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The Logics and Politics of Environmental Flows - A Review

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ABSTRACT: Environmental flows (or Eflows) refer to water that is allocated to the environment through the deliberate release of stored water or planned allocations. Since the late 20th century, Eflows have become increasingly influential in water policy. Over several decades, the research, policy and practice of Eflows has broadened from addressing flow requirements of specific river reaches or the needs of significant species such as salmon, to a broader focus on integrated strategies that aim to sustain rivers' diverse values. Eflow research has generated an extensive literature that is focused on the scientific and sociopolitical dimensions of managing river flows. We examine this literature critically, tracing the development, application and expansion of Eflows and exploring the shifting norms, framings and assumptions that underpin their theory and practice, including contestations about policy decisions. Our analysis indicates that the politics of environmental flows refracts socially constructed and contested views about nature and river systems and raises fundamental questions about how decisions are made and who decides. While there is a tendency to try to depoliticise Eflows by rendering decisions technical, we argue that, like all water allocation decisions and all water science, Eflows involve sociopolitical contestations about the control of rivers. These contestations are fundamentally about who has the power to make decisions on allocating water and what beliefs, worldviews and frameworks guide these decisions. We conclude that recognising the value-laden character of Eflows research and practice is an essential step towards recognising the value-laden character of river science and management. To achieve more equitable negotiations on deciding how rivers are managed, we argue for an explicit recognition of the political dimensions of Eflows, including a greater awareness of the cultural and ontological politics involved.

KEYWORDS: Environmental flows, ecological flows, adaptive governance, nature-culture ontologies, rivers

INTRODUCTION

Environmental or ecological flows, or Eflows, are the focus of an extensive academic and grey literature. Most Eflows research is located in the natural sciences, particularly hydrology, ecology and ecohydrology that focuses on the scientific and technical dimensions of understanding, assessing and managing rivers and their flows. There is also a growing social sciences literature on Eflows, which explores the cultural, social, legal and policy complexities of governing rivers. This interpretive review does not attempt a comprehensive assessment of all research on Eflows; instead, it outlines the shifting norms, framings and key assumptions that are involved.

We begin in Section 2 with a brief history of Eflows that traces their emergence and growth in importance in contemporary water management and policy. We note that this growth occurred mainly over the last four decades – the span of a single working life. Section 3 outlines the main paradigms underpinning Eflows science, policy and practice – the natural flows and ecosystem management paradigms. Section 4 examines the main rationales and challenges for Eflows, while Section 5 explores some reasons why there is an abundance of methods, approaches and techniques for Eflows assessment and evaluation. Section 6 looks at the tensions involved in the different ontologies and contested politics of Eflows. This is followed by our conclusions.

BACKGROUND – A BRIEF HISTORY OF EFLOWS

Four decades of environmental flows

Eflows became increasingly influential in water policy, theory, practice and scholarship during the late 20th and early 21st centuries (Dyson et al., 2003; Hirji and Davis, 2009; Arthington, 2022). Over the last four decades, the idea of Eflows has broadened from a relatively narrow focus; addressing the habitat needs of significant species such as salmon or providing flows to specific river reaches or wetlands, to a broader focus on sustaining riverine systems' diverse values (Poff and Matthews, 2013; O'Brien et al., 2018; Arthington et al., 2018; Anderson et al., 2019).

Over these decades, concepts and techniques have evolved and methods have diversified in scope, impact and application (Tharme, 2003; Poff and Matthews, 2013; Acreman et al., 2014a; Opperman et al., 2018). Eflows are formalised in many countries' laws, policies and strategies (Acreman et al., 2014b). Internationally, they feature in agreements of the European Union (EC 2016) and the Conference of the Parties to the Convention on Biological Diversity.[1] With greater legal recognition, challenges have shifted from getting Eflows onto the policy agenda to implementing and evaluating policy and practice (Wineland et al., 2022). With implementation, awareness of the complexity of riverine systems has grown, as has awareness of the sociopolitics of allocating and managing environmental water (Acreman et al., 2014a; Anderson et al., 2019; Wineland et al., 2022).

