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POLICY BRIEF
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Critical Factors for Water Policy to Enable Effective Environmental Flow Implementation

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During the last two decades many countries have recognized the integral part that environmental flows should play in water management and have incorporated environmental flow provisions as they have updated water policy. This brief sets out generic recommendations for governments and other stakeholders on factors that, if reflected in policy frameworks, are likely to enable scaling up of environmental flow implementation. Our recommendations have been informed by a review of political, economic, social and scientific enabling factors that led to environmental flow implementation in eight rivers across the world. Legislation and regulation are pre-requisites for effective environmental flow implementation. Depending on context, we describe a number of other factors that can provide a foundation for effective environmental flows policy.

Keywords: environmental flows, water policy, implementation, enabling factors, water management, dams, water allocation

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INTRODUCTION

UN Sustainable Development Goal target 6.4 recognizes the need to ensure "sustainable withdrawals and supply of freshwater" (https://sustainabledevelopment.un.org/sdg6). In hydrological terms, sustainable withdrawals should allow for the maintenance or restoration of environmental flows (e-flows) for the benefit of downstream water users, maintenance of valuable ecosystem services (e.g., fisheries), and safeguarding of biodiversity and cultural values. Indeed, it has been argued that the environmental litmus test of water security is continued flow through rivers and other freshwater ecosystems of sufficient quantities of water, at critical times of year (Tickner and Acreman, 2013). Many countries have incorporated e-flow provisions as they have updated water policy. Implementation of policies has been challenging primarily because of lack of political will, imperfect understanding of costs and benefits, and limitations in institutional capacity and resources (Le Quesne et al., 2010). Nevertheless, success stories have emerged.

This brief sets out generic recommendations for governments and other stakeholders on factors that, if reflected in policy frameworks, are likely to enable scaling up e-flow implementation to larger spatial scales (basin, jurisdiction), to a greater number of jurisdictions, and to more rivers overall. These recommendations were derived from a review of e-flow implementation in eight rivers across the Americas, Africa, Asia, Europe, and Australia (Harwood et al., 2017, see **Table 1**). The intention is not to produce a prescriptive approach to policy development for e-flow implementation; measures should always be informed by context. Rather, the aim is to stimulate thinking about specific measures that could be encapsulated in, or promoted by, water policies, based on documented experiences.

POLICY OPTIONS AND IMPLICATIONS

Our case study review identified a range of enabling factors; for the purposes of this policy brief we have grouped these into four categories. These factors and examples of their importance in the case studies we reviewed are presented in **Table 2.**

Legislation and Regulation

We found that the fundamental enabling factor that underpins most, if not all, cases of successful e-flow implementation is the existence of conducive legislation and regulation. The type of legislation and regulation behind the implementation of e-flows varies greatly; however, long-term protection or restoration of flows for the environment is dependent on there being a legislated framework within which to act. In broad terms, laws reflect the values of society, thus jurisdictions that have e-flows written into their laws and regulations have demonstrated at least some consideration of the ecosystem services and values that rivers provide. We identify three principal types of legislation that have facilitated e-flow implementation:

1. **Water Management Legislation**
   If the governing entity responsible for water management (national or state/provincial level) has set a standard or regulation that mandates e-flows, it creates momentum for both protection and restoration of e-flows. For example, in Mexico the National Water Law of 1992 recognized the environment as a legitimate user of water.
2. **Endangered Species or Other Environmental Legislation**
   In the US, the Endangered Species Act has been the single most powerful lever for protecting and restoring e-flows. In Australia, commitments to both the Convention on Biological Diversity and the Ramsar Convention were used as the basis for the Commonwealth (federal) government to assume leadership for water decision-making in the Murray-Darling Basin.

TABLE 1 | Details of the case study watersheds.

