Author/s:
Mussehl, ML;Horne, AC;Webb, JA;Poff, NLR

Title:
Purposeful Stakeholder Engagement for Improved Environmental Flow Outcomes

Date:
2022-01-25

Citation:
Mussehl, M. L., Horne, A. C., Webb, J. A. & Poff, N. L. R. (2022). Purposeful Stakeholder Engagement for Improved Environmental Flow Outcomes. Frontiers in Environmental Science, 9, https://doi.org/10.3389/fenvs.2021.749864.

Persistent Link:
https://hdl.handle.net/11343/302559

frontiers in Environmental Science

PERSPECTIVE
published: 25 January 2022
doi: 10.3389/fenvs.2021.749864

Purposeful Stakeholder Engagement for Improved Environmental Flow Outcomes

Meghan L. Mussehl[1]*, Avril C. Horne[1], J. Angus Webb[1] and N. LeRoy Poff[2,3]

[1]Environmental Hydrology and Water Resources Group, Department of Infrastructure Engineering, The University of Melbourne, Melbourne, VIC, Australia, [2]Department of Biology, Colorado State University, Fort Collins, CO, United States, [3]Institute for Applied Ecology, University of Canberra, Canberra, ACT, Australia

Rivers are dynamic social-ecological systems that support societies and ecosystems in a multitude of ways, giving rise to a variety of user groups and competing interests. Environmental flows (e-flows) programs developed to protect riverine environments are often conceived by water managers and researchers. This is despite continued calls for increased public participation to include local communities and Indigenous peoples in the development process. Failure to do so undermines social legitimacy and program effectiveness. In this paper, we describe how adaptive management of e-flows allows an opportunity to incorporate a diversity of stakeholder views through an iterative process. However, to achieve this, stakeholder engagement must be intentionally integrated into the adaptive management cycle. Stakeholder engagement in e-flows allows for the creation of a shared understanding of a river and opens collaborative and innovative management strategies that address multiple axes of uncertainty. Here, we describe a holistic framework that unifies current participatory engagement attempts and existing technical methods into a complete strategy. The framework identifies the primary steps in an e-flows adaptive management cycle, describes potential roles of various stakeholders, and proposes potential engagement tools. Restructuring e-flows methods to adequately include stakeholders requires a shift from being driven by deliverables, such as reports and flow recommendations, to focusing on people-oriented outcomes, such as continuous learning and fostering relationships. While our work has been placed in the context of e-flows, the intentional integration of stakeholder engagement in adaptive management is pertinent to natural resources management generally.

Keywords: adaptive management, rivers, participatory methods, stakeholder engagement, social-ecological system (SES), environmental water, environmental flows (e-flows)

OPEN ACCESS

Edited by:
Rebecca Elizabeth Tharme, Riverfutures Ltd., United Kingdom

Reviewed by:
Marloes L. Mul, IHE Delft Institute for Water Education, Netherlands
Nitin Kaushal, World Wide Fund for Nature, India

***Correspondence:**
Meghan L. Mussehl
mmussehl@student.unimelb.edu.au

Specialty section:
This article was submitted to Freshwater Science, a section of the journal Frontiers in Environmental Science

Received: *30 July 2021*
Accepted: *30 December 2021*
Published: *25 January 2022*

Citation:
Mussehl ML, Horne AC, Webb J and Poff NL (2022) Purposeful Stakeholder Engagement for Improved Environmental Flow Outcomes. Front. Environ. Sci. 9:749864. doi: 10.3389/fenvs.2021.749864

INTRODUCTION

Rivers and the communities that live with them are inextricably intertwined (Wantzen et al., 2016; Anderson et al., 2019). Our values, beliefs, and cultural understandings of rivers are as dynamic as the flowing waters and extend beyond a biophysical perspective. In the quest to protect freshwater ecosystems worldwide, environmental flows (hereafter *e-flows*) programs have been developed and instituted that describe and quantify the water a river needs to sustain these complex systems (Arthington et al., 2018). In decades past, the water management sector described rivers in primarily biophysical terms and articulated the river as an entity that could be “objectively known” and managed (Anderson et al., 2019). Increasing awareness of the complexities of river-human-ecology interactions, and the multitude of ways water flows through both social and ecological systems, challenge the notion of the river as a bounded, non-social object (Linton and Budds, 2014). Coupled with calls for more participatory decision-making in e-flows management (Pahl-Wostl et al., 2013; Conallin et al., 2017), this shift in understanding necessitates new management strategies that increase the diversity of perspectives represented by those living in river catchments. This is echoed in the updated 2018 Brisbane Declaration on Environmental Flows, which defines e-flows in relation to "human cultures, economies, sustainable livelihoods, and well-being" and proceeds to outline six statements that explicitly reference the societal, economic, and historical significance of flows (Arthington et al., 2018). The Declaration goes on to call for engagement and empowerment of communities and stakeholders in relation to e-flows and acknowledges the diversity of cultural contexts in which these programs take place. Despite this call, no clear framework for doing so exists. Here, we contribute to this dialogue by proposing an e-flows framework that broadly defines stakeholder groups, delineates their roles, and links purposeful participatory methods to the adaptive management cycle to improve public legitimacy and management outcomes in e-flows.

Rivers and communities are intertwined social-ecological systems that encompass the complex interactions between river ecosystems, human society, and the management structures and institutions that mediate our relationships with rivers. Social-ecological systems are inherently complex and contain multiple dimensions of uncertainty, such as environmental and climactic variables, ecosystem unknowns, and social behaviors and relationships that can be difficult to understand or predict (Rogers et al., 2013). In river management, water flows are more than just a biophysical phase of the hydrologic cycle; they encapsulate cultural, historical, and political narratives of rivers (Bakker, 2012; Perreault, 2014; Anderson et al., 2019). E-flows management thus takes place within an intricate web of physical and abstract hydro-social relationships. Adequately dealing with this level of multi-layered complexity calls for the development of new problem solving approaches within the specific context of the social-ecological system (Stringer et al., 2006; Allan and Watts, 2018; Godden and Ison, 2019).

Major obstacles to the implementation of e-flows programs are often social and political in nature, with researchers citing a lack of effective stakeholder engagement, limited public acceptance, and political reluctance as significant challenges (Le Quesne et al., 2010; Horne et al., 2017; Harwood et al., 2018). In response, there have been calls to improve stakeholder engagement in the e-flows assessment process, increasing the diversity of perspectives represented and reflecting the values of communities within the catchment (Horne et al., 2017; Arthington et al., 2018). These calls for increased engagement in e-flows take place within the context of a wider "participatory turn" in water management (Holzkämper et al., 2012; Cook et al., 2013; Harrington, 2017). Arguments for increased participation in water management are numerous, from claims regarding increased cost-efficiency to a normative call for just and equitable environmental management practices (Stoll-Kleemann and Welp, 2006; Stringer et al., 2006). However, stakeholder engagement and community participation often fail to deliver the desired outcomes, likely because they are implemented in an ad-hoc manner and only achieve a shallow level of engagement (Cook et al., 2013; Jager et al., 2016; Conallin et al., 2017). Perhaps not surprisingly, suitable frameworks to guide participatory processes are lacking, particularly for water practitioners attempting to achieve multiple cultural, ecological, and economic objectives.

In the last half century, as the science and practice of e-flows has evolved, a variety of different actors have been involved in developing and implementing e-flows assessment methods. Originally the discipline was dominated by researchers and biologists focused on the relationships between river flows and a single species, developing hydrologic methodologies to determine the necessary amount of in-stream water (Tennant, 1976; Tharme, 2003; Poff and Matthews, 2013). While these early methods are described as being purely technical, there was some consideration given to social-flow relationships both in the development of e-flows methodologies and in river regulation in the early 20th century. Both recreational and aesthetic values were considered in the original Tennant method and included in river studies in the US at the time (Brown et al., 1991; Anderson et al., 2019). In the 1980s concern about pollution, over-allocation, and ecosystem integrity led to the development of more nuanced e-flows methodologies including habitat simulation, hydraulic rating, and more sophisticated hydrologic methods (Tharme, 2003; Poff et al., 2017). However, many of these early e-flow assessments were still top-down, expert driven projects with limited community or Indigenous involvement.

Over time, the scope of participants has widened to include conservationists, ecologists, water managers, policy makers, and NGOs as more "holistic" methodologies rose to prominence in the 1990s and early 2000s (Poff and Matthews, 2013; Poff et al., 2017). Holistic approaches such as the *Building Block Methodology* (BBM) and *Downstream Response to Imposed Flow Transformation* (DRIFT) described social components and objectives, but articulated the social and biophysical as discrete systems and still relied almost exclusively on the guidance of expert opinion (King and Louw, 1998; King et al., 2003; Anderson et al., 2019). Some researchers have used the Ecological Limits of Hydrologic Alteration (ELOHA) framework, a holistic approach to e-flows assessments, as a foundation to explore methods of increasing engagement and incorporating a greater understanding of social-ecological relationships (Poff et al., 2010; Finn and Jackson, 2011; Martin et al., 2015). The Sustainable Management of Hydrologic Alterations (SUMHA) framework tailored ELOHA to explicitly consider stakeholder objectives and to garner participation from water agencies and stakeholders in a process of organizational learning (Pahl-Wostl et al., 2013). While these approaches made significant advances in how we conceptualize flow-ecology dynamics and proposed robust strategies for e-flows management, they are still limited by an imposed division between nature and society (Conallin et al., 2018b; Anderson et al., 2019).

The growing awareness of the myriad of ways in which society and water are intimately connected and even co-constituted is evident in the fields of engineering and geography through scholarship on socio-hydrology and hydrosocial studies respectively (Linton and Budds, 2014; Wesselink et al., 2017; Ross and Chang, 2020). At the same time, the field of ecology has articulated the concept of social-ecological systems to describe highly complex systems where society and ecosystems are coupled through both direct and indirect interactions that are difficult to predict (Ostrom, 2009; Maldonado et al., 2020). Adequately handling the complexity of the interactions between flows, societies, and ecosystems will require new e-flows methodologies that reflect multiple perspectives of the river and articulate these relationships. These methodologies will require greater involvement from all involved stakeholders to capture these interactions.

Recent projects within the last few decades have explicitly explored the connections between society and rivers in attempts to characterize and even quantify social-flow relationships as well as expand the scope of who is involved in the process of water management. These projects challenge previous approaches that divided rivers and societies into separate entities and explore social-ecological relations in new ways. They push us to think beyond a unidirectional transfer of ecosystem services to recognize multiple value systems for rivers and to develop pluralistic management approaches (Himes and Muraca, 2018; Anderson et al., 2019).

In India, there has been significant work in the last decade to address issues regarding the management of the Ganga River, an extremely large and complex basin with millions of people dependent on the river for economic, cultural, and spiritual needs. Several projects related to the introduction of e-flows to the Ganga have incorporated significant stakeholder involvement, recruiting a wide array of participants for the process-from international experts and NGOs to local community members and water users (O'Keefe et al., 2012). An emphasis was placed on developing approaches to integrate social and cultural views into e-flows including an analysis of the cultural and spiritual water requirements within an e-flows assessment on the Ganga (Lokgariwar et al., 2014; Kaushal et al., 2019). In Australia and New Zealand the concept of cultural flows has been introduced in parallel to e-flows to better articulate and protect Maori and Aboriginal stakes in river catchments. These regions have even been home to emerging collaborative partnerships between Indigenous organizations and water managers (Tipa and Nelson, 2008; Memon and Kirk, 2012; Crow et al., 2018; Jackson and Nias, 2019). While we have presented a few examples of the current advances in the ways e-flows management can be expanded to include social-flow interactions more adequately, Anderson et al. (2019) investigates a wide range of these projects, making it clear that this work is happening on a global scale.