A broad international consensus on the importance of Eflows is articulated in the Brisbane Declaration, which was crafted at the River Symposium in Brisbane, Australia in 2007 and revised in 2017 (River Symposium, 2007; Arthington et al., 2018). This statement emphasises the significance of Eflows for biodiversity conservation, human welfare and ecosystem health. The Declaration defines Eflows as, "the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being" (River Symposium, 2018). The 2018 Declaration includes an Action Agenda of 35 recommendations to support Eflows through legislation, programmes and research; these emphasise diverse partnerships, participation and respect for cultural diversity.

[1] The Conference of the Parties to the Convention on Biological Diversity at its seventh meeting in Kuala Lumpur in 2004 adopted the following decisions on biological diversity of inland water ecosystems: "At appropriate levels (regional, national, subnational and local), encourage the identification of stressed inland waters, the allocation and reservation of water for the maintenance of ecosystem functions, and the maintenance of environmental flows as an integral component of appropriate legal, administrative and economic mechanisms", and, "For transboundary inland water ecosystems, undertake, where feasible and appropriate and by agreement between the Parties concerned, collaborative impact and environmental flow assessments when applying the Convention's guidelines for incorporating biodiversity-related issues into environmental impact assessment legislation and/or processes and in strategic environmental assessment".

Origins of the Eflows discourse

The origins of the Eflows discourse can be found in the broader environmentalism of the late 1970s and early 1980s when conservation movements mobilised against the excesses of industrialisation (Hajer, 1996; Dryzek, 2021). As the deleterious environmental impacts of large dams became more widely recognised, efforts increased to constrain the relentless damming and industrial development of rivers (Kellow, 1989; Graf, 1999; WCD, 2000; Moore et al., 2010). Associated efforts to restore riverine environments included the provision of Eflows, both operationally and legally (Tharme, 2003; Dyson et al., 2003). Initially, many Eflows were compensation flows to rivers that were directly affected by dams (Arasteh, 2005; Poff and Matthews, 2013). Adversely affected communities downstream of major dams and inter-basin diversion projects, such as Australia's Snowy Mountains Scheme, advocated for the restoration of flows based on claims about environmental and social justice (Erskine et al., 1999; Alexandra and Rickards, 2021). International organisations, such as the Nature Conservancy and the International Union for Conservation of Nature (IUCN), also campaigned for the formal adoption of Eflows (Dyson et al., 2003; Richter et al., 2003, 2006.

The no-dams movement and free-flowing rivers

Pivotal events that helped reinforce the need for a new deal for rivers included the disastrous chemical pollution of the Rhine in 1986 (Schwabach, 1989; Giger, 2009), and the public campaigns to reverse decisions to construct the Gordon-below-Franklin Dam in Tasmania, Australia (Kellow, 1989) and the Loyettes Dam on the Rhône in France (Mertha and Lowry, 2006; Flaminio, 2021). The success of these campaigns gave rise to the no-dams movement, energising its mission to protect 'wild' free-flowing rivers from further dams (Kellow, 1989). Generally, the ideal of protecting and restoring rivers became more firmly rooted in the body politic.

Eflows, Integrated Water Resources Management, and the World Commission on Dams

During the 20th century, water's productive powers were harnessed extensively for agricultural and industrial development and to advance the foreign policy objectives of powerful states (Linton and Budds, 2014; Schmidt, 2017). In many countries, water resource developments were a manifestation of iconic nation-building that reinforced established political regimes (Swyngedouw and Boelens, 2018). Large dams are assemblages of concrete, steel, technology and politics that demonstrate the power of nation states over nature became symbols of modernisation and progress (Sneddon, 2015; Swyngedouw and Boelens, 2018; Menga and Swyngedouw, 2018). Large-scale hydro-economic development dominated many of the world's rivers (Grill et al., 2019) and spawned influential technocratic elites whose power relies on controlling water and water policies (Molle et al., 2009).

