holistic methods aimed at supporting biological communities and ecosystem functions (e.g. Ecological Limits of Hydrologic Alteration, ELOHA: Poff et al., 2010) and targets based on deviation from unaltered hydrographs (e.g. presumptive standards approach, Richter, Davis, Apse, & Konrad, 2011). Furthermore, the field of environmental flows is entering a transition

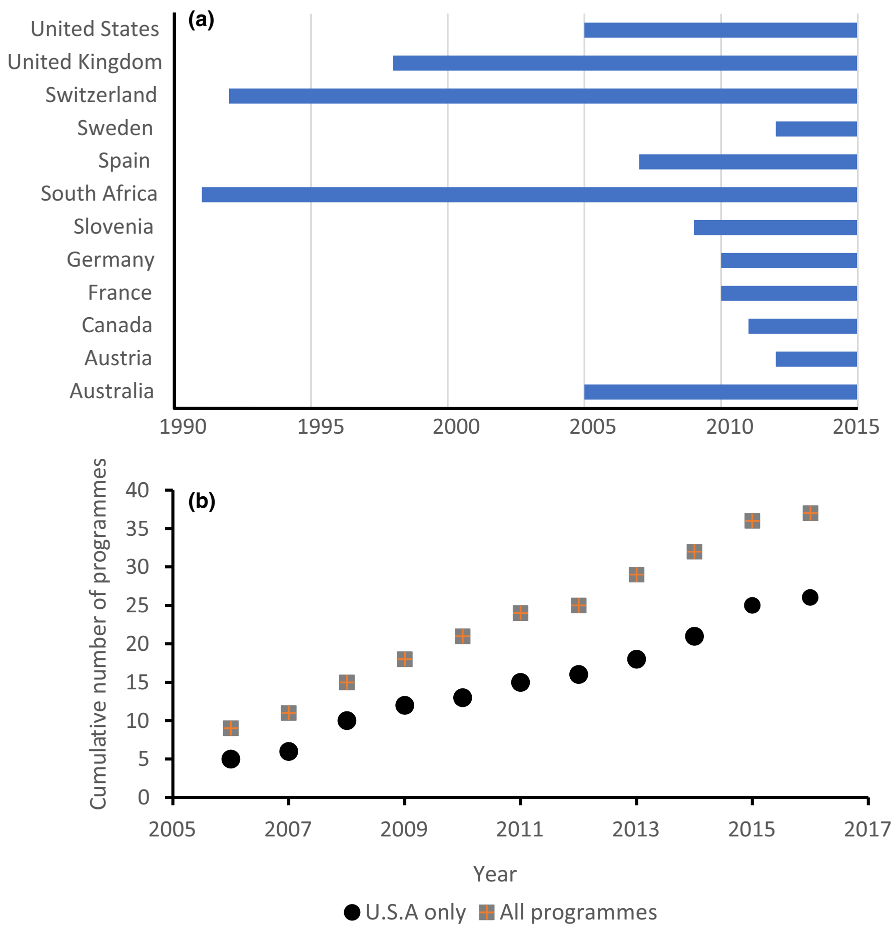

FIGURE 1 A representative subset of federal and provincial governments showing approximate inception and length of environmental water science programmes (a) and cumulative growth in number of environmental water science programmes in the U.S.A. compared to programmes worldwide (b). Information presented in this figure was obtained from numerous published sources including The Nature Conservancy, and a series of governmental reports from Australia, Canada, China, the European Union, South Africa, the United States, as well as several individual U.S. States

phase from a focus on lotic waters to one that includes the water requirements of all freshwater bodies. Accommodating this important shift may require more flexible or new terminology as discussed in recent synthesis works (Arthington, Kennen, Stein, & Webb, 2018; Horne et al., 2017). This means that environmental water assessment methods, as well as implementation approaches and strategies, can differ with waterbody type and across political jurisdictions, continents and even across individual basins that traverse multiple states, provinces or countries. These jurisdictional differences exacerbate the challenges of managing and regulating environmental water regimes.

Moreover, as technical sophistication in the methods used to assess and evaluate environmental water regimes increase, researchers need to be more proactive in translating the results of advanced modelling methodologies into user-friendly tools. These may include Web-based applications and decision support systems that provide easily navigable graphical user interfaces, with options for flow scenario testing and insight into the effects of climate change or changes in water availability (e.g. Cartwright, Caldwell, Nebiker, & Knight, 2017; Williamson et al., 2015). Such tools need to be adaptable to local conditions and needs, but also highly transferable across river basins or political jurisdictions, thus allowing the broader exchange of ecological and hydrologic/hydraulic information and models to support the balancing of water management decisions for human and ecosystem needs.