Country	River	Short description
USA	Savannah	Flows for 500 km from Blue Ridge Mountains into Atlantic Ocean. Droughts in the 1990s, water quality challenges, endangered fish conservation and recreational values presented opportunities to implement e-flows through adaptive reservoir operations
Australia	Murray-Darling	Australia's longest and most important river, flowing through four states and home to 2 million people (including Aboriginal groups), with more than 30,000 wetlands including protected areas. The challenge is to share water so that urban and agricultural supplies are balanced with indigenous and environmental needs. Over-allocation and prolonged drought magnified this challenge and presented the political opportunity to implement e-flows.
China	Yangtze	The third longest river in Asia, home to 177 endemic fish species and provider of 36% of freshwater fish consumed in China. The Three Gorges Dam is by some measures the largest in the world. It has significantly altered the flow regime of the river. Concern about declining freshwater fish catch stimulated collaboration between the dam operator and other stakeholders to trial e-flow releases during critical times for fish reproduction.
UK	Kennet	A small chalk river in southern England and a significant tributary of the River Thames. Over abstraction of groundwater, primarily for urban supply, led to reduced flows over a number of years. Advocacy by environmental NGOs prompted the water utility and environmental regulator to investigate, and eventually implement, e-flows facilitated by the availability of alternative supplies from less stressed catchments.
South Africa	Crocodile	A tributary of the transboundary Inkomati River (shared with Swaziland and Mozambique), the Crocodile River forms the southern boundary of Kruger National Park. The requirements of water-sharing commitments with Mozambique and concerns about water stress led to reconsideration of allocations to irrigated agriculture and urban areas and eventually to implementation of an e-flows regime.
Mexico	San Pedro Mezquital	A largely free-flowing river running for 540 km from the western Sierra Madre Mountains through the Marismas Nacionales Biosphere Reserve and into the Pacific Ocean. Although not currently water-stressed, concerns about future pressures on water resources and impacts on ecological integrity led to implementation of an Environmental Water Reserve which safeguards an annual flow volume for the river.
Pakistan	Poonch	Originates in the western foothills of the Pir Panajal mountain range before running through the Poonch Mahaseer National Park and joining the Jhelum River. An environmental and social impact assessment of the planned Gulpur Hydropower Project highlighted the lack of sufficient consideration of potential impacts on downstream flows. Subsequent e-flow assessment illustrated the potential for redesign of the project to facilitate e-flows and provide environmental and socio-economic benefits.
India	Ganga	Flowing for 2,500 km from the Himalayas to the Bay of Bengal, the Ganga is sacred to hundreds of millions of people but also under pressure from pollution, flow diversions and other threats. The 2013 Kumbh, a hugely significant religious festival during which tens of millions of people bathed in the river, provided a unique opportunity to demonstrate how e-flows could be implemented in the Upper Ganga.

TABLE 2 | Enabling factors that support successful e-flow implementation.