Late in the 20th century, the environmental turn challenged this dominance, legitimising broader definitions of water's values and emphasising the need to manage water for multiple social and environmental outcomes. Attending to environmental concerns became central to Integrated Water Resources Management (IWRM) – a framework that was widely promoted as a panacea for the late 20th century's water problems (Molle, 2009; Schmidt, 2017). The rise of Eflows can be seen as a marker of the transition from hydro-developmentalism (Mercer et al., 2007; Linton, 2014) to IWRM with its attempts at more carefully balancing economic, environmental and social concerns (GWP, 2004; Schmidt, 2017; Overton et al., 2014).

In the last decades of the 20th century, a crisis of confidence in the dam-building mission led to the World Commission on Dams (WCD). Using consensus-based processes, the WCD developed guidelines that were intended to reduce or mitigate the harmful social and environmental consequences of new dams (Moore et al., 2010). The WCD report, published in 2000, articulates the changing sentiments about large dams; it states that,

> understanding, protecting and restoring ecosystems at river basin level is essential to foster equitable human development and the welfare of all species. Options assessment and decision-making around river development prioritises the avoidance of impacts, (…) [and] releasing tailor-made environmental flows can help maintain downstream ecosystems and the communities that depend on them (WCD, 2000: 25).

Some governments and international financial institutions such as Germany's Agency for International Cooperation (GIZ) revised their policies in line with WCD guidelines (Hirji and Davis, 2009; Moore et al., 2010). While the triumphant hydro-developmentalism of previous eras is now less prominent, new dam proposals are resurgent, driven by geopolitical concerns about water, energy and food security in a changing climate (Allouche et al., 2019; Flaminio, 2021; Middleton, 2022; IEA, 2022).

The evolution of Eflows theory and practice

The concept of Eflows arose from attempts to redress the ecologically significant negative impacts of the major anthropogenic flow alterations that occurred mostly over the last century. They are often defined as a means of overcoming the excesses of exploiting rivers for economic development (Richter et al., 2003; Dyson et al., 2003; Arthington et al., 2006; Poff and Matthews, 2013).

Eflows theory, policy and practice (praxis) attempt to rebalance how rivers are managed. For this rebalancing, it uses a variety of assessment, planning and operational techniques (Acreman et al., 2014b; Opperman et al., 2018). As Eflow techniques evolved, the Eflows agenda expanded beyond compensation flows (Poff and Matthews, 2013), and with recognition of rivers as complex ecological systems came the growing expectation that river restoration is feasible (Naiman, 2013).

Poff and Matthews (2013) outline three stages of Eflows assessment and technical development. The first stage, they call emergence and synthesis, spanned the period from the late 1980s to the mid-1990s. This stage drew on countless centuries of observations, river management practices, and ecological theories to inform thinking about the crucial roles of hydrologic dynamics in riverine ecosystems. Prior to this, Eflow studies were predominantly reductionist; they focused on the needs of a single species (usually a valued game fish) below large dams, mainly in the USA and Europe (ibid). The second phase, consolidation and expansion, occurred between the mid-1990s and the mid-2000s, when ecological science became more influential in guiding policy and management. In the third and current phase of globalisation and new challenges, Poff and Matthews (ibid) claim that Eflows science is transitioning from its narrower focus on aquatic conservation to the broader remit of "social-ecological sustainability", moving from the more technical dimensions of flow planning to more expansive concepts such as resilience and adaptive river basin governance (see also Pahl-Wostl et al., 2012, 2013).

ENVIRONMENTAL FLOWS PARADIGMS

The Eflows literature adopts two main paradigms. The natural flow paradigm is "based on minimising flow regime alterations from a natural condition" (Acreman et al., 2014b: 446), while the ecosystem services paradigm is one in which "environmental flows are targeted towards achieving specific outcomes" (ibid). The natural flows paradigm focuses on nature's intrinsic values, while the ecosystem services paradigm is more instrumental, focusing attention on benefits to humans (Nordensvard et al., 2021). In practice, the two approaches are frequently blended. Eflows may be assessed, for example, in contrast to modelled 'natural' pre-development flows; however, techniques are then used to assess flows and target them towards specific ecosystem service outcomes. The two paradigms also share an underlying assumption that humans and nature are separate and that their needs are different and competing; it thus follows that water needs to be allocated between competing users (humans and the environment). Below, we outline the two paradigms and some of the criticisms of each. We then turn to the idea of balancing flows for different needs using techniques such as cost – benefit analysis.