The need to incorporate both technical and social knowledge bases into e-flows assessments requires a broader management framework that can accommodate the manifold uncertainties arising from transdisciplinary collaboration. Adaptive management fills this need, as it provides tools for managers to deal with the complexity and uncertainty inherent in social-ecological systems (Holling, 1978; Pahl-Wostl et al., 2008; Webb et al., 2018). Adaptive management is a learning-by-doing approach intended to foster cyclical learning through time. Conceptualizations of learning within this process can vary depending on what the focus of learning is, who does the learning, and how it is used (Allan and Watts, 2018). Webb et al. (2018) identified two main learning themes in adaptive management. At one end of the spectrum are programs centered on technical learning largely supported by modeling; on the other, there are programs centered on learning about the social-ecological system supported through social learning undertaken by diverse participants. Strategic, collaborative, and participatory frameworks have all been proposed as different takes on the adaptive management concept. These versions all depend heavily on stakeholder engagement and suggest structured approaches to decision making and knowledge production (Roux and Foxcroft, 2011; Fujitani et al., 2017; Kingsford et al., 2017; Allan and Watts, 2018). Adaptive management provides a useful scaffold to incorporate multiple types of knowledge, diverse values, empirical data, and institutions in e-flows management. While attempts at socially aware and culturally appropriate e-flows assessments are already occurring across the world, incorporating a structured learning process will allow for knowledge transfer within and between e-flows programs. Calls for stakeholder engagement often sit outside current flow assessment methodologies, making it difficult to contextualize and integrate participatory methods (Conallin et al., 2017). To address this gap, we propose a general framework that meaningfully engages diverse stakeholders for the purpose of developing e-flows targets, assessment, and management. This framework places the participatory process around the adaptive management framework, building in key opportunities for engagement at every stage.

ADDRESSING CHALLENGES FOR THE MANAGEMENT OF E-FLOWS

E-flows implementation faces significant challenges, the most critical of which are socio-political in nature. E-flows management takes place in the context of complex social-ecological systems which are inherently dynamic, uncertain environments. The challenges of managing river systems under natural climactic and environmental uncertainty are compounded by the risks associated with anthropogenic climate change and complicated by changeable socio-political contexts. While adaptive management was developed specifically to address issues of complexity and uncertainty, the approach has not always been successful at creating sustained management programs or instigating significant policy changes. Many approaches to adaptive management are not intentionally designed to address the social challenges faced by e-flows implementation. Working with diverse stakeholders within a catchment is challenging, as participants will come to the process with different values, perspectives, and knowledge. Supporting social learning and fostering community ownership within management processes is essential for building program legitimacy. Below, we discuss four ways that an adaptive management approach based in participatory methods addresses the social challenges presented by e-flows management.

Co-Production of Knowledge

All knowledge is inevitably situated and partial, and management strategies that are limited to a few forms of knowledge have limited capacity to generate innovative solutions to complex problems (Haraway, 1988; Matos, 2015; Rosendahl et al., 2015). Transdisciplinary knowledge co-production that embeds scientific and non-scientific knowledge into research and decision-making processes has become a popular, yet difficult, objective within water governance (Brugnach and Özerol, 2019). Knowledge co-production is a pluralistic approach that appreciates the validity and relevance of multiple ways of knowing. It brings together diverse sources of knowledge and perspectives to generate "context-specific knowledge" and explore potential strategies for tackling complex problems (Miller et al., 2008; Reyers et al., 2015; Norström et al., 2020). Engaging with different participants in knowledge co-production also improves social networks, cultivates communal ownership, and builds capacity for future engagement (Armitage et al., 2011). Co-production can take place in a multitude of ways, depending on how the participation is structured and the overarching goals of the program. Within adaptive management, co-production can occur from the point of project initiation, when problems are identified, framed, and placed in context. Conceptual and quantitative models can be produced using multiple sources of knowledge and are based on the values and inquiries of the participatory group. Adaptive management learning processes that integrate specialist, local, traditional, and social knowledge bases widen the scope of learning that can be pursued and open up new avenues of exploration in the management of the system (Fernández-Giménez et al., 2019).

The National Freshwater Ecosystem Priority Areas (NFEPA) project in South Africa is a useful example of a national-scale freshwater conservation project that targeted knowledge co-production. Over the course of the 4-year process, over 450 participants were involved in the co-production of conservation goals and spatial data that ultimately resulted in an atlas and implementation manual identifying 37 areas for conservation. These results are available freely on a supporting website and uptake within the identified areas has been promising (Nel et al., 2016). The NFEPA process was designed to create space for dialogue among participants from diverse knowledge backgrounds and they successfully engaged in the co-production from developing objectives to the final production of maps.

Social Learning to Support Adaptive Management

Pairing social and technical learning through iterative processes enables wider stakeholder ownership of knowledge and can encourage collaborative environmental governance (Wyborn, 2015; McLoughlin et al., 2016; van der Molen, 2018). Adaptive management traditionally uses a *single-loop* learning approach, in which management is conceptualized as an experiment within the system and the results of the experiment are used to update knowledge of the system and design new management strategies (Stem et al., 2005). While this type of learning is critical to the adaptive management process, this style of deductive hypothesis testing assumes the ongoing validity of underlying values and goals. *Double-loop* learning describes institutional learning, in which the decision making processes themselves are updated through iterations (Williams, 2011; Petersen et al., 2014; Williams and Brown, 2018). Beyond this, *triple-loop* learning encourages stakeholders to revisit and modify the underlying beliefs and perceptions that drive management (Pahl-Wostl, 2006). Social learning to support institutional reframing occurs through collective processes in which learners' beliefs are updated through successive interactions with one another and the management environment (Pahl-Wostl, 2006; Fernández-Giménez et al., 2019).

Embedding social learning into the adaptive management cycle will allow us to critically examine the institutional frameworks and processes that govern e-flows management Assessing these structures and making incremental changes will allow a shift from rigid river regulation to a "multifunctional dynamic landscape" (Pahl-Wostl, 2006). Social learning, whether structured within management or emerging organically, is highly dependent on "learning spaces" where stakeholders can share knowledge, develop common understandings, and work cooperatively (Lumosi et al., 2019). Moellenkamp et al. (2010) explored how intentional, informal participatory processes run in parallel to the formal water management process facilitated social learning and provided avenues for experimentation. They found that the participatory process facilitated institutional changes and shifts in applied methodology for management (Moellenkamp et al., 2010). Restructuring the adaptive management cycle to create learning spaces through the integration of participatory processes allows participants to engage in critical social learning about the relationships between stakeholders, management frameworks, and the river.

Recognizing and Addressing Multiple Sources of Uncertainty

E-flows management is complicated by the many uncertainties associated with a complex social-ecological system, including unknown flow-ecology relationships (Bunn and Arthington, 2002; Lynch et al., 2018; Watts et al., 2020), measurement uncertainty (Stewardson and Rutherfurd, 2006; Goguen et al., 2020), the dynamics of a non-stationary climate and environment (Milly et al., 2008; ThompsonLaizé et al., 2014; Poff, 2018), and ambiguous or shifting social perceptions of the water resource systems (Gleick, 2000; Hogl et al., 2012). Adaptive management seeks to reduce the uncertainties associated with ecological systems through a structured learning process (Williams, 2011; Webb et al., 2017). Recognition and transparency regarding uncertainty fosters trust between stakeholder groups and increases acceptance of management programs despite these uncertainties (Acreman et al., 2014; Conallin et al., 2018b). Previous literature on e-flows and water resources has focused on ecological and environmental uncertainty; social-ecological relationships and perceptions of management represent another axis of uncertainty. This will be increasingly the case as we adjust to managing under a changing climate where different sets of trade-offs and decisions will be needed (Horne et al., in review). Societal and personal values regarding the environment also shift over time (Kendal and Raymond, 2019) and in response to engagement with environmental issues and political dialogues (Hards, 2011; Corner et al., 2014; Wolsko, 2017). Maintaining legitimacy through time will require transparency about uncertainty and non-stationarity in both physical and social dimensions of environmental water management. We suggest that social values regarding flows and management are also non-stationary and that diverse stakeholder engagement throughout the adaptive management cycle will allow us to capture these changing social-ecological contexts and embed them into management.

Fostering Program Legitimacy

Legitimacy is crucial to the success of adaptive e-flows management, as public trust and confidence in management agencies is what allows them to function (Horne et al., 2017; O'Donnell and Garrick, 2017). The concept of legitimacy can be constrained by a focus on the centrality of government institutions and agencies that are presumed to be acting in the public interest and supported by sound technical guidance (Gearey and Jeffrey, 2006; Godden and Ison, 2019). In countries where federal and state institutions are responsible for e-flows governance, community participation is often mandated through legal instruments that may have a narrow, inflexible definition of engagement (Godden and Ison, 2019). Fostering legitimacy for e-flows programs and associated management is two pronged, requiring focus on both *input* and *output* legitimacy (Hogl et al., 2012; O'Donnell et al., 2019). E-flows programs have previously depended largely on building output-based legitimacy, defining their credibility based on the success and efficacy of their management programs as shown through scientific indicators. While this is a necessary component of overall legitimacy, building input legitimacy in parallel through process-focused, stakeholder driven initiatives builds public trust and confidence for program success, and in turn helps to bolster trust in program outputs. Input legitimacy focuses on transparency, access, representation, and accountability throughout decision making and management. These values encourage stakeholders to create a shared understanding of the problem and develop a shared vision for success (Cullen, 1990; Webb et al., 2010).

In an analysis of water management projects in the Netherlands, van Buuren et al. (2012) describe throughput legitimacy as the carry through of democratic principles and deliberative opportunities throughout the management process. In one of their case studies, there were protests following a dike improvement proposal that had no community input. In response to the protests, the original proposal was scrapped, and a collaborative process was developed with the agreement that any new proposal must have public support. The new process emphasized communication and transparency by building in key opportunities for citizens to contribute their voice. This new process complemented existing institutions and frameworks, leading to a hybridized strategy with greater throughput legitimacy (van Buuren et al., 2012).

Key Definitions

Stakeholder Engagement - targeted involvement of identified stakeholder groups with a vested interest in the outcome of environmental flows management. Involvement may be cursory, involving primarily information relay and consultation, but may extend to more in-depth engagement and collaborative governance.

Participatory Methods - a directed form of stakeholder engagement, participatory methods enable a diverse set of stakeholders to play an active role in shaping management strategies and solutions, encouraging communal ownership of outcomes.

Social Learning - Changes in the attitudes, perceptions, and knowledges of stakeholders instigated by social interactions between one another and with institutional frameworks. These shifts must impact the management decisions and the relational dynamics of the group and may extend beyond the individual participants to influence perceptions within the wider community.

Knowledge Co-production - by valuing and using specialist, local, traditional and other types of knowledge, new management solutions are generated that would not have been otherwise articulated.

Legitimacy - the ongoing social acceptance of an institution or organization's actions regarding an issue based on the perceived effectiveness and appropriateness of the actions.

FRAMEWORK FOR INCORPORATING STAKEHOLDER ENGAGEMENT IN E-FLOWS

The framework we outline here is designed around a participatory approach to the adaptive management e-flows that purposefully incorporates a diverse range of stakeholder perspectives and knowledge. This framework is flexible and can be adapted the range of contexts in which e-flows are implemented. We break down the adaptive management cycle, identifying when and how stakeholders might participate to support social learning and knowledge co-production.

Primary Stakeholders Involved in the E-Flows Process

Stakeholders are broadly defined as the individuals, organizations, and institutions that have an interest in the outcome of an e-flows program. This definition casts a wide net, particularly given that stakeholders may define themselves as

TABLE 1 | E-flows case studies with participants grouped into stakeholder categories.

Case Study	Stakeholder categories			
	Indigenous Peoples	***Local Community***	***Water Managers***	***Researchers***
Patuca River, Honduras Esselman and Opperman (2010)	Representatives from local Miskito, Tawahka, and Mestizo communities	Local boat captains NGO and government agency representatives from within river area	Engineers and hydrologists from ENEE (National organization in charge of hydropower dam operation)	The Nature Conservancy (acted as facilitators, modelers, and contributed technical expertise) Honduran and international experts in aquatic ecology and other related disciplines
Kaiela (Lower Goulburn) River, Australia Horne et al. (2021) in this issue)	Water Officers from local Aboriginal organizations within the catchment area	Landholders Individual citizens involved in local environmental advisory group Local Council members	Basin-level Catchment Management Authority Department of Environment, Land, Water, and Planning (Sets and manages State-level environmental water policy) Commonwealth Environmental Water Office (Owns and manages environmental water) Goulburn-Murray Water (Manages flow operations on river) Murray-Darling Basin Authority	University research team (acted as facilitators, modelers, and contributed technical expertise) Panel of discipline experts in aquatic ecology, fluvial geomorphology, and related fields

such and seek engagement while other stakeholders may actively choose not to be involved. The narrative around stakeholder engagement has often focused on the aspirational inclusion of communities, framing the community participants as stakeholders while other participants, such as bureaucrats, managers, and experts, are responsible for facilitating the engagement process. In practice, it is rare that e-flows projects frame these other participants as stakeholders with distinct values and perspectives. However, previous literature in the field of e-flows identified three primary categories of stakeholders, distinguishing researchers, and water managers as discrete stakeholder groups along with local communities (Edelenbos et al., 2011; Webb et al., 2018). Webb et al. (2018) conceptualized these groups within a Venn diagram, where management strategies and projects involve different combinations of groups. In addition to these three groups, we have added Indigenous peoples as a discrete group, given their unique relationship with and knowledge of catchments, their recognition by existing governance frameworks, and their traditional and ongoing role as custodians (Nania and Guarino, 2014; Wilson, 2014; Jackson, 2017; Moggridge et al., 2019). E-flows management, like all natural resource management, is underpinned by the values, data, knowledge, and people involved in the process (Kennedy and Koch, 2004). Management strategies involve different contributions from these stakeholder groups and an ideal adaptive management approach would lie at the intersection of the four groups.