Enabling factor categories	Description of enabling factors	Example
Legislation and regulation	A fundamental factor in most e-flow implementation success stories; Jurisdictions that have e-flows written into their laws and regulations have acknowledged the ecosystem services and values that rivers provide.	Legislation played a particularly important role in the Murray-Darling Basin where the Water Act 2007 led to water reform through the establishment of the Commonwealth Environmental Water Office and the development of the Murray-Darling Basin Plan that limits how much water can be extracted from any sub-basin (i.e., a cap on abstraction).
	Allocation mechanisms can be used as legal or policy tools to impose conditions on water users or establish water reserves for the environment.	Following the implementation of a cap on abstraction in the Murray-Darling Basin, the development of a system that allows the trading of water rights has been immensely important in restoring e-flows.
Collaboration and leadership	A wide range of stakeholder input is critical for e-flow implementation from the outset. It is critical that competitors for water, and agencies that will implement e-flow prescriptions, are part of the decision-making process in setting objectives and determining appropriate flows. Those responsible for implementing e-flows, such as water management agencies, hydropower operators or irrigators, have to buy in to the process otherwise they will continually fight and try to undermine it.	At the start of the process of implementing e-flows in the Savannah River (USA), different interests around the reservoirs (e.g., flood management, hydropower generation, in-reservoir recreation) were concerned that there would be an adverse impact from e-flow implementation on their particular interest, and many individuals and groups resisted these changes. This barrier was overcome by holding workshops and public hearings. Collaborative workshops also enabled the reservoir operators and engineers to participate in the development of e-flows and share their knowledge on how the river responds to reservoir operations.
	A champion is needed to drive the process forward; there are many challenges to e-flow implementation and to overcome these there needs to be a person, several people, or an organization pushing the process along and finding solutions.	One of the most prominent examples of champions in our case studies was Brian Jackson at the IUCMA in the Crocodile River case study who improved e-flow implementation by starting a dialogue with irrigation stakeholders and Kruger National Park to develop appropriate objectives and an e-flow regime the stakeholders accepted.
Resources and capacity	E-flow implementation requires a natural and social scientific understanding of the needs of the species or resource one is trying to protect or restore, and how these needs relate to flow magnitude, timing, duration, frequency and rate of change.	The work done by fish biologists and hydrologists in identifying the spawning locations of Chinese carp in the reaches downstream of the Three Gorges Dam, along with the important hydrologic indicators and their ranges for natural spawning that can be mimicked when designing e-flows, was vital. From a social perspective, the surveys carried out prior to Kumbh 2013 were important in determining appropriate flows for the spiritual rituals.
	Having the institutional capacity to understand the need for e-flows and how these are determined and monitored is an important factor in implementation.	The need for greater capacity was probably most pronounced in the Poonch River case study: here, the need for additional e-flow assessment was determined by an international funding agency (the Asian Development Bank), and the assessment was led by an international consulting firm from South Africa who worked closely with local stakeholders.
	Consistent funding for the technical studies and stakeholder engagement processes required to determine appropriate e-flows is a common barrier to e-flow implementation. Typically these measures cost a small fraction of the wider costs of major water infrastructure schemes, but can save substantial effort later on.	Acting collaboratively, WWF and the Mexican water allocation authority, CONAGUA, were responsible for securing funding for the Environmental Water Reserves program from the Interamerican Development Bank (IDB), WWF, and Alliances of WWF-Gonzalo Río Arronte Foundation and WWF-Carlos Slim Foundation. The involvement of CONAGUA was considered critical in securing the necessary funds.
	Similarly, securing the necessary funding for e-flow implementation, monitoring and management is critical.	WWF and a local NGO successfully campaigned for many years for a legislative change that enabled Thames Water to fund an e-flow implementation scheme on the River Kennet.
	The development of technical standards and guidelines for a region on how to determine, monitor and adapt e-flows for ecological and socio-economic components, and on what methods work best in different situations, are an important tool to streamline assessments and overcome barriers of capacity.	The publication of a national standard on e-flow assessment was a key enabling factor in the San Pedro Mezquital case study as it provided certainty over the approved approach. The importance of environmental standards set by international funding agencies was demonstrated in the Poonch River case study as adherence to these standards led to a more sustainable project design, which enabled the project to proceed.
	Tools are required to help managers make decisions on e-flows based on water availability and balancing the requirements of multiple water-users.	The IUCMA in South Africa uses decision-support and forecasting tools to manage e-flows in real time based on the available water in the Crocodile River. Similarly, the US Army Corps of Engineers uses real-time data collection and reservoir models to aid its releases of e-flow pulses from its dams on the Savannah and other rivers.
Monitoring and adaptive management	Flow data are critical in determining natural flow levels and water availability. Physical, geomorphological, ecological, social and economic data are important in determining how the ecosystem and those who depend on it are responding to e-flow implementation, and to inform adaptive management.	The best example of adaptively managing e-flows based on data collected from a network of monitoring stations in our case studies is the Savannah River, where lessons over an 8 to 10-year period of test releases were used to refine e-flows. From a social perspective, monitoring of e-flow releases on the Ganga River during Kumbh 2013 demonstrated the initial success of that program.

3. **Regulations on Dam Operations**
   In the US, licensing (and re-licensing) requirements set by the Federal Energy Regulatory Commission (FERC) have opened the door for e-flow advocates to set dam operating conditions that facilitate e-flows. Regulations in China governing the operations of the Three Gorges Dam have been adjusted to provide e-flows for ecological, social, and economic benefits.

Although fundamental, legislation alone is rarely sufficient. For example, in South Africa the National Water Act enacted in 1998 called for an ecological reserve of water and the formation of catchment management agencies, but it was 2006 before the Inkomati-Usuthu Catchment Management Agency was formed (the country's first) and another 5 years before e-flow implementation. Pahl-Wostl et al. (2012) noted that innovative legal frameworks are necessary to effectively address water related management problems, but are not sufficient without additional policy measures. The precise mechanisms set out in legal frameworks need to be defined according to local context and in light of the nature of e-flow implementation challenges. Horne et al. (2017) described a typology of water allocation mechanisms for environmental purposes, broadly split into two types: mechanisms that impose conditions on water users (e.g., a cap on total water abstraction), and mechanisms that establish a legal right to water for the environment itself (e.g., an environmental water reserve).