The natural flows paradigm

The natural flows paradigm (Poff et al., 1997) is highly influential. It underpins a great deal of Eflows scholarship and provides the foundation for much subsequent research and practice (Acreman et al., 2014b). The paradigm's foundational premise is that the integrity of flowing water systems depends largely on their natural, dynamic character (Poff et al., 1997). Rivers, their connectivity, and their rhythms and movements through landscapes are thus understood as the object to be conserved. Rivers close to their 'natural', 'undisturbed' or 'pre-development' flow regimes are deemed to be healthier than those that are modified. The aim of managed flow regimes is thus to mimic natural flow patterns as much as possible, and flow planning should adopt scientific approaches to determining these requirements (Poff et al., 1997; Acreman et al., 2014b). Applying this principle means protecting free-flowing rivers from prospective exploitation or denaturalisation (Dynesius and Nilsson, 1994; Grill et al., 2019). For those rivers already seen as over-exploited for industry, irrigation and hydropower, the goal is the restoration of flow patterns to as close to natural as is feasible (Richter et al., 2003; Arthington et al., 2006; Acreman et al., 2014b). Restoring flows is often part of wider programmes to restore rivers (Harris and Heathwaite, 2012).

The natural flows approach has faced significant challenges in moving from advocating broad principles to their application (Acreman et al., 2014b; Wineland et al., 2022). Arthington et al. (2006: 1312), for example, explain that the rapid acceptance of the natural flow concept was, "accompanied by an expectation that ecologists can easily provide specific environmental flow prescriptions for riverine ecosystems. Unfortunately, translating general hydrologic-ecological principles and knowledge into specific management rules for particular river basins and reaches remains a daunting challenge". Even if these specific prescriptions could be accurately determined, the natural flow approach faces several other significant criticisms

First, many modified rivers cannot be feasibly restored to natural flows. While the natural flow paradigm assumes that the desired regime is the natural or 'unmodified' condition, "this may be unrealistic where flow regimes have been altered for many centuries and are likely to change with future climate change" (Acreman et al., 2014b: 433); neither are all flow or riverine modifications negative or undesirable.

Second, modified river flows provide many societal benefits, and choices about rivers are socially, if not democratically, determined. Eflows often compete with flow modifications that serve contemporary societies' needs for water supply, irrigation, hydropower and flood protection. River management choices thus stem from socially and historically defined and negotiated objectives, not scientific prescriptions (Acreman et al., 2014a; Capon and Capon, 2017). Acreman et al. (2014a: 469) state that social choices are central to determining flows; they argue that whether riverine ecosystems are deemed "desirable or undesirable is a matter of social choice, which may be influenced by historical decisions or future expectations". They further argue that, "if the aim is for a natural ecosystem, [then] a natural flow regime (or a regime minimally altered from natural) is required, whereas if the aim is a particular ecosystem state or set of services, then a designed flow regime is needed". Ideally, the societal negotiations and political choices involved in setting goals, management priorities and flow objectives are explicit, equitable and transparent (Dyson et al., 2003; Dore et al., 2010; Lazarus et al., 2011).

Third, ecological restoration targets based on natural benchmarks may no longer be appropriate under nonstationary, Anthropocene conditions (Ross et al., 2015). Climate change alters rivers, catchments and floodplain ecosystems, shifting them into new states (Stein et al., 2022). As a result, Eflows are more difficult to plan and implement, with less-predictable outcomes (Stein et al., 2022). Instead of referencing some past 'natural' benchmark, planning techniques suited to future climates are needed (Alexandra, 2020, 2021; Judd et al., 2022).