Conceptualizing engagement between stakeholders in complex management scenarios is always difficult. We have defined four broad stakeholder categorizations (Indigenous peoples, water managers, researchers, and local community) to enable a discussion of how stakeholder participants might engage with the adaptive management process. These broad groupings are useful, as this is how stakeholders are often identified for inclusion in the participatory process, regardless of how their role in the process is defined or evolves. Using these categories to identify and recruit stakeholder participants ensures that critical groups of stakeholders are included throughout the process. This is particularly important, given that key stakeholder groups are often left out of the management process (Webb et al., 2018) leading to incomplete learning cycles and poor social legitimacy. We recognize that these categories are broad and include a myriad of possible participants and organizational arrangements. The stakeholder participants for any program will be influenced by the scale of the project and by the governance structures and policies already in place. It is also important to note that this framework, as with any management framework, will not be able to describe all the possible nuance of stakeholder participants and arrangements. Rather, it is a tool for conceptualizing these relationships within the adaptive management context.

Table 1 highlights two e-flows case studies with a range of participants, and groups the participants into the stakeholder categories used for this framework. In the Honduran case study, a large multi-national NGO, The Nature Conservancy, was asked to fulfill the role of facilitator as well as complete much of the technical work associated with the e-flows assessment. Hence, we have defined them as researchers within our stakeholder categories. The only water managers involved in the Honduran case study were technical and engineering representatives from the ENEE, a quasi-governmental hydropower management agency that is responsible for dam operations. The workshop consultation process for their project included representatives from Indigenous communities, local government officials and NGOs, and a range of Honduran and international experts (Esselman and Opperman, 2010). The Australian case study included a range of participants in an e-flows assessment. While the project was organized by the local catchment management authority, a university team acted as the project leads, facilitating workshops and supplying technical modeling expertise. In addition to the university team, a

TABLE 2 | Key features of each stakeholder group based on the four elements that underpin the e-flows process.

Stakeholder group	*People*	*Knowledge*	*Data*	*Values*
Local Community	Diverse group that may represent many varied interests, including recreational, economic, and cultural. Typically live in close proximity to river, but may only be occasional users of the river	Lay knowledge is primarily based on experience with the river through time and space Cultural understandings of the river and riparian area also represent a unique knowledge base Knowledge of social relationships between stakeholders and socio-economic-riverine context	While not always holders of data themselves, community stakeholders may have knowledge of unique data sets from previous projects Community stakeholders may be a source of social or economic data	Values may be extremely diverse among this group, ranging from community-based to economic to conservation Values can be process-based and related to their experience with the decision-making process
Researchers	Primarily consulting scientists and academics who may or may not live near the river Typically have a specific domain of expertise may have spent many years working with this river or in the same region	Technical knowledge of flow-ecology relationships and river processes Understanding and experience with technical tools and software associated with modelling	Access to specific technical data sets regarding ecology and hydrology May have access to research networks in order to obtain datasets	Values of researchers may be diverse as well, often based on ensuring the use of the best available science
Water Managers	Institutional or agency representatives responsible for maintaining river resources and implementing management Different levels of management range from federal to state to local, influencing perspective of individual stakeholders from this group Carry the risk of failure and are responsible for mismanagement	Understanding of legislation and regulations required for implementation Knowledge of local and regional constraints related to water delivery Knowledge of institutional hierarchies and decision-making context that shapes management	Access to datasets held at an institutional level. May include ecological, meteorological, and hydrologic data	Personal values of individual stakeholders in this group may be superseded by values and objectives of respective agencies
Indigenous peoples	Indigenous peoples may identify themselves as traditional custodians or owners of the river and connected landscape Indigenous peoples' right to be included in the decision-making process may be legitimized through a legal framework. Regardless of whether this framework is in place, they should be included as a stakeholder group	Traditional ecological knowledge and understandings of the river Management/Custodianship knowledge that predates colonial settlement Cultural, social and economic knowledge of the river that is tied to long historical traditions	Due to marginalization in existing institutions, access to formal data sets may not exist Some data may exist through previous projects seeking to formalize Indigenous knowledge may be present, but intellectual property rights need to be negotiated	Values of Indigenous groups may vary widely and cannot be easily summarized Values may be connected to identity and long-standing connection to landscapes Values may be related to rights to natural resources management

panel of discipline experts were recruited for the project, fulfilling the role of researchers within our framework. Local community participants included local elected council members, landholders, irrigators, and other interested citizens. The water policy officers from two local Aboriginal organizations were also included in workshops and played a role on the project steering committee. Given the complicated governance structure surrounding water in Australia, several different water management agencies were included, representing basin, state, and local scales of management (Horne et al., 2021).

Table 2 outlines some key features of these four stakeholder categories and the importance of their roles throughout the e-flows process. First, we note that here we refer to Indigenous peoples as stakeholders; however, we acknowledge that in some contexts it would be better to refer to them as rights holders (see Jackson, 2018; Latta, 2018; Pomart, 2020). Potential roles of Indigenous groups are highly context specific and depend on multiple factors including but not limited to: the empowerment of groups at both federal and local levels, the degree of colonization, historical disenfranchisement, and the extent of Indigenous diasporas (Woodward and McTaggart, 2016; Stefanelli et al., 2017; Clapcott et al., 2018; Norman, 2018). While we have described Indigenous peoples as a stakeholder group akin to water managers and local communities, it is important to understand the significance of customary management practices and dynamic social-ecological relationships that predate colonial settlement and persist today despite post-colonial institutionalization (United Nations Declaration on the Rights of Indigenous Peoples, 2008; Chen et al., 2018; Magdaleno, 2018). Indigenous groups have varied recognition and legal rights within water governance globally (Macpherson, 2019). Currently, Indigenous communities and organizations assert custodial rights, challenge existing governance frameworks, and form collaborative partnerships with non-Indigenous organizations. The ways in which Indigenous communities engage with water governance varies from country to country and regionally within nations. Leading and participating in various forms of water governance (including e-flows) can play an important role in self-determination (von der Porten and de Loë, 2013; Pirsoul and Armoudian, 2019). Because of the importance of context-based approaches for Indigenous inclusion, we do not make specific recommendations for their role in the e-flows process. However, we recommend that Indigenous groups be included as early as possible and throughout the adaptive management cycle using any participatory guidelines developed by the groups themselves (Jackson et al., 2012; Crow et al., 2018). Community is often the focal point of engagement programs in natural resources management, and it is widely recognized that community support is critical for the sustained success of e-flows programs (Horne et al., 2017; Allan and Watts, 2018; Watts et al., 2020). However, when poorly executed, these attempts can become tokenistic, and shallow engagement can harm the long-term success of flows programs (Conallin et al., 2017; Pirsoul and Armoudian, 2019). The definition of community is often left amorphous but can be broadly defined as individuals and groups who live or work locally and have a stake in the decision-making process. This may include irrigators, recreational users, conservationists, local government and politicians, as well as other concerned citizens who identify themselves as stakeholders. Community participants bring specific local knowledge to the decision-making context and can reflect broader community-based values and perspectives. This localized knowledge is rooted in the day-to-day experiences with the river and reflects social understandings of the system. Because the umbrella of community covers a range of individuals and groups, a broad spectrum of viewpoints will be present and there is a potential for conflict and competing perspectives, both within the group and with other stakeholder groups (Haddaway et al., 2017). While negotiating these dynamics is a challenge, with careful conflict resolution it can also be an opportunity to identify shared values and engage in critical social learning (Carr, 2015; Conallin et al., 2017). Successful engagement with community members will recognize their role in knowledge co-production and increase their capacity to participate in all phases of the adaptive management cycle, including decision making.

The published literature has tended to view researchers as unbiased experts in their field and has depended heavily on their guidance in creating water management policy (Stewardson and Webb, 2010); thus valuing this technical knowledge above other forms (Edelenbos et al., 2011). However, casting researchers as impartial and neutral observers can be problematic given observed expert bias (de Little et al., 2018) and the intrinsic personal perspectives individual researchers bring to their interactions (Yamamoto, 2012; Mandel and Tetlock, 2016). Similarly, water agency representatives are seldom framed as stakeholders in e-flows management, as they are often the organizers of stakeholder engagement activities. Water agency representatives also bring their own biases and values to the decision making process, particularly when considering risk (Kosovac and Davidson, 2020). Although researchers and agency representatives are typically considered 'outside' the formal engagement process, the groups share key aspects with other stakeholders. They have a unique knowledge of the system, often live within or near the catchment of concern, and have a vested interest in catchment management.

Restructuring e-flows management to acknowledge researchers and agency representatives as distinct stakeholders akin to community and Indigenous peoples opens new avenues of collaboration and creates space for dialogue between the groups. Researchers and agency representatives can play a meaningful role in knowledge creation when framed as stakeholders with unique sets of values, data, and knowledge (Rosendahl et al., 2015). Placing researchers and agency reps amongst other stakeholders allows them to make their values and perspectives explicit. These values then become one piece of the larger management puzzle, on a par with those of other groups, and allows decision makers to balance multiple types of knowledge and varied perspectives (Hare and Pahl-Wostl, 2002; Hare et al., 2006; Raymond et al., 2010; Edelenbos et al., 2011).

It is important to recognize that stakeholder groups are neither homogenous nor static; each group's perspectives will be dynamic, varying both within the group and through time (Steyaert and Jiggins, 2007; Conallin et al., 2017). Therefore, engagement programs should be conceptualized as long-term programs that continuously reengage with participants, recruit new participants, and are self-reflective enough to capture changing perspectives and relationships. Stakeholder recruitment and analysis, detailed in **Table 2** under the Planning heading, is a critical step in identifying the stakeholder participants and beginning the engagement program. Stakeholder analysis can be used to systematically identify the individuals or groups who have a long-standing interest in e-flows decisions, are potentially impacted by management actions, or are already in a position of influence (Reed, 2008; Reed et al., 2009; Conallin et al., 2017). A stakeholder analysis may also identify existing social interactions between the various groups and the river, including potential sources of tension and conflict. Building a flexible engagement strategy will help account for these considerations, allowing different stakeholder groups to participate in the ways they deem appropriate and when they have the capacity to do so.