This Special Issue builds on previous work by providing broad example applications and case studies that illustrate implementation of ecohydrological approaches and provide empirical observations on the efficacy of these approaches. The previous Special Issue on "Environmental Flows: Science and Management" published in *Freshwater Biology* in 2010 strongly moved the field forward by introducing new methods and analytical techniques such as the ELOHA framework, ecological trait analysis, Bayesian hierarchical modelling and Integrated Basin Flow Assessment (Arthington et al., 2010). In this Special Issue, we continue that legacy by including studies from Australia, Europe and North America that cover the development of novel technical tools, models and methods necessary for implementation of environmental water regimes, as well as examples of how these tools can be integrated into water management programmes.

Papers in this Special Issue are organised around three major themes:

1. *Method development and testing*. Research on the development of methods used to support stronger flow–ecology relationships and establish environmental water recommendations intended to maintain ecologically sustainable flow patterns for diverse biological endpoints. Papers in this theme explore the transferability of flow–ecology relationships (Chen & Olden, 2018), advances in assemblage-level assessments (Cuffney & Kennen, 2018), hydrologic modelling (Sengupta et al., 2018), development of hydraulic habitat models (Mierau et al., 2018) and advanced analytical methods (Webb, de Little, Miller, & Stewardson, 2018), and development of biological response models that relate changes in hydrology and hydraulics to an ecological outcome or effect (Bond et al., 2018; Mazor et al., 2018).
2. *Application case studies*. Case studies that present application of flow–ecology response models designed to help environmental water science practitioners to better understand how alterations in streamflow and increasing levels of water scarcity affect the viability and integrity of aquatic ecosystems. Papers in this theme discuss case study examples including assessment of snowmelt conditions (Steel, Peek, Lusardi, & Yarnell, 2018), identification of high-risk watersheds (Zimmerman et al., 2018) and tools with improved capacity and diagnostic resolution (McKenna, Reeves, & Seelbach, 2018; Monk et al., 2018) that can be integrated into water resource management programmes at the local, state, provincial, regional and national levels.
3. *Efficacy evaluation*. Research and case studies that evaluate the effectiveness of environmental water programmes at achieving their desired hydrological and ecological objectives or evaluating complex scenarios with multiple interacting stressors. Papers in this theme illustrate successes, challenges and provide evaluations of how well current programmes have worked (Stewardson & Guarino, 2018); how well conceptual models have performed relative to expectations (Gendaszek, Burton, Magirl, & Konrad, 2018); the influence of drought on flow–ecology relationships (Lynch, Leasure, & Magoulick, 2018); and recommendations for ways to improve both the science and implementation of environmental water practice (Wheeler, Wenger, & Freeman, 2018). This theme also includes recommendations for refinements that can improve the ability of flow–ecology tools to distinguish anthropogenic effects from changes due to climate variability (Hain et al., 2018).

Also included are several conceptual papers that actively look to the future of environmental water science and management, and provide recommendations on how this discipline needs to evolve. Topics covered include the challenges associated with evaluating legacy effects and long-term trends (Thompson, King, Kingsford, Mac Nally, & Poff, 2018); the challenge of incorporating non-stationarity principles into ecohydrological investigations, and therefore calling for a fundamental shift in environmental water regime studies from managing for variability (of historical conditions) to managing for ecological resilience (Poff, 2018); and proposals for how scientific research might better interact with aquatic ecosystem management to more effectively translate knowledge into action and foster sensible scientific investment strategies so that collective knowledge can be translated into wise environmental water management decisions (Stoffels, Bond, & Nicol, 2018).

The Special Issue concludes with a synthesis of recent advances in environmental flows science and water management and a look ahead at some of the challenges still facing environmental water science practitioners (Arthington et al., 2018). Not all the challenges identified in the 2010 Special Issue of *Freshwater Biology* on environmental flows science and water management (Arthington et al., 2010) have been met. For example, "integrated water resource management" that incorporates ground- and surface-water regimes in support of river conservation and restoration or “adaptive environmental management” approaches that address uncertainties and risk and facilitate follow-up interaction among scientists and managers are only beginning to emerge. However, as greater diversity and transferability are achieved, environmental water science will continue to progress and support the needs of water managers and decision-makers around the globe.

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