Fourth, the ideal of natural flows relies on imaginaries of rivers largely unmodified by people. The central concept of 'naturalness' can ignore, marginalise or denigrate cultural connections to rivers and can limit acceptance of their co-evolved or hybrid nature. Given the long history of human modifications to rivers and their catchments (including large-scale deforestation), many rivers have co-evolved with human cultures (Zhang et al., 2018; Macklin and Lewin, 2019; Linton and Krueger, 2020; Moggridge and Thompson, 2021). The logic of using naturalistic benchmarks as the basis for policy targets is increasingly being questioned (see, for example, Linton and Krueger, 2020, for a critical examination of naturalistic targets in the European Water Framework).

The ecosystem services paradigm

The ecosystem services paradigm, in contrast to the natural flows paradigm, frames Eflows as techniques for achieving specific outcomes such as improved water quality or a desired ecological state (Acreman et al., 2014b). Eflows are valued for delivering ecosystem services (the social goods nature can provide) (Boulton et al., 2016). Underpinning this paradigm is an instrumental framing of nature, as a supplier of resources and services, that uses financial market concepts and metaphors (Dempsey and Robertson, 2012; Sullivan, 2013). This paradigm helps bring professionalised river management into a framework of public policies that are largely dominated by neoliberal economics (Ahlers and Zwarteveen, 2009).

The paradigm arises from comprehensive efforts to recognise and value different ecosystem services – from conserving habitat to cultural heritage – using economic methods (Costanza et al., 1997; Robertson, 2016; Fish et al., 2016). These approaches are promoted through influential publications such as the Millennium Ecosystem Assessment (MEA, 2005), Mainstreaming the Economics of Nature (TEEB, 2010), and Towards a Green Economy (UNEP, 2011).

Thousands of valuation studies have attempted to value ecosystem services (de Groot et al., 2012), including those provided by aquatic ecosystems (Boulton et al., 2016; Grizzetti et al., 2016) and Eflows (Gopal, 2016; Jorda-Capdevila and Rodríguez-Labajos, 2017). Methodologies such as the Services Provision Index specifically aim to assess the ecosystem services provided by Eflows (Korsgaard et al., 2008). Yang et al. (2016) found strong correlations between increasing Eflows and increases in ecosystem services. Kaiser et al. (2020), however, found that few studies empirically quantify changes in ecosystem service benefits; instead, most studies rely on modelling changes or assume, without providing solid evidence, that river restoration increases ecosystem services.

The ecosystem services approach faces three main critiques. The first is methodological and stems from the many intersecting uncertainties that riddle ecosystem service valuations. There are many uncertainties within Eflow practice and science (Acreman et al., 2014b) and in river restoration programmes generally (Harris and Heathwaite, 2012; Kaiser et al., 2020). Multiple uncertainties also plague ecosystem services valuations because numerous speculative assumptions make them prone to error propagation (Dempsey and Robertson, 2012; Robertson, 2016). Flawed or imperfect valuation methods and logics mean that estimates of ecosystem values are questionable (Toman, 1998; Sullivan, 2013; Kaiser et al., 2020); this undermines the ability to confidently allocate Eflows on the basis of such valuations.

The second critique of the ecosystem services paradigm is practical and conceptual. While many ecosystem valuation studies are motivated by the assumption that better and more accurate valuations will lead to better policy decisions, the utility of such studies for policy is questionable. Laurans and Mermet's (2014) international review of policy impacts found that policymakers rarely draw on ecosystem service valuation studies in formulating policy decisions and that valuations of ecosystem services rarely determine the outcome of policy deliberations. Underlying the limited practical utility of Eflows valuations is the understanding that the studies do not capture social complexities. In particular, many ecosystem processes and benefits are not reducible to monetary figures. Acreman et al. (2014b: 443) explain that while some "benefits, such as fisheries, have a market value and are included within traditional economic analyses, other benefits, such as maintenance of biodiversity or cultural services, including human community cohesion, cannot be readily assigned financial values". While cultural connections to rivers are deep, complex and evolving, rivers' cultural and relational dimensions are extremely difficult to value (Capon and Capon, 2017; Anderson et al., 2019). Further, attempts to value and then trade off different riverine values using financial logics may denigrate and demean other ways of relating to their nature (Laborde and Jackson, 2022). With the depth of their material and cultural connections, the value of rivers may be priceless, even close to infinity. The idea of rivers' values being close to infinity builds on Toman (1998) and Pagiola et al. (2004) arguments that attempts to value the world's ecosystems services are fundamentally flawed and even infinity may be a severe underestimate of these values, and as they suggest, little can be done with an underestimate of infinity.