Participatory Adaptive Management for E-Flows

Adaptive management has previously been identified as a useful approach for e-flows based on its ability to deal with complex and uncertain systems (Webb et al., 2018). The adaptive management cycle is an iterative process divided into three primary phases, *planning, learning, and doing*. **Figure 1** illustrates how the common steps in e-flows management align with the phases of adaptive

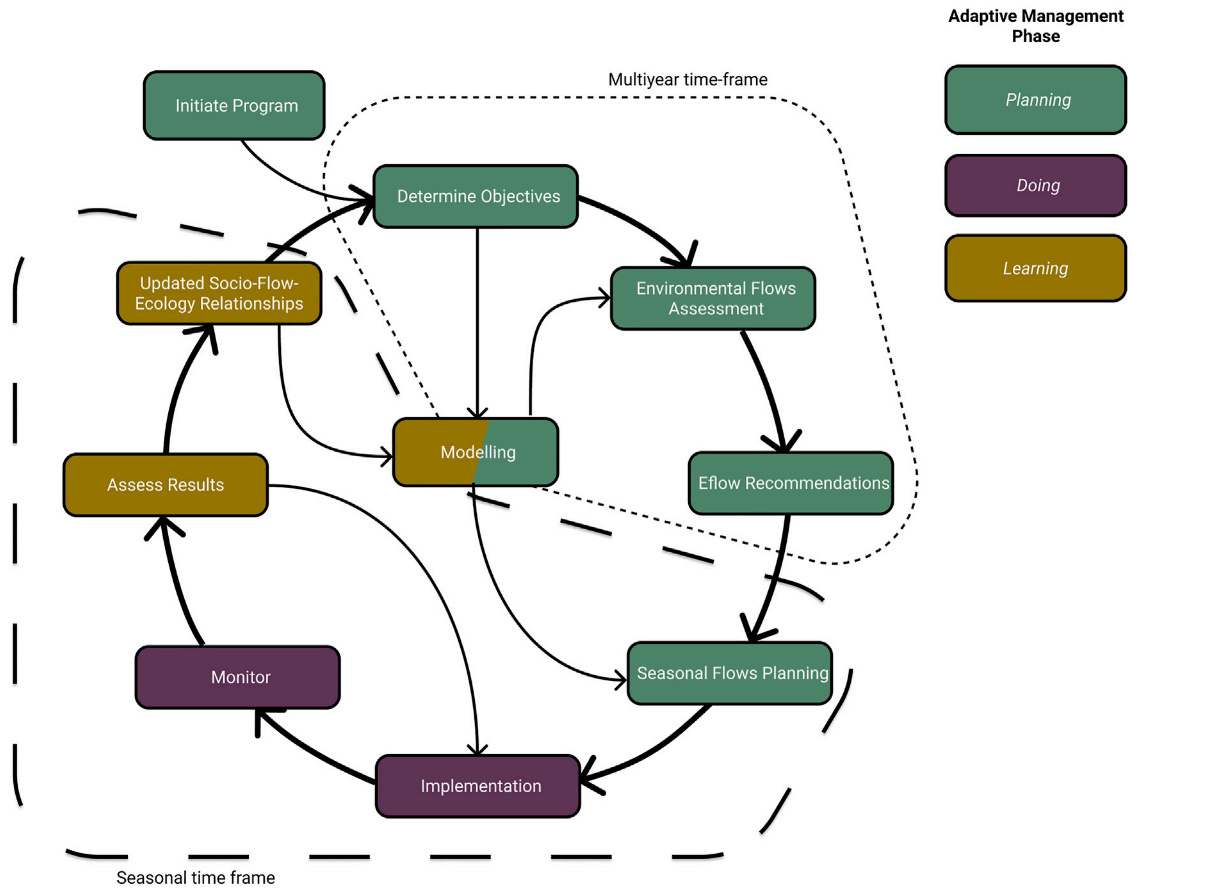

FIGURE 1 | The phases of adaptive management in e-flows: Planning (shown in green), Doing (shown in purple) and Learning (shown in gold). The boxes show the activities involved in e-flows adaptive management. The majority of planning takes place within a longer multi-year time frame while doing and learning takes place on a seasonal and ongoing basis. The e-flows activities here correspond directly with the activities described in **Table 3**.

management. Mapping these two processes together allows us to determine where in the cycle various stakeholder groups should be engaged and in what manner. Each phase of the adaptive management cycle presents an opportunity for meaningful stakeholder engagement allowing the phases to be underpinned by the people, knowledge, data, and values of each stakeholder group. Successful engagement will involve all four stakeholder groups to varying degrees in every phase, with contributions from each group changing over time. It is impossible to define the exact level engagement for different stakeholder groups at every step of e-flows management and being too prescriptive in this regard runs the risk of limiting a program's ability to evolve through time. We believe that the context of each e-flows program and the stakeholders themselves should determine the level of engagement and guide tool selection.

Table 2 provides detail on the e-flows activities that align with the phases of the adaptive management cycle shown in **Figure 1**. We suggest guiding principles for each of these phases and elaborate on some the important considerations for these activities. In **Table 2**, we have focused on activities that typically take place during e-flows management, such as environmental flows assessment and recommendations, modeling, and monitoring, etc. These activities can all include engagement with the four stakeholder groups but are often not structured to include participation as a fundamental component of the activity. The participatory methods highlighted in **Table 2** are broad frameworks or concepts that will require a suite of tools to execute, including workshops, steering committees, focus groups and other tasks (Hare et al., 2006). These participatory methods have been identified through a survey of the literature regarding stakeholder engagement in natural resources management, though we do not present a comprehensive list of all possible participation frameworks and tools. These methods should be selected based on the context of individual projects and approaches, including the resources and capacity of stakeholder groups involved.

Many of the activities in the planning phase of e-flows management fall under the broad umbrella of the e-flows assessment (printed in bold within the Planning row in **Table 3**), an activity that occurs in the initial implementation of a program and is periodically updated (Tharme, 2003; Jain, 2012). Much of the planning for an e-flows program takes place on a long-term time scale, as e-flows assessments take a considerable amount of time and resources to conduct. In practice, a broad e-flows assessment is often conducted every 5–10 years for a catchment. Seasonal and yearly

TABLE 3 | Role and form of participation across the adaptive management cycle.

Adaptive management phase	E-Flows activities	Guiding principles	Considerations	Participatory methods	References
Plan	Program Initiation	Early and intentional stakeholder engagement through a transparent strategy	Diverse avenues of participation and ongoing stakeholder recruitment can give programs more flexibility and resiliency	Stakeholder Engagement Plan	Conallin et al. (2017)
	Situation Analysis	Program strategy places emphasis on trust building and social and organizational relationships	Conflict will arise and is an inherent feature of participatory processes but is not always an impassable barrier to cooperation	Stakeholder Recruitment and Analysis/ Conflict Mapping	Reed et al. (2009), Young et al. (2016), Haddaway et al. (2017), Fisher et al. (2020)
	E-flows Assessment	Participant values as a starting point for program initiation and vision planning	Regardless of methodology for e-flows assessment, diverse types of knowledge can be included	Shared Vision Planning	Connor et al. (2012), Palmer et al. (2013)
	Creating a Vision	Validating and utilizing multiple types of knowledge that can influence future monitoring and modeling efforts	Objectives for program are not limited to the biophysical conditions of the river	Participatory Modelling	Hare (2011), Robles-Morua et al. (2014), Voinov et al. (2018)
	Determine Hierarchy of Objectives	Indigenous peoples' role as right holders should be addressed and Indigenous organizations should be contacted immediately upon program discussions		Structured Decision Making	Gregory et al. (2012), Failing et al. (2013), Guerrero et al. (2017), DeWeber and Peterson (2020)
	Evaluating Options			Knowledge Co-production	Djenontin and Meadow (2018), Norström et al. (2020)
	Defining Targets Flow Recommendations Flow Implementation Plans Modeling Documentation			Thresholds of Potential Concern	McLoughlin et al. (2011), Roux and Foxcroft (2011)
Do	Implementation	Proactive communication with stakeholders and community throughout doing phase	Implementation is unlikely to involve all participants all the time. However, implementation of flows should be transparent and well communicated to all	Citizen Science Programs	Aceves-Bueno et al. (2015), Hadj-Hammou et al. (2017)
	Monitoring	Inclusion of participants in implementation and monitoring ensures that targets and measures align with overarching program values and objectives	Indigenous peoples may play an active role in flow implementation depending upon capacity and roles within management area	Indigenous Community Based Monitoring	Wilson et al. (2018), Reed et al. (2020)
	Documentation	Monitoring is critical to e-flows programs for justification of flows and supporting learning processes	Monitoring should be designed engage all interested participants and should be made accessible for multiple levels of engagement		
		Monitoring should extend beyond the bounds of traditional biophysical approaches and should be inclusive of multiple sources of knowledge	Learning happens continuously throughout the doing phase as management is adjusted intra-yearly in response to shifting factors. This learning can be done with participants and should be well documented		
		Datasets and documentation should be widely accessible and updated regularly to ensure all participants have access	Participants can help guide management decisions when drastic events necessitate a response outside of planning phase		

(Continued on following page)

TABLE 3 | (*Continued*) Role and form of participation across the adaptive management cycle.

Adaptive management phase	E-Flows activities	Guiding principles	Considerations	Participatory methods	References
Learn	Assess Results	Engagement in multiple levels of learning (technical, social, and organizational) is crucial to ongoing adaptive management	Accurate and thorough records of learning phase activities support ongoing adaptive management and application to other projects	Institutional or Double Loop Learning	Fitzpatrick, (2006), Kunler and Lemos (2008)
	Update Flow-Ecology-Society Relationships	Use of best available science to contextualize flow-ecology relationships	Databases of monitoring and technical learning need to be accessible to a wide variety of stakeholders	Reflexive or Triple Loop Learning	McLoughlin et al. (2020)
	Update Understanding of Participant Relationships	Learning focuses not just on updated flow-ecology relationships, but learning about the decision-making process and social-ecological relationships	Accessible and widely disseminated knowledge, including accessible science communication	Knowledge Co-production	Djenontin and Meadow (2018), Norström et al. (2020)
	Reevaluate Management Structures Modeling Documentation		Learning needs to be well-resourced, particularly social learning. This may include a specific position within the management program or require cross-disciplinary training	Participatory Modelling	Basco-Carrera et al. (2017), Falconi and Palmer (2017)
Repeat	Reflection	Reflection on the success of the adaptive management cycle and on the stakeholder engagement plan to support multiloop learning	Determining how this role will be supported and funded through time will be critical for carrying lessons learned forward	Reflector Role	Webb et al. (2018)
	Documentation		Reflector role may be filled by a single individual or by a group of participants. The reflector role could be a way for community participants to engage deeply with the project and encourage continued involvement		

e-flows planning takes place on a much shorter time frame and is informed by the e-flows assessment as well as updated learning. Successful stakeholder engagement for the program begins with the early development of an engagement strategy that is supported by the involvement of participant stakeholders from its conception (McLoughlin et al., 2016; Conallin et al., 2017). Stakeholders should be embedded in this planning phase through an inclusive approach that prioritizes stakeholder values in the creation of a shared vision and the development of program objectives.

The doing phase (detail in second row of **Table 3**) consists primarily of implementation and monitoring. Implementation of flows or supplying specific flows to the river via a weir or dam, is informed by the planning phase and targets the objectives agreed upon by stakeholders. While flow implementation may fall to water agencies, within-year changes to flow management can be done with stakeholder involvement. Well-designed monitoring programs support adaptive management within the specific context of the program (Williams, 2011; Gawne et al., 2020). Monitoring programs present a unique opportunity for all stakeholders and the wider community to engage in data collection and learn about the hydro-social and ecological conditions of the river through hands-on experience, fostering multi-directional learning and a sense of environmental stewardship (Conallin et al., 2018a).

The learning phase (detail in third row of **Table 3**) is often ambiguously described in the literature on adaptive management, but it is acknowledged to be the crucial step for reengagement with the adaptive management cycle (Horne et al., 2017). We emphasize here that learning extends beyond updating the flow-ecology relationships and includes social and organizational learning as well through a focus on multi-loop learning with the inclusive involvement of all participants (Williams and Brown, 2018; McLoughlin et al., 2020). A key aspect of adaptive management is continued iterative learning through repeating the cycle, and a lack of repetition is often blamed for the failure of adaptive management projects (Biggs et al., 2011; Fernández-Giménez et al., 2019). Proper documentation and oversight can improve the chances of adaptive management success, ensuring that lessons learned are communicated to participants and the wider community and enabling learning within and between programs. This documentation and oversight can be carried out through a designated *Reflector* role within the program (see the fourth row of **Table 3**) (Webb et al., 2018).