Our case studies highlight the role of these mechanisms. For example, a cap on total water abstraction was set for the Murray-Darling Basin overall, followed by Sustainable Diversion Limits for individual sub-basins, which has the effect of protecting all water remaining in the system once limits are reached. Meanwhile, the San Pedro Mezquital River case study is an excellent example of the establishment of an environmental water reserve. The presidential decree in this case includes conditions that provide a clear framework for authorizing future water abstraction.

As a result of the numerous challenges in re-allocating water from existing rights-holders, it is best if e-flows are protected as a reserve or a cap on allocations whenever possible, and if such a cap or reserve is put in place it is done before water becomes over-allocated (Dyson et al., 2008). This will be more politically expedient and cheaper to administer than the re-allocation or reduction of existing rights, or the enforcement of regulations against multiple users. The case studies on the Kennet, Murray-Darling, and Crocodile rivers demonstrate the challenges of attempting to re-allocate or reduce existing water use rights. Nevertheless, the establishment of water trading mechanisms in the Murray-Darling Basin (Murray Darling Basin Authority, 2017) and water banks in the western US (Harwood et al., 2014) indicate that innovative solutions can be found.

Collaboration and Leadership

Human uses of rivers are extremely diverse, as are the ways in which different people, communities and organizations rely on rivers (Horne et al., 2017). E-flow implementation therefore typically faces many politically challenging realities and conflicts between water uses. Given this, Pahl-Wostl et al. (2013) emphasize that the development of e-flows should, from the outset, include input from a wide range of stakeholders on possible trade-offs and synergies between different water uses. A critical early step where stakeholder input is required is agreement on a vision for the river and realistic, achievable, flow-related objectives that most people can support (Dyson et al., 2008). Objectives will be different for different rivers, or even parts of the same river, and will depend on the political, social, economic, and ecological context (O'Keeffe and Le Quesne, 2009).

Our case studies confirmed that collaboration is an essential ingredient for success. Many individuals and organizations have roles to play. Collaboration ensures that stakeholders understand the need for e-flows and how trade-offs between conflicting demands are assessed, and are engaged in the decision-making process. Without this understanding, the implementation process is likely to be undermined by water users unsupportive of e-flows, or not enforced by the agencies responsible for oversight. Structured Decision Making is a valuable process for such collaboration and provides a mechanism for reviewing available information, setting objectives, addressing uncertainty, evaluating trade-offs between competing demands, and making decisions (Gregory et al., 2012).

Given the range of stakeholders involved, the frequent need to resolve conflicts between water users, and the technical and resource challenges often faced (section Resources and Capacity), our case studies highlighted the importance of one or multiple champions to drive the process forward. A champion who holds a senior position within a regulatory authority responsible for water allocation can be a powerful force, often spurring rapid action; however, other organizations such as NGOs can also drive implementation. For Mexico's environmental water reserves (EWR) program, a champion within WWF was successful in persuading the director of CONAGUA, the water allocation authority, of the value of protecting e-flows. The director of CONAGUA, in turn, spurred e-flow assessments in almost double the original target number of watersheds. Together, WWF and CONAGUA were responsible for securing funding for the EWR program, including from the Interamerican Development Bank (IDB).

Political champions for e-flows can also help smooth the road to implementation. This was evident in the River Kennet case study, where a ministerial ally to local and national NGOs helped pass a Water Act through parliament necessary for the e-flow restoration project to secure adequate funding. Champions in international funding agencies can also facilitate action through adherence to standards and the provision of funds, two of the other key enabling factors for successful e-flow implementation (**Table 2**). The role champions and "policy entrepreneurs" (Huitema and Meijerink, 2010) can play has also been highlighted in achieving better water resource management (Lenton and Muller, 2009; Straith et al., 2014).