Third, ecosystem services valuations of Eflows are also critiqued politically, subject to the more general criticisms of ecosystem service valuations (Dempsey and Robertson, 2012; Sullivan, 2013; Robertson, 2016). While ecosystem services ideas can highlight nature's diverse values and modify the neoliberal discourse, they are critiqued for perpetuating neoliberalism (Budds, 2004; Ahlers and Zwarteveen, 2009), extending its influence in public policy through financial market framings (McCarthy and Prudham, 2004; Dempsey and Robertson, 2012), which results in the commodification of the environment, through processes which Sullivan describes as the spectacular financialisation of nature (Sullivan, 2013).

Balancing demands and optimising Eflows, costs-benefits and tradeoffs

The two Eflows paradigms described above share a common assumption that over-exploitation of rivers has significant consequences (costs) for society and that reinstating flows produces benefits (Dyson et al., 2003; Richter and Thomas, 2007). From this perspective, the critical tasks for those developing water policies are optimising flows and crafting compromises that distribute costs and benefits by allocating water resources efficiently and effectively between different claimants or user groups. Underpinning these tasks are economics-based assumptions about the competition for scarce resources between competing users. Contestations for water shares can be between humans and nature, between one component of nature and another (for example, instream versus floodplain wetlands), between human claimants (such as urban versus rural users or upstream versus downstream communities), or between economically important sectors (such as irrigation versus recreational users or hydropower versus fisheries).

Historically, cost-benefit analysis (CBA) has been an important analytical tool for assessing water resources projects such as dam proposals and it is increasingly being applied to Eflows assessments (Qureshi et al., 2007; Bennett, 2008; Horne et al., 2018). The credibility and relevance of any cost-benefit analysis depend on the costs and benefits included, the types and scale of impacts considered, and the assumptions about the risks, impacts and distributional consequences of different options including future energy, food and water supplies (Moore et al., 2010; Lebel et al., 2020; Middleton, 2022). The precise nature of the costs and benefits of altered flow regimes are hard to determine because riverine ecosystems are complex and dynamic (Harris and Heathwaite, 2012), as are stakeholders' values (Capon and Capon, 2017). Many of the benefits of Eflows are diffuse and more difficult to determine than are the losses to irrigation or hydroelectricity production (Dyson et al., 2003; Bardina et al., 2016; Bejarano et al., 2019). Any precision offered by detailed studies may thus be illusionary. Precision may be unnecessary, however, given the large scale of the systems (river basins, floodplains, estuaries) and any analysis can be seen to contribute to the political economy of policy decisions (Dyson et al., 2003) that can impact the lives and livelihoods of many millions of people (Lebel et al., 2020).

Optimisation of flow decisions is a common theme in the literature (Derepasko et al., 2021). Some studies are optimistic about finding optimal Eflow solutions, for example identifying modifications to hydropower production regimes so that small production losses can generate significant ecological benefits (Renöfält et al., 2010; Bejarano et al., 2019). The extensive literature on salmon and hydropower provides fascinating accounts of attempts to optimise flows between two distinct outcomes – the needs of economically, biologically and culturally significant fish populations and hydropower generation. This comprehensive literature is mostly from the Pacific Northwest of the USA (Blumm, 1980; Blumm and Simrin, 1991; Opperman et al., 2019) and northern Europe, including Scandinavia (Halleraker et al., 2007; Renöfält et al., 2010; Fjeldstad et al., 2012; Soininen et al., 2019; Widén et al., 2022). It spans work on the genetic and evolutionary responses of salmon populations to hydropower dams (Waples et al., 2008; Haraldstad et al., 2021), the beneficial impacts of dam removal (Kuby et al., 2005; Fjeldstad et al., 2012; Opperman et al., 2019), and the modification of structures and their operations to enable fish passage (Nyqvist et al., 2017; Opperman et al., 2019). These studies illustrate how implementing Eflows involves legal and operational reforms, knowledge of hydro-ecology, and assessments of flow management options.