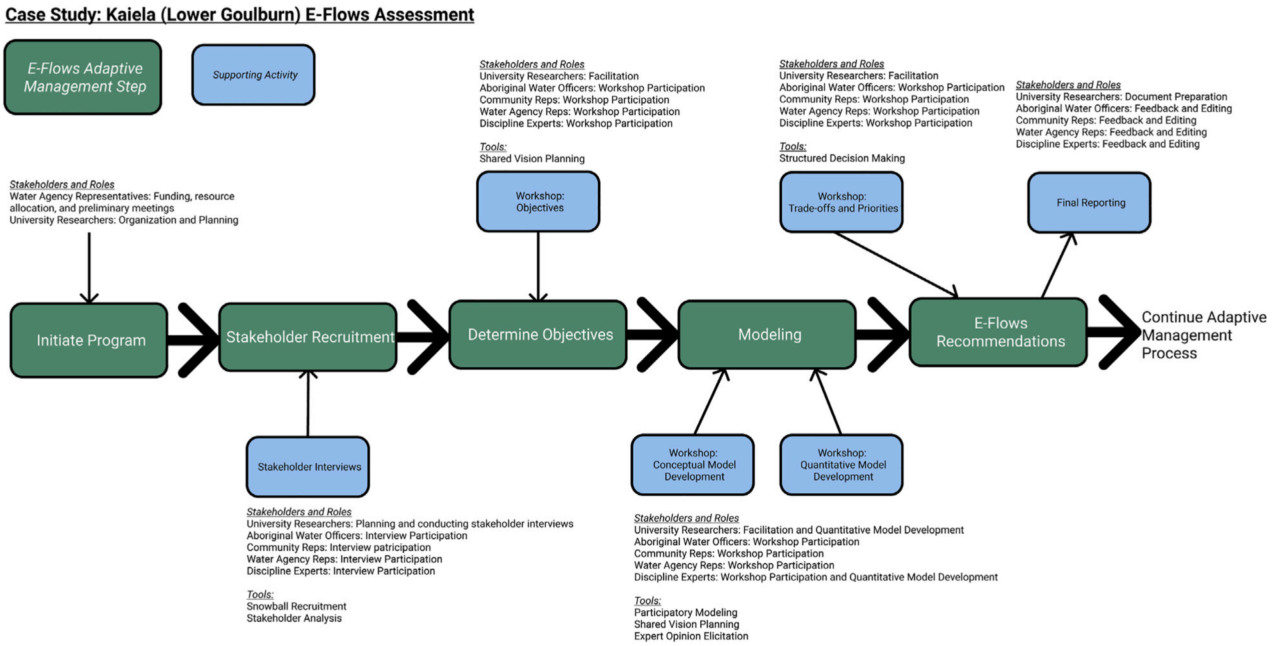

FIGURE 2 | Diagram showing the planning phase of an adaptive management cycle for e-flows management. The case presented here is an e-flows assessment for the Kaiela (Lower Goulburn) River in Northern Victoria, Australia. The boxes in green show the e-flows activities while the boxes in blue show the associated activities for these steps. The stakeholder roles and tools used are explained for each of these activities. While this process focused on the planning phase through an e-flows assessment, adaptive management is expected to continue through to doing and learning phases.

CASE STUDY: KAIELA (LOWER GOULBURN) E-FLOWS ASSESSMENT

To ground these concepts in a real-world application, the Kaiela E-flows Assessment is presented as a case study in **Figure 2** (further details are given in Horne et al., 2021 in this special issue). The Kaiela River is located within the contentious Murray-Darling basin in Australia, where over-allocation and significant drought has historically caused water scarcity and tension between water user groups. The Goulburn Catchment Management Authority (GBCMA) is responsible for local catchment management and e-flows planning. An environmental flows assessment was undertaken in 2019–20. A key focus for the GBCMA was placing a greater emphasis on stakeholder engagement and explicitly addressing the complexity and uncertainty around the context of e-flows management. For these reasons, this project was conceived within a wider process of adaptive management.

Figure 2 focuses on the planning portion of the adaptive management cycle, where most of the work for an e-flows assessment takes place. The University of Melbourne was engaged to facilitate and manage the e-flows assessment, but also played a dual role as scientists. The project focused on principles of participatory modeling when developing the project plan, shown through an emphasis on the modeling stage of the project. The project was developed around a series of participatory workshops that were attended by all stakeholders and designed to facilitate knowledge coproduction. Stakeholder participants for this project are detailed in **Table 1**. A panel of discipline experts was assembled to participate in all workshops and provide input to quantification of ecological models using a formal expert elicitation approach. Representatives from the different federal and state water agencies participated in the workshop series. **Figure 2** details when and how these stakeholder groups were involved in the planning stage of this adaptive management program.

This case study only shows the application of these concepts in the planning portion of the adaptive management cycle. The University of Melbourne team was only engaged for the purpose of conducting an e-flows assessment and has not been directly involved in implementation or monitoring. The GBCMA undertakes monitoring and iterative processes of planning and management outside the scope of the project presented here. Full case studies of the adaptive management cycle where iterative social learning cycles have been completed are difficult to demonstrate. This is due to the long time frames necessary for successful adaptive management and social learning. In contrast, university and government funding cycles for research and e-flows projects are often quite short. This challenge is explored further in the following discussion.

DISCUSSION

The framework we have proposed in this paper links participation to the already widely accepted concept of adaptive management of e-flows. It recognizes the inherent similarities between existing participatory methods and the adaptive management cycle. Making this connection serves a number of benefits, including allowing improved acknowledgement and addressing of uncertainty, allowing for multiple ways of knowing, and linking usually isolated "science" processes to the participatory approach. At the centre of the framework is the creation of a shared vision and transparent values to guide management activities. Allowing stakeholders to guide their own involvement and constantly reengaging with participants builds authentic relationships to support the management of catchments, creating credible e-flows programs that reflect the diversity of perspectives within the catchment. By incorporating a greater diversity of knowledge, including local and traditional knowledges, participatory-based management has the potential to generate a deeper understanding of the complex social-ecological system. Managers are currently tasked with balancing biophysical objectives of e-flows programs with social/cultural factors within the catchment. Our framework provides a platform to explore the myriad ways the biophysical and the social/cultural are interconnected, and creates space for difficult conversations, such as value prioritization and ecological vulnerabilities in a changing climate. Open and flexible participatory adaptive management allows us to create and test alternative management paradigms in a structured and documented way.

Within a participatory adaptive management framework, stakeholders can engage with the issue of uncertainty on multiple levels. Dealing with uncertainty is one of the primary reasons for utilizing an adaptive management approach, but it can often be difficult to discuss and contextualize what exactly is meant by uncertainty and to communicate ideas across stakeholder groups. Supporting transdisciplinary conversations allows us to come to a shared understanding of what uncertainty means within the system, how it may be quantified, and the best ways to address it. We also believe that involving a greater diversity of perspectives and creating a shared vision will foster greater resilience within e-flows programs, addressing multiple axes of uncertainty.

Including a structured engagement program as a fundamental component of e-flows management ensures relationships and trust are developed over the long term. This creates opportunities for the participants to reflect on shifting political tides and social sentiments over time. We believe that e-flows management can then be responsive to social and relational uncertainties, an element of uncertainty that is frequently overlooked in technically focused approaches. Open dialogue and collaborative knowledge production cultivate trust and allow the group to revise management elements over time, developing mechanisms to respond to changing conditions. This trust is also a crucial component of program legitimacy, wherein participants trust that the decision-making process is reflective of the group's shared values and emergency decisions can be made efficiently with limited dissent.

Reformulating the adaptive management framework to adequately integrate stakeholder engagement and community participation will require a significant cultural shift within the e-flows community of practice. While there has been an increasing recognition of the importance of stakeholder engagement in e-flows, most approaches still focus on technical solutions to physical problems without sufficiently considering the societal context of management. We suggest that there needs to be a balance between output driven technical solutions and socially based strategies focusing on long-term outcomes. Building lasting relationships between stakeholder groups within the context of adaptive management allows for flexible management that is responsive to the changing nature of social-ecological systems. Engagement with community members and other stakeholder groups ensures that management reflects the values of the community and utilizes a variety of knowledge sources and data.

We have advocated for increased involvement of Indigenous groups and for the reconsideration of their role in water management to acknowledge their traditional and ongoing relationship with land and water and potential to act as rightsholders. While we have not made specific recommendations here, we would like to draw attention to work already taking place on this issue. Cultural flows assessments, performed in combination with or parallel to an e-flows assessment, will help managers and Indigenous peoples understand the quantity and quality of water required to maintain spiritual, economic, cultural, social, and environmental needs of communities (MLDRIN, 2007; Lokgariwar et al., 2014; Jackson, 2017; Tipa and Associates Ltd., 2018). Another avenue for establishing Indigenous peoples as rightsholders is the creation of Indigenous partnerships for water management. Water is implicitly tied to economic development through consumptive and agricultural uses, and when Indigenous peoples are excluded from management conversations their communities are disenfranchised. Indigenous partnerships in the co-management of water will guarantee that Indigenous peoples have a say in development projects and empower their communities through forms of self-governance (Hemming et al., 2019; Mooney and Cullen, 2019; Markham et al., 2021).

We recognize that implementing an adaptive management framework centered on participatory methods will be a challenge for practitioners faced with real-world constraints and limitations. Significant obstacles are presented by resource and time availability. Short-term funding cycles and timelines limit the long-term planning necessary to foster authentic relationships between stakeholders. Pre-existing tensions and distrust between stakeholders can make initiating engagement difficult and increase the chances of conflict disrupting the process. Moreover, once an engagement process is underway, it can be derailed by stakeholder burnout and high turnover among participants. Dealing with the complexity presented by these challenges will require managers and facilitators to embrace a "messier" e-flows process than the linear, technocratic approaches they are used to. First and foremost, it is important for project organizers to be honest and transparent with participants about the goals of the project and the extent of engagement available in the process, particularly regarding influence over decision-making. Transparency is critical to aligning stakeholder expectations and fostering trust throughout the engagement process. Project managers should work with stakeholders to develop a flexible engagement plan that includes multiple types of participation and is responsive to shifting stakeholder needs, desires and capacity. Building engagement capacity and identifying process champions within all stakeholder groups will improve long-term project resilience.

It is important to keep in mind that a participatory adaptive management framework requires continuity. The engagement process does not end with one project, but constantly seeks to reengage and encourage stakeholder relationships with the e-flows program. Ensuring continuity throughout the life of an e-flows program fosters trust and encourages the development of program legitimacy. Structuring management approaches for long-term, multi-project engagement could transform e-flows management. Building capacity among Indigenous and community stakeholders for long-term participation, knowledge co-production, and shared decision making will allow for creative management approaches reflective of community values and character, and ultimately lead to the enduring success of e-flows programs.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors contributed to the discussion of the main concepts and structure of the paper. MM designed the framework and wrote the final manuscript with editing and contributions from AH, JW, and NP.

FUNDING

MM is funded through ARC Linkage project LP170100598. Avril Horne is funded through an ARC DECRA fellowship DE180100550. Much of the thinking for this paper occurred during an e-flows study for the Kaiela (Lower Goulburn River), Victoria, Australia funded by the Victorian Department of Environment, Land, Water and Planning.

ACKNOWLEDGMENTS

We thank the Goulburn Broken Catchment Management Authority and the community, Yorta Yorta and Taungurung representatives, management, and researcher stakeholders who engaged in the process. We would like to acknowledge the traditional and ongoing custodians of the land on which we work and live. We would like to recognize their continued connection to the natural environments that support and sustain our communities.

REFERENCES

Aceves-Bueno, E., Adeleye, A. S., Bradley, D., Tyler Brandt, W., Callery, P., Feraud, M., et al. (2015). Citizen Science as an Approach for Overcoming Insufficient Monitoring and Inadequate Stakeholder Buy-In in Adaptive Management: Criteria and Evidence. *Ecosystems* 18, 493–506. doi:10.1007/s10021-015-9842-4

Acreman, M. C., Overton, I. C., King, J., Wood, P. J., Cowx, I. G., Dunbar, M. J., et al. (2014). The Changing Role of Ecohydrological Science in Guiding Environmental Flows. *Hydrological Sci. J.* 59, 433–450. doi:10.1080/02626667.2014.886019

Allan, C., and Watts, R. J. (2018). Revealing Adaptive Management of Environmental Flows. *Environ. Manage.* 61, 520–533. doi:10.1007/s00267-017-0931-3

Anderson, E. P., Jackson, S., Tharme, R. E., Douglas, M., Flotemersch, J. E., Zwarteveen, M., et al. (2019). Understanding Rivers and Their Social Relations: A Critical Step to advance Environmental Water Management. *WIREs Water* 6, e1381. doi:10.1002/wat2.1381

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., and Patton, E. (2011). Co-management and the Co-production of Knowledge: Learning to Adapt in Canada's Arctic. *Glob. Environ. Change* 21, 995–1004. doi:10.1016/j.gloenvcha.2011.04.006

Arthington, A. H., Bhaduri, A., Bunn, S. E., Jackson, S. E., Tharme, R. E., Tickner, D., et al. (2018). The Brisbane Declaration and Global Action Agenda on Environmental Flows (2018). *Front. Environ. Sci.*, 6, 45. 15, pp. doi:10.3389/fenvs.2018.00045

Bakker, K. (2012). Water: Political, Biopolitical, Material. *Soc. Stud. Sci.* 42, 616–623. doi:10.1177/0306312712441396

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., and Giardino, A. (2017). Collaborative Modelling or Participatory Modelling? A Framework for Water Resources Management. *Environ. Model. Softw.* 91, 95–110. doi:10.1016/j.envsoft.2017.01.014

Biggs, H., Breen, C., Slotow, R., Freitag, S., and Hockings, M. (2011). How Assessment and Reflection Relate to More Effective Learning in Adaptive Management. *Koedoe* 53. doi:10.4102/koedoe.v53i2.1001