Resources and Capacity

Scientific understanding has a key role in guiding flow management. However, the particular type of science—or other disciplinary expertise—needed depends upon the outcomes to be protected or attained through e-flow management. Early e-flow science was focused on the conservation of a few targeted species, requiring knowledge and data on the relationship between specific flow conditions and the life cycle requirements of those species. This is still relevant in some situations. In the Three Gorges Dam case study, fish biologists and hydrologists were critical in identifying the spawning locations of Chinese carp in the reaches downstream of the dam, along with the important hydrologic indicators and their ranges for natural spawning that were mimicked when designing e-flows. In other situations, desired e-flow outcomes have expanded to encompass entire aquatic communities, or to include ecological functions such as sediment transport. Consequently, the array of necessary disciplinary expertise has expanded greatly. When social outcomes, such as restoration of fisheries or recreational benefits, are included, the requisite expertise expands again to include economics, human health, and other social sciences.

Effective e-flow implementation requires an understanding of the needs of the species or resource one is trying to protect or restore and how these needs relate to flow magnitude, timing, duration, frequency, and rate of change. However, natural systems, and the communities dependent upon them, are complicated and variable, posing significant analytical challenges. These challenges are compounded when trying to link flows to ecosystem services valued by humans because the causative chain of linkages becomes more complicated (Parker and Oates, 2016). Accordingly, a process for prioritizing trans-disciplinary research, involving natural and social scientific disciplines, should be promoted and supported (Tickner et al., 2017). Nevertheless, e-flow prescriptions should be targeted and only as complex as the context requires. It has proven exceedingly difficult to implement complex e-flow specifications intended to mimic elements of natural flow variability (i.e., by including both intra- and inter-annual variations in flow; Richter et al., 2011).

Lack of resources and/or technical capacity was a barrier to implementation across many of our case studies, as it was in the 20+ case studies examined by Le Quesne et al. (2010). E-flow determination, implementation, and management requires the assembly and analysis of data, individuals trained in a number of different fields, coordination of stakeholders and experts, use of hydrologic models and other decision support tools, and government managers to license and enforce standards. In complex situations with multiple water users, experienced facilitators are also required to balance conflicting needs and facilitate generation of solutions that stakeholders can support. Similar to the implementation of river basin plans (Pegram et al., 2013), these tasks require sustainable funding over many years and the ability to retain expertise. The involvement of various stakeholders often means that capacity-building is a necessary early component of e-flow assessment and determination processes, regardless of jurisdiction. Accordingly, the process may need to start simple to foster understanding and support and demonstrate implementation success within a timeframe that maintains stakeholder support (O'Keeffe, in review).

A common trend across our case studies, both in developed and developing countries, was the learning and understanding gained as the e-flow determination process evolved, and the disappointment that such knowledge often had to be re-taught as a result of turnover. One remedy to the lack of capacity in determining e-flows is to harness the capacity of international organizations experienced in conducting e-flow assessments in a diverse array of scenarios and climates. This approach was taken in the Poonch River case study, as Mira Power hired both a local consultant, Hagler Bailly, and a consulting team from South Africa, Southern Waters, experienced in conducting the Downstream Response to Imposed Flow Transformation (DRIFT; King et al., 2003) e-flow assessment.

Another remedy to an initial lack of capacity is the development of technical standards and guidelines for a region or jurisdiction. This can guide practitioners in appropriate e-flow determination and help overcome inertia when determining which method for e-flow determination is best given the array of techniques available (Tharme, 2003; Acreman et al., 2014). Richter et al. (2011) noted that many good intentions to protect e-flows have stalled due to confusion about which assessment method is "best." The publication of a national standard on e-flow assessment was a key enabling factor in the San Pedro Mezquital case study that provided certainty over the approved approach.

Monitoring and Adaptive Management

Despite marked advances in e-flow science (Acreman et al., 2014), uncertainty remains in the understanding of flow-ecology relationships (e.g., Bradford and Heinonen, 2008; Poff and Zimmerman, 2010; Bradford et al., 2011). Uncertainty means it is important to implement monitoring and adaptive management to ensure that e-flows have the desired outcome. Monitoring outcomes of e-flow implementation is also important to demonstrate the benefits to water managers, the broader public, and politicians (King et al., 2015). Implementing a monitoring program presents its own challenges given the complexity of aquatic ecosystems, natural variability in response variables (e.g., fish abundance and diversity), the multitude of confounding environmental variables (e.g., temperature, land use change), and sustained financial cost. This makes it essential to identify suitable ecological indicators, objectives, methods, and timeframe for the monitoring program (Locke et al., 2008; King et al., 2015), similar to programs aimed specifically at river restoration (Speed et al., 2016).