Attempts to find optimal solutions that manage tradeoffs between hydropower and salmon can generate win-win outcomes in the form of optimal flows that minimise losses in fish and power generation. These cases, however, involve two well-defined variables: fish and electricity production. Optimisation attempts become increasingly complex when more variables, contested values, and more-profound uncertainties are involved (Capon and Capon, 2017, Lebel et al., 2020).

The struggles facing optimisation are evident in studies that point to the tradeoffs and possibly irreconcilable complexities that are involved in assessing proposed dams, such as the hydropower dams that are planned for the Mekong Basin (Intralawan et al., 2018; Lebel et al., 2020; Middleton, 2022). Questions about who benefits from changed flow regimes and who bears the costs (often displaced and downstream communities) are pertinent to any analysis of dam proposals (WCD, 2000; Intralawan et al., 2018; Middleton, 2022). Overall, there is growing concerns that complex tradeoffs between energy, food and water security are oversimplified, obscured or ignored in cost-benefit analyses of proposed dams, such as those planned in the Mekong Basin (Lebel et al., 2020). In addition, optimisation equations often exclude the costs and consequences of sedimentation impacts, which builds bias into the calculations (Landwehr et al., 2020). Optimisation may be an impossible aim when juggling the complex variables that are involved in managing rivers for a wide range of competing values. Optimising flow decisions may thus exemplify one of the 'nirvana concepts' that are common in water resource management, that is, concepts that are broadly appealing but impossible to implement (Molle, 2008).

EFLOW LOGICS, RATIONALES AND CHALLENGES

Eflows have a range of rationales and are used to deliver on a variety of objectives. In this section, we outline three common, interconnected rationales for Eflows: improving river health, biodiversity conservation, and enhancing cultural values and connections to rivers.

Eflows for healthy river ecosystems

The most generalised benefit of Eflows is often described as 'healthy rivers for healthy communities'. Since the 1990s, it has become axiomatic that healthy river ecosystems are good for humans (Karr, 1999; Boulton, 1999). Indeed, the Brisbane Declaration (River Symposium, 2018) states that, "Healthy freshwater ecosystems – rivers, lakes, floodplains, wetlands, and estuaries – provide clean water, food, fibre, energy and many other benefits that support economies and livelihoods around the world. They are essential to human health and well-being".

The idea of healthy freshwater ecosystems is almost impossible to argue against; it is an appealing normative goal. How river health is achieved, however, is often scientifically complex and politically contentious (Harris and Heathwaite, 2012; Alexandra and Rickards, 2021). Eflows are generally accepted as being central to achieving healthy river ecosystems; however, exact relationships in riverine ecosystems are often uncertain and river restoration programmes do not have a strong record of success despite several decades of massive public expenditure (Harris and Heathwaite, 2012).

River health and Eflows studies typically draw on the disciplines of freshwater biology, ecology, hydrology and ecohydrology (Norris and Thoms, 1999; Boulton, 1999; Acreman et al., 2014b), and on economics and public policy (see, for example, Dyson et al., 2003; Qureshi et al., 2007; Bennett, 2008). Many studies focus on biota and their relationships to flow regimes. Norris and Thoms (1999: 197), for example, proposed that river health studies examine, "relationships between environmental variables that affect aquatic biota, such as habitat structure, flow regime, energy sources, water quality and biotic interactions". In contrast to targeting specific biota such as threatened species for conservation (Espinoza et al., 2021), particular species are selected and monitored as indicators of river ecosystem health (Davies et al., 2010). Monitoring programmes aim to select and use 'indicator species' that have a reliable response to flow regimes. These species' abundance and distribution are then used as flow metrics (see, for example, King et al., 2009) in combination with assessments of other human interventions to determine river health scores (Davies et al., 2010). Through monitoring these indicators, river health goals become more tangible while also advancing knowledge of