Brown, T. C., Taylor, J. G., and Shelby, B. (1991). Assessing the Direct Effects of Streamflow on Recreation: a Literature Review. *J. Am. Water Resour. Assoc* 27, 979–989. doi:10.1111/j.1752-1688.1991.tb03147.x

Brugnach, M., and Özerol, G. (2019). Knowledge Co-production and Transdisciplinarity: Opening Pandora's Box. *Water* 11, 1997. doi:10.3390/w11101997

Bunn, S. E., and Arthington, A. H. (2002). Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environ. Manage.* 30, 492–507. doi:10.1007/s00267-002-2737-0

Carr, G. (2015). Stakeholder and Public Participation in River basin Management-An Introduction. *WIREs Water* 2, 393–405. doi:10.1002/wat2.1086

Chen, Y.-s., Suchet-Pearson, S., and Howitt, R. (2018). Reframing Indigenous Water Rights in 'modern' Taiwan: Reflecting on Tayal Experience of Colonized Common Property. *Int. J. Commons* 12, 378–401. doi:10.18352/ijc.823

Clapcott, J., Ataria, J., Hepburn, C., Hikuroa, D., Jackson, A.-M., Kirikiri, R., et al. (2018). Mātauranga Māori: Shaping marine and Freshwater Futures. *New Zealand J. Mar. Freshw. Res.* 52, 457–466. doi:10.1080/00288330.2018.1539404

Conallin, J. C., Dickens, C., Hearne, D., and Allan, C. (2017). "Stakeholder Engagement in Environmental Water Management," in *Water for the Environment.* Editors A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman (Academic Press), 129–150. doi:10.1016/B978-0-12-803907-6.00007-3

Conallin, J., McLoughlin, C. A., Campbell, J., Knight, R., Bright, T., and Fisher, I. (2018a). Stakeholder Participation in Freshwater Monitoring and Evaluation Programs: Applying Thresholds of Potential Concern within Environmental Flows. *Environ. Manage.* 61, 408–420. doi:10.1007/s00267-017-0940-2

Conallin, J., Wilson, E., and Campbell, J. (2018b). Implementation of Environmental Flows for Intermittent River Systems: Adaptive Management and Stakeholder Participation Facilitate Implementation. *Environ. Manage.* 61, 497–505. doi:10.1007/s00267-017-0922-4

Connor, J., Cartwright, L., and Stephenson, K. (2012). Collaborative Water Supply Planning: A Shared Vision Approach for the Rappahannock Basin in Virginia. *Crit. Transitions Water Environ. Resour. Manage.*, 1–9. doi:10.1061/40737(2004)323

Cook, B. R., Kesby, M., Fazey, I., and Spray, C. (2013). The Persistence of 'normal' Catchment Management Despite the Participatory Turn: Exploring the Power Effects of Competing Frames of Reference. *Soc. Stud. Sci.* 43, 754–779. doi:10.1177/0306312713478670

Corner, A., Markowitz, E., and Pidgeon, N. (2014). Public Engagement with Climate Change: the Role of Human Values. *Wires Clim. Change* 5, 411–422. doi:10.1002/wcc.269

C. Pahl-Wostl, P. Kabat, and J. Möltgen (Editors) (2008). *Adaptive and Integrated Water Management: Coping with Complexity and Uncertainty* (Berlin Heidelberg: Springer-Verlag). doi:10.1007/978-3-540-75941-6

Crow, S. K., Tipa, G. T., Booker, D. J., and Nelson, K. D. (2018). Relationships between Maori Values and Streamflow: Tools for Incorporating Cultural Values into Freshwater Management Decisions. *New Zealand J. Mar. Freshw. Res.* 52, 626–642. doi:10.1080/00288330.2018.1499538

Cullen, P. (1990). The Turbulent Boundary between Water Science and Water Management. *Freshw. Biol* 24, 201–209. doi:10.1111/j.1365-2427.1990.tb00319.x

de Little, S. C., Casas-Mulet, R., Patulny, L., Wand, J., Miller, K. A., Fidler, F., et al. (2018). Minimising Biases in Expert Elicitations to Inform Environmental Management: Case Studies from Environmental Flows in Australia. *Environ. Model. Softw.* 100, 146–158. doi:10.1016/j.envsoft.2017.11.020

DeWeber, J. T., and Peterson, J. T. (2020). Comparing Environmental Flow Implementation Options with Structured Decision Making: Case Study from the Willamette River, Oregon. *J. Am. Water Resour. Assoc.* 56, 599–614. doi:10.1111/1752-1688.12845

Djenontin, I. N. S., and Meadow, A. M. (2018). The Art of Co-production of Knowledge in Environmental Sciences and Management: Lessons from International Practice. *Environ. Manage.* 61, 885–903. doi:10.1007/s00267-018-1028-3

Edelenbos, J., van Buuren, A., and van Schie, N. (2011). Co-producing Knowledge: Joint Knowledge Production between Experts, Bureaucrats and Stakeholders in Dutch Water Management Projects. *Environ. Sci. Pol.* 14, 675–684. doi:10.1016/j.envsci.2011.04.004

Esselman, P. C., and Opperman, J. J. (2010). Overcoming Information Limitations for the Prescription of an Environmental Flow Regime for a Central American River. *E&S* 15. doi:10.5751/ES-03058-150106

Failing, L., Gregory, R., and Higgins, P. (2013). Science, Uncertainty, and Values in Ecological Restoration: A Case Study in Structured Decision-Making and Adaptive Management. *Restor Ecol.* 21, 422–430. doi:10.1111/j.1526-100X.2012.00919.x

Falconi, S. M., and Palmer, R. N. (2017). An Interdisciplinary Framework for Participatory Modeling Design and Evaluation-What Makes Models Effective Participatory Decision Tools. *Water Resour. Res.* 53, 1625–1645. doi:10.1002/2016WR019373

Fernández-Giménez, M. E., Augustine, D. J., Porensky, L. M., Wilmer, H., Derner, J. D., Briske, D. D., et al. (2019). Complexity Fosters Learning in Collaborative Adaptive Management. *E&S* 24. doi:10.5751/ES-10963-240229

Finn, M., and Jackson, S. (2011). Protecting Indigenous Values in Water Management: A Challenge to Conventional Environmental Flow Assessments. *Ecosystems* 14, 1232–1248. doi:10.1007/s10021-011-9476-0

Fisher, J., Stutzman, H., Vedoveto, M., Delgado, D., Rivero, R., Quertehuari Dariquebe, W., et al. (2020). Collaborative Governance and Conflict Management: Lessons Learned and Good Practices from a Case Study in the Amazon Basin. *Soc. Nat. Resour.* 33, 538–553. doi:10.1080/08941920.2019.1620389

Fitzpatrick, P. (2006). In it Together: Organizational Learning through Participation in Environmental Assessment. *J. Env. Assmt. Pol. Mgmt.* 08, 157–182. doi:10.1142/s1464333206002463

Fujitani, M., McFall, A., Randler, C., and Arlinghaus, R. (2017). Participatory Adaptive Management Leads to Environmental Learning Outcomes Extending beyond the Sphere of Science. *Sci. Adv.* 3, e1602516. doi:10.1126/sciadv.1602516

Gawne, B., Hale, J., Stewardson, M. J., Webb, J. A., Ryder, D. S., Brooks, S. S., et al. (2020). Monitoring of Environmental Flow Outcomes in a Large River basin: The Commonwealth Environmental Water Holder's Long-term Intervention in the Murray-Darling Basin, Australia. *River Res. Applic* 36 (4), 630–644. doi:10.1002/rra.3504

Gearey, M., and Jeffrey, P. (2006). Concepts of Legitimacy within the Context of Adaptive Water Management Strategies. *Ecol. Econ.* 60, 129–137. doi:10.1016/j.ecolecon.2006.02.014

Gleick, P. H. (2000). A Look at Twenty-First Century Water Resources Development. *Water Int.* 25, 127–138. doi:10.1080/02508060008686804

Godden, L., and Ison, R. (2019). Community Participation: Exploring Legitimacy in Socio-Ecological Systems for Environmental Water Governance. *Australas. J. Water Resour.* 23, 45–57. doi:10.1080/13241583.2019.1608688

Goguen, G., Caissie, D., and El-Jabi, N. (2020). Uncertainties Associated with Environmental Flow Metrics. *River Res. Applic* 36, 1879–1890. doi:10.1002/rra.3716

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., and Ohlson, D. (2012). *Structured Decision Making: A Practical Guide to Environmental Management Choices*. John Wiley & Sons.

Guerrero, A. M., Shoo, L., Iacona, G., Standish, R. J., Catterall, C. P., Rumpff, L., et al. (2017). Using Structured Decision-making to Set Restoration Objectives when Multiple Values and Preferences Exist. *Restor Ecol.* 25, 858–865. doi:10.1111/rec.12591

Haddaway, N. R., Kohl, C., Rebelo da Silva, N., Schiemann, J., Spök, A., Stewart, R., et al. (2017). A Framework for Stakeholder Engagement during Systematic Reviews and Maps in Environmental Management. *Environ. Evid.* 6, 11. doi:10.1186/s13750-017-0089-8

Hadj-Hammou, J., Loiselle, S., Ophof, D., and Thornhill, I. (2017). Getting the Full Picture: Assessing the Complementarity of Citizen Science and agency Monitoring Data. *PLOS ONE* 12, e0188507. doi:10.1371/journal.pone.0188507

Haraway, D. (1988). Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. *Feminist Stud.* 14, 575–599. doi:10.2307/3178066

Hards, S. (2011). Social Practice and the Evolution of Personal Environmental Values. *Environ. Values* 20, 23–42. doi:10.3197/096327111x12922350165996

Hare, M. (2011). Forms of Participatory Modelling and its Potential for Widespread Adoption in the Water Sector. *Env. Pol. Gov.* 21, 386–402. doi:10.1002/eet.590

Hare, M., and Pahl-Wostl, C. (2002). Stakeholder Categorisation in Participatory Integrated Assessment Processes. Integrated Assessment 3. Available at: http://journals.sfu.ca/int_assess/index.php/iaj/article/view/95 (Accessed July 19, 2019).

Hare, M. P., Barreteau, O., Beck, M. B., Mostert, E., Tàbara, J. D., and Letcher, R. (2006). Methods for Stakeholder Participation in Water Management. Edward Elgar Publishing Available at: https://www.elgaronline.com/view/9781845427450.00017.xml (Accessed November 12, 2020).

Harrington, C. (2017). The Political Ontology of Collaborative Water Governance. *Water Int.* 42, 254–270. doi:10.1080/02508060.2017.1309507

Harwood, A. J., Tickner, D., Richter, B. D., Locke, A., Johnson, S., and Yu, X. (2018). Critical Factors for Water Policy to Enable Effective Environmental Flow Implementation. *Front. Environ. Sci.* 6. doi:10.3389/fenvs.2018.00037

Hemming, S., Rigney, D., Bignall, S., Berg, S., and Rigney, G. (2019). Indigenous Nation Building for Environmental Futures: Murrundi Flows through Ngarrindjeri Country. *Australasian J. Environ. Manage.* 26, 216–235. doi:10.1080/14486563.2019.1651227

Himes, A., and Muraca, B. (2018). Relational Values: the Key to Pluralistic Valuation of Ecosystem Services. *Curr. Opin. Environ. Sustainability* 35, 1–7. doi:10.1016/j.cosust.2018.09.005

HoglKvardaNordbeckand Pregernig (2012). Legitimacy and Effectiveness of Environmental Governance – Concepts and Perspectives : Environmental Governance. Environmental Governance: THe Challenge of Legitimacy and Effectiveness Available at: https://www.elgaronline.com/view/edcoll/9781849802703/9781849802703.00008.xml [Accessed July 15, 2020].

Holling, C. S. (1978). Adaptive Environmental Assessment and Management. John Wiley & Sons. Available at: http://pure.iiasa.ac.at/id/eprint/823/(Accessed February 16, 2020).