Monitoring social and economic outcomes generated by an e-flow regime is also critical (Dyson et al., 2008; Pahl-Wostl et al., 2013). Surveys of people's perception of change can also be useful (Speed et al., 2016), and our case studies illustrate growing public awareness of e-flow values, as demonstrated by public acceptance of protective measures implemented for the management of the Poonch River Mahaseer National Park, and in the public support for management of flows within the Ganga River to enable a successful Kumbh 2013. Parker and Oates (2016) note that to ensure equitable distribution of river-related benefits, decisions regarding trade-offs between conflicting needs must be transparent, inclusive, and based on the best available evidence. Only through proper monitoring will the ecological, social, and economic consequences of e-flow decisions be validated and available to help inform adaptive management and future decisions (Richter et al., 2006; Pahl-Wostl et al., 2013; Pegram et al., 2013; King et al., 2015).

ACTIONABLE RECOMMENDATIONS

Our review of case studies demonstrated a number of ways in which policy interventions can facilitate e-flow implementation. The route to success will be dependent on system- and jurisdiction-specific concerns and legal, political, institutional, social, economic, and ecological contexts. This supports the conclusion of Le Quesne et al. (2010) that there is no single correct approach to the implementation of e-flows; instead, the approach must be carefully tailored to the context. It also reinforces insights from broader literature on water resource management about the need to acknowledge complexity (Zeitoun et al., 2016) and the need for trans-disciplinary approaches to policy, planning, and research on water resources and ecosystem management (Tickner et al., 2017). Despite this finding, there are some common truths that emerge from our case study review that lead to the following recommended actions:

1. Enact **clear and effective legislation and regulation**, and maintain the political will to implement and enforce;
2. **Implement some level of protection as early as possible** since it is easier to restrict allocation than to reallocate water;
3. **Engage meaningfully with stakeholders** to garner understanding and support;
4. Secure sufficient **resources and capacity** for e-flow design (including stakeholder engagement), implementation, and monitoring and adaptive management;
5. Consider how e-flow implementation will affect not just **ecological, but also economic and social conditions** for different groups of people;
6. Keep e-flow prescriptions as scientific as possible according to the level of risk and intensity of water use, and within the available financial and human resource constraints–but balance this with the need to **keep science targeted and only as complex as the context allows**, and with the need for clear non-technical communication of the issues with stakeholders; and
7. **Monitor ecological, social and economic outcomes** of e-flow implementation and manage adaptively.

CONCLUSIONS

With the rise of water scarcity across the globe and the pressures on water resources increasing from factors such as population growth, economic transition and climate change, the number of "working rivers" that serve multiple functions is growing. Rivers that provide ecological, social, economic, and cultural value must be healthy; otherwise they will cease to deliver many or all of these benefits. Legislative and policy regimes are being continually updated and e-flows are increasingly playing a central role in water allocation regimes, infrastructure design and operation, and water resource management more broadly. Implementation of e-flows is now a critical part of sustainable water management.

Successful e-flow implementation is invariably underpinned by legislation, but to meet policy objectives for e-flow implementation and achieve the SDG target of ensuring "sustainable withdrawals and supply of freshwater" it will be necessary to develop policies that incorporate measures for, and stimulate investment in, improving technical capacity, engaging stakeholders, setting standards, encouraging champions, establishing monitoring networks, and developing innovative solutions to reallocate water. Our case study analysis showed the range of roles that different stakeholders can play in implementing e-flows and highlights the collective, collaborative effort required. This policy brief builds on this experience and provides recommendations for governments and other stakeholders that will enable the successful scaling up of e-flow implementation if reflected in appropriate legislation and policy.

AUTHOR CONTRIBUTIONS

AH and DT conceived and drafted the outline of the manuscript with input from BR and AL. AH, SJ, and XY acquired and interpreted the information gathered for the work, with DT, BR, and AL providing critical input on implications and recommendations. AH and DT drafted sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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