Holzkämper, A., Kumar, V., Surridge, B. W. J., Paetzold, A., and Lerner, D. N. (2012). Bringing Diverse Knowledge Sources Together - A Meta-Model for Supporting Integrated Catchment Management. *J. Environ. Manage.* 96, 116–127. doi:10.1016/j.jenvman.2011.10.016

Horne, A. C., Webb, J. A., O'Donnell, E., Arthington, A. H., McClain, M., Bond, N., et al. (2017). Research Priorities to Improve Future Environmental Water Outcomes. *Front. Environ. Sci.* 5. doi:10.3389/fenvs.2017.00089

Jackson, S. (2017). "How Much Water Does a Culture Need? Environmental Water Management's Cultural Challenge and Indigenous Responses," in *Water for the Environment* (Elsevier), 173–188. doi:10.1016/B978-0-12-803907-6.00009-7

Jackson, S., and Nias, D. (2019). Watering Country: Aboriginal Partnerships with Environmental Water Managers of the Murray-Darling Basin, Australia. *Australasian J. Environ. Manage.* 26, 287–303. doi:10.1080/14486563.2019.1644544

Jackson, S., Tan, P.-L., Mooney, C., Hoverman, S., and White, I. (2012). Principles and Guidelines for Good Practice in Indigenous Engagement in Water Planning. *Journal of Hydrology* 474, 57–65. doi:10.1016/j.jhydrol.2011.12.015

Jackson, S. (2018). Water and Indigenous Rights: Mechanisms and Pathways of Recognition, Representation, and Redistribution. *WIREs Water* 5, e1314. doi:10.1002/wat2.1314

Jager, N., Challies, E., Kochskämper, E., Newig, J., Benson, D., Blackstock, K., et al. (2016). Transforming European Water Governance? Participation and River Basin Management under the EU Water Framework Directive in 13 Member States. *Water* 8, 156. doi:10.3390/w8040156

Jain, S. K. (2012). Assessment of Environmental Flow Requirements. *Hydrol. Process.* 26, 3472–3476. doi:10.1002/hyp.9455

Kaushal, N., Babu, S., Mishra, A., Ghosh, N., Tare, V., Kumar, R., et al. (2019). Towards a Healthy Ganga-Improving River Flows through Understanding Trade Offs. *Front. Environ. Sci.* 7, 83. doi:10.3389/fenvs.2019.00083

Kendal, D., and Raymond, C. M. (2019). Understanding Pathways to Shifting People's Values over Time in the Context of Social-Ecological Systems. *Sustain. Sci.* 14, 1333–1342. doi:10.1007/s11625-018-0648-0

Kennedy, J. J., and Koch, N. E. (2004). Viewing and Managing Natural Resources as Human-Ecosystem Relationships. *For. Pol. Econ.* 6, 497–504. doi:10.1016/j.forpol.2004.01.002

King, J., Brown, C., and Sabet, H. (2003). A Scenario-Based Holistic Approach to Environmental Flow Assessments for Rivers. *River Res. Applic.* 19, 619–639. doi:10.1002/rra.709

King, J., and Louw, D. (1998). Instream Flow Assessments for Regulated Rivers in South Africa Using the Building Block Methodology. *Aquat. Ecosystem Health Manage.* 1, 109–124. doi:10.1080/14634989808656909

Kingsford, R. T., Roux, D. J., McLoughlin, C. A., Conallin, J., and Norris, V. (2017). "Strategic Adaptive Management (SAM) of Intermittent Rivers and Ephemeral Streams," in *Intermittent Rivers and Ephemeral Streams*. Editors T. Datry, N. Bonada, and A. Boulton (Academic Press), 535–562. doi:10.1016/B978-0-12-803835-2.00021-8

Kosovac, A., and Davidson, B. (2020). Is Too Much Personal Dread Stifling Alternative Pathways to Improving Urban Water Security. *J. Environ. Manage.* 265, 110496. doi:10.1016/j.jenvman.2020.110496

Kunler, L., and Lemos, M. (2008). Managing Waters of the Paraíba Do Sul River Basin, Brazil. *Ecology And Society* 13. Available at: https://www.jstor.org/stable/26267967?seq=1#metadata_info_tab_contents [Accessed February 25, 2021].

Latta, A. (2018). Indigenous Rights and Multilevel Governance: Learning from the Northwest Territories Water Stewardship Strategy. *iipj* 9. doi:10.18584/iipj.2018.9.2.4

Le Quesne, T., Kennedy, E., and Weston, D. (2010). The Implementation Challenge: Taking Stock of Government Policies to Protect and Restore Environmental Flows. World Wide Fund For Nature (WWF) Available at: https://wwfeu.awsassets.panda.org/downloads/the_implementation_challenge.pdf [Accessed October 20, 2020].

Linton, J., and Budds, J. (2014). The Hydrosocial Cycle: Defining and Mobilizing a Relational-Dialectical Approach to Water. *Geoforum* 57, 170–180. doi:10.1016/j.geoforum.2013.10.008

Lokgariwar, C., Chopra, R., Smakhtin, V., Bharati, L., and O'Keeffe, J. (2014). Including Cultural Water Requirements in Environmental Flow Assessment: an Example from the Upper Ganga River, India. *Water Int.* 39, 81–96. doi:10.1080/02508060.2013.863684

Lumosi, C. K., Pahl-Wostl, C., and Scholz, G. (2019). Can 'learning Spaces' Shape Transboundary Management Processes? Evaluating Emergent Social Learning Processes in the Zambezi basin. *Environ. Sci. Pol.* 97, 67–77. doi:10.1016/j.envsci.2019.04.005

Lynch, D. T., Leasure, D. R., and Magoulick, D. D. (2018). The Influence of Drought on Flow-Ecology Relationships in Ozark Highland Streams. *Freshw. Biol.* 63, 946–968. doi:10.1111/fwb.13089

Macpherson, E. J. (2019). *Indigenous Water Rights in Law and Regulation: Lessons from Comparative Experience*. Cambridge: Cambridge University Press. doi:10.1017/9781108611091

Magdaleno, F. (2018). Flows, Ecology and People: Is There Room for Cultural Demands in the Assessment of Environmental Flows. *Water Sci. Tech.* 77, 1777–1781. doi:10.2166/wst.2018.075

Maldonado, A. D., Morales, M., Aguilera, P. A., and Salmerón, A. (2020). Analyzing Uncertainty in Complex Socio-Ecological Networks. *Entropy* 22, 123. doi:10.3390/e22010123

Mandel, D. R., and Tetlock, P. E. (2016). Debunking the Myth of Value-Neutral Virginity: Toward Truth in Scientific Advertising. *Front. Psychol.* 7. doi:10.3389/fpsyg.2016.00451

2021 Markham, F., Hooper, F., Rigney, G., Hartwig, L. D., Woods, R., and Jackson, S. Water Injustice Runs Deep in Australia. Fixing it means handing control to First Nations. *The Conversation*. Available at: http://theconversation.com/water-injustice-runs-deep-in-australia-fixing-it-means-handing-control-to-first-nations-155286 [Accessed February 28, 2021].

Martin, D. M., Labadie, J. W., and Poff, N. L. (2015). Incorporating Social Preferences into the Ecological Limits of Hydrologic Alteration (ELOHA): a Case Study in the Yampa-White River basin, Colorado. *Freshw. Biol.* 60, 1890–1900. doi:10.1111/fwb.12619

Matos, C. G. de. (2015). Whose Knowledge? Reflecting on the Plurality of Knowledge Production in Contentious Politics. *DIE ERDE – J. Geographical Soc. Berlin* 146, 175–188. doi:10.12854/erde-146-15

McLoughlin, C. A., Deacon, A., Sithole, H., and Gyedu-Ababio, T. (2011). History, Rationale, and Lessons Learned: Thresholds of Potential Concern in Kruger National Park River Adaptive Management. *Koedoe* 53. doi:10.4102/koedoe.v53i2.996

McLoughlin, C. A., Thoms, M. C., and Parsons, M. (2020). Reflexive Learning in Adaptive Management: A Case Study of Environmental Water Management in the Murray Darling Basin, Australia. *River Res. Applic* 36, 681–694. doi:10.1002/rra.3607

McLoughlin, C., Thoms, M., Marshall, G., and Parsons, M. (2016). Reflexive Learning in the Practice of Adaptive Freshwater Management. Available at: https://rune.une.edu.au/web/handle/1959.11/27601 [Accessed July 16, 2020].

Memon, P. A., and Kirk, N. (2012). Role of Indigenous Māori People in Collaborative Water Governance in Aotearoa/New Zealand. *J. Environ. Plann. Manage.* 55, 941–959. doi:10.1080/09640568.2011.634577

Miller, T. R., Baird, T. D., Littlefield, C. M., Kofinas, G., Chapin III, F. S., III, and Redman, C. L. (2008). Epistemological Pluralism: Reorganizing Interdisciplinary Research. *E&S* 13. doi:10.5751/ES-02671-130246

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., et al. (2008). Stationarity Is Dead: Whither Water Management. *Science* 319, 573–574. doi:10.1126/science.1151915

MLDRIN (2007). *Echuca Declaration*.

Moellenkamp, S., Lamers, M. a. J., Huesmann, C., Rotter, S., Pahl-Wostl, C., Speil, K., et al. (2010). Informal Participatory Platforms for Adaptive Management. Insights into Niche-Finding, Collaborative Design and Outcomes from a Participatory Process in Te Rhine Basin. *Ecol. Soc.* 15, 41. doi:10.5751/es-03588-150441

Moggridge, B. J., Betterridge, L., and Thompson, R. M. (2019). Integrating Aboriginal Cultural Values into Water Planning: a Case Study from New South Wales, Australia. *Australasian J. Environ. Manage.* 26, 273–286. doi:10.1080/14486563.2019.1650837

Mooney, W., and Cullen, A. (2019). Implementing the Aboriginal Waterways Assessment Tool: Collaborations to Engage and Empower First Nations in Waterway Management. *Australasian J. Environ. Manage.* 26, 197–215. doi:10.1080/14486563.2019.1645752

Nania, J., and Guarino, J. (2014). *Restoring Sacred Waters: A Guide to Protecting Tribal Non-consumptive Water Uses in the Colorado River Basin*. Boulder: University of Colorado. Getches-Wilkinson Center for Natural Resources, Energy, and the Environment Available at: https://scholar.law.colorado.edu/books_reports_studies/1.

Nel, J. L., Roux, D. J., Driver, A., Hill, L., Maherry, A. C., Snaddon, K., et al. (2016). Knowledge Co-production and Boundary Work to Promote Implementation of Conservation Plans. *Conservation Biol.* 30, 176–188. doi:10.1111/cobi.12560

Norman, E. S. (2018). Toward a Global Water Ethic: Learning from Indigenous Communities. *Ethics Int. Aff.* 32, 237–247. doi:10.1017/S0892679418000333

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., et al. (2020). Principles for Knowledge Co-production in Sustainability Research. *Nat. Sustain.* 3, 182–190. doi:10.1038/s41893-019-0448-2

O'Donnell, E. L., and Garrick, D. E. (2017). "Chapter 26 - Defining Success: A Multicriteria Approach to Guide Evaluation and Investment," in *Water for the Environment*. Editors A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman (Academic Press), 625–645. doi:10.1016/B978-0-12-803907-6.00026-7

O'Donnell, E. L., Horne, A. C., Godden, L., and Head, B. (2019). Cry Me a River: Building Trust and Maintaining Legitimacy in Environmental Flows. *Australas. J. Water Resour.* 23, 1–13. doi:10.1080/13241583.2019.1586058

O'Keefe, J., Kaushal, N., Bharati, L., and Smakhtin, V. (2012). *Assessment of Environmental Flows for the Upper Ganga Basin*. New Delhi, India: World Wide Fund for Nature- India. (WWF-India) Available at: https://www.wwfindia.org/?7420/Assessment-of-Environmental-Flows-for-the-Upper-Ganga-Basin (Accessed October 13, 2021).

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325, 419–422. doi:10.1126/science.1172133

Pahl-Wostl, C., Arthington, A., Bogardi, J., Bunn, S. E., Hoff, H., Lebel, L., et al. (2013). Environmental Flows and Water Governance: Managing Sustainable Water Uses. *Curr. Opin. Environ. Sustainability* 5, 341–351. doi:10.1016/j.cosust.2013.06.009

Pahl-Wostl, C. (2006). The Importance of Social Learning in Restoring the Multifunctionality of Rivers and Floodplains. *E&S* 11. doi:10.5751/ES-01542-110110

Palmer, R. N., Cardwell, H. E., Lorie, M. A., and Werick, W. (2013). Disciplined Planning, Structured Participation, and Collaborative Modeling - Applying Shared Vision Planning to Water Resources. *J. Am. Water Resour. Assoc.* 49, 614–628. doi:10.1111/jawr.12067

Perreault, T. (2014). What Kind of Governance for what Kind of Equity? towards a Theorization of justice in Water Governance. *Water Int.* 39, 233–245. doi:10.1080/02508060.2014.886843

Petersen, B., Montambault, J., and Koopman, M. (2014). The Potential for Double-Loop Learning to Enable Landscape Conservation Efforts. *Environ. Manage.* 54, 782–794. doi:10.1007/s00267-014-0337-4

Pirsoul, N., and Armoudian, M. (2019). Deliberative Democracy and Water Management in New Zealand: a Critical Approach to Collaborative Governance and Co-management Initiatives. *Water Resour. Manage.* 33, 4821–4834. doi:10.1007/s11269-019-02400-x

Poff, N. L. (2018). Beyond the Natural Flow Regime? Broadening the Hydro-Ecological Foundation to Meet Environmental Flows Challenges in a Non-stationary World. *Freshw. Biol.* 63, 1011–1021. doi:10.1111/fwb.13038

Poff, N. L., and Matthews, J. H. (2013). Environmental Flows in the Anthropocence: Past Progress and Future Prospects. *Curr. Opin. Environ. Sustainability* 5, 667–675. doi:10.1016/j.cosust.2013.11.006

Poff, N. L., Richter, B. D., Arthington, A. H., Bunn, S. E., Naiman, R. J., Kendy, E., et al. (2010). The Ecological Limits of Hydrologic Alteration (ELOHA): a New Framework for Developing Regional Environmental Flow Standards. *Freshw. Biol.* 55, 147–170. doi:10.1111/j.1365-2427.2009.02204.x

Poff, N. L., Tharme, R. E., and Arthington, A. H. (2017). "Chapter 11 - Evolution of Environmental Flows Assessment Science, Principles, and Methodologies," in *Water for the Environment*. Editors A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman (Academic Press), 203–236. doi:10.1016/B978-0-12-803907-6.00011-5

Pomart, P. N. (2020). Reframing Indigenous Peoples from Stakeholders to Rightsholders. *Proceedings* 2020, 20874. doi:10.5465/AMBPP.2020.20874abstract

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., and Evely, A. C. (2010). Integrating Local and Scientific Knowledge for Environmental Management. *J. Environ. Manage.* 91, 1766–1777. doi:10.1016/j.jenvman.2010.03.023

Reed, G., Brunet, N. D., and Natcher, D. C. (2020). Can Indigenous Community-Based Monitoring Act as a Tool for Sustainable Self-Determination. *The Extractive Industries and Society* 7, 1283–1291. doi:10.1016/j.exis.2020.04.006

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., et al. (2009). Who's in and Why? A Typology of Stakeholder Analysis Methods for Natural Resource Management. *J. Environ. Manage.* 90, 1933–1949. doi:10.1016/j.jenvman.2009.01.001

Reed, M. S. (2008). Stakeholder Participation for Environmental Management: A Literature Review. *Biological Conservation* 141, 2417–2431. doi:10.1016/j.biocon.2008.07.014

Reyers, B., Nel, J. L., O'Farrell, P. J., Sitas, N., and Nel, D. C. (2015). Navigating Complexity through Knowledge Coproduction: Mainstreaming Ecosystem Services into Disaster Risk Reduction. *Proc. Natl. Acad. Sci. USA* 112, 7362–7368. doi:10.1073/pnas.1414374112

Robles-Morua, A., Halvorsen, K. E., Mayer, A. S., and Vivoni, E. R. (2014). Exploring the Application of Participatory Modeling Approaches in the Sonora River Basin, Mexico. *Environ. Model. Softw.* 52, 273–282. doi:10.1016/j.envsoft.2013.10.006

Rosendahl, J., Zanella, M. A., Rist, S., and Weigelt, J. (2015). Scientists' Situated Knowledge: Strong Objectivity in Transdisciplinarity. *Futures* 65, 17–27. doi:10.1016/j.futures.2014.10.011

Ross, A., and Chang, H. (2020). Socio-hydrology with Hydrosocial Theory: Two Sides of the Same coin. *Hydrological Sci. J.* 65, 1443–1457. doi:10.1080/02626667.2020.1761023

Roux, D. J., and Foxcroft, L. C. (2011). The Development and Application of Strategic Adaptive Management within South African National Parks. *Koedoe* 53, 01–05. doi:10.4102/koedoe.v53i2.1049

Stefanelli, R. D., Castleden, H., Harper, S. L., Martin, D., Cunsolo, A., and Hart, C. (2017). Experiences with Integrative Indigenous and Western Knowledge in Water Research and Management: a Systematic Realist Review of Literature from Canada, Australia, New Zealand, and the United States. *Environ. Rev.* 25, 323–333. doi:10.1139/er-2016-0114

Stem, C., Margoluis, R., Salafsky, N., and Brown, M. (2005). Monitoring and Evaluation in Conservation: a Review of Trends and Approaches. *Conservation Biol.* 19, 295–309. doi:10.1111/j.1523-1739.2005.00594.x

Stewardson, M., and Rutherfurd, I. (2006). Quantifying Uncertainty in Environmental Flow Assessments. *Australas. J. Water Resour.* 10, 151–159. doi:10.1080/13241583.2006.11465288

Stewardson, M., and Webb, J. A. (2010). "Modelling Ecological Responses to Flow Alteration: Making the Most of Existing Data and Knowledge," in *Ecosystem Response Modelling in the Murray-Darling Basin*, 37–49.

Steyaert, P., and Jiggins, J. (2007). Governance of Complex Environmental Situations through Social Learning: a Synthesis of SLIM's Lessons for Research, Policy and Practice. *Environ. Sci. Pol.* 10, 575–586. doi:10.1016/j.envsci.2007.01.011

Stoll-Kleemann, S., and Welp, M. (2006). "Towards a More Effective and Democratic Natural Resources Management," in *Stakeholder Dialogues in Natural Resources Management: Theory and Practice Environmental Science and Engineering*. Editors S. Stollkleemann and M. Welp (Berlin, Heidelberg: Springer), 17–39. doi:10.1007/978-3-540-36917-2_2

Stringer, L. C., Dougill, A. J., Fraser, E., Hubacek, K., Prell, C., and Reed, M. S. (2006). Unpacking "Participation" in the Adaptive Management of Social–Ecological Systems: a Critical Review. *E&S* 11. doi:10.5751/ES-01896-110239

Tennant, D. L. (1976). Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources. *Fisheries* 1, 6–10. doi:10.1577/1548-8446(1976)001<0006:ifrffw>2.0.co;2

Tharme, R. E. (2003). A Global Perspective on Environmental Flow Assessment: Emerging Trends in the Development and Application of Environmental Flow Methodologies for Rivers. *River Res. Applic.* 19, 397–441. doi:10.1002/rra.736

ThompsonLaizé, J. R., LaizéAcreman, C. L. R., Green, A. J., Acreman, M. C., and Kingston, D. G. (2014). Climate Change Uncertainty in Environmental Flows for the Mekong River. *Hydrological Sci. J.* 59, 935–954. doi:10.1080/02626667.2013.842074

Tipa and Associates Ltd (2018). *Guidelines for Undertaking a Cultural Flows Preference Study*.

Tipa, G., and Nelson, K. (2008). Introducing Cultural Opportunities: a Framework for Incorporating Cultural Perspectives in Contemporary Resource Management. *J. Environ. Pol. Plann.* 10, 313–337. doi:10.1080/15239080802529472

United Nations Declaration on the Rights of Indigenous Peoples (2008). United Nations Declaration on the Rights of Indigenous Peoples. Available at: http://www.un.org/esa/socdev/unpfii/documents/DRIPS_en.pdf.

van Buuren, A., Klijn, E.-H., and Edelenbos, J. (2012). Democratic Legitimacy of New Forms of Water Management in the Netherlands. *Int. J. Water Resour. Dev.* 28, 629–645. doi:10.1080/07900627.2011.627756

van der Molen, F. (2018). How Knowledge Enables Governance: The Coproduction of Environmental Governance Capacity. *Environ. Sci. Pol.* 87, 18–25. doi:10.1016/j.envsci.2018.05.016

Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P. D., Bommel, P., et al. (2018). Tools and Methods in Participatory Modeling: Selecting the Right Tool for the Job. *Environ. Model. Softw.* 109, 232–255. doi:10.1016/j.envsoft.2018.08.028

von der Porten, S., and de Loë, R. C. (2013). Collaborative Approaches to Governance for Water and Indigenous Peoples: A Case Study from British

Columbia, Canada. *Geoforum* 50, 149–160. doi:10.1016/j.geoforum.2013.09.001

Wantzen, K. M., Ballouche, A., Longuet, I., Bao, I., Bocoum, H., Cissé, L., et al. (2016). River Culture: an Eco-Social Approach to Mitigate the Biological and Cultural Diversity Crisis in Riverscapes. *Ecohydrology & Hydrobiology* 16, 7–18. doi:10.1016/j.ecohyd.2015.12.003

Watts, R. J., Dyer, F., Frazier, P., Gawne, B., Marsh, P., Ryder, D. S., et al. (2020). Learning from Concurrent Adaptive Management in Multiple Catchments within a Large Environmental Flows Program in Australia. *River Res. Applic* 36, 668–680. doi:10.1002/rra.3620

Webb, J. A., Stewardson, M. J., Chee, Y. E., Schreiber, E. S. G., Sharpe, A. K., and Jensz, M. C. (2010). Negotiating the Turbulent Boundary: the Challenges of Building a Science - Management Collaboration for Landscape-Scale Monitoring of Environmental Flows. *Mar. Freshw. Res.* 61, 798–807. doi:10.1071/MF09059

Webb, J. A., Watts, R. J., Allan, C., and Conallin, J. C. (2018). Adaptive Management of Environmental Flows. *Environ. Manage.* 61, 339–346. doi:10.1007/s00267-017-0981-6

Webb, J. A., Watts, R. J., Allan, C., and Warner, A. T. (2017). "Chapter 25 - Principles for Monitoring, Evaluation, and Adaptive Management of Environmental Water Regimes," in *Water for the Environment*. Editors A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman (Academic Press), 599–623. doi:10.1016/B978-0-12-803907-6.00025-5

Wesselink, A., Kooy, M., and Warner, J. (2017). Socio-hydrology and Hydrosocial Analysis: toward Dialogues across Disciplines. *WIREs Water* 4, e1196. doi:10.1002/wat2.1196

Williams, B. K. (2011). Adaptive Management of Natural Resources-Framework and Issues. *J. Environ. Manage.* 92, 1346–1353. doi:10.1016/j.jenvman.2010.10.041

Williams, B. K., and Brown, E. D. (2018). Double-Loop Learning in Adaptive Management: The Need, the Challenge, and the Opportunity. *Environ. Manage.* 62, 995–1006. doi:10.1007/s00267-018-1107-5

Wilson, N. J. (2014). Indigenous Water Governance: Insights from the Hydrosocial Relations of the Koyukon Athabascan Village of Ruby, Alaska. *Geoforum* 57, 1–11. doi:10.1016/j.geoforum.2014.08.005

Wilson, N. J., Mutter, E., Inkster, J., and Satterfield, T. (2018). Community-Based Monitoring as the Practice of Indigenous Governance: A Case Study of Indigenous-Led Water Quality Monitoring in the Yukon River Basin. *J. Environ. Manage.* 210, 290–298. doi:10.1016/j.jenvman.2018.01.020

Wolsko, C. (2017). Expanding the Range of Environmental Values: Political Orientation, Moral Foundations, and the Common Ingroup. *Journal of Environmental Psychology* 51, 284–294. doi:10.1016/j.jenvp.2017.04.005

Woodward, E., and Marrfurra McTaggart, P. (2016). Transforming Cross-Cultural Water Research through Trust, Participation and Place. *Geographical Res.* 54, 129–142. doi:10.1111/1745-5871.12136

Wyborn, C. A. (2015). Connecting Knowledge with Action through Coproductive Capacities: Adaptive Governance and Connectivity Conservation. *Ecol. Soc.* 20. doi:10.5751/es-06510-200111

Yamamoto, Y. T. (2012). Values, Objectivity and Credibility of Scientists in a Contentious Natural Resource Debate. *Public Underst Sci.* 21, 101–125. doi:10.1177/0963662510371435

Young, J. C., Thompson, D. B. A., Moore, P., MacGugan, A., Watt, A., and Redpath, S. M. (2016). A Conflict Management Tool for Conservation Agencies. *J. Appl. Ecol.* 53, 705–711. doi:10.1111/1365-2664.12612

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling editor is currently organizing a Research Topic with one of the authors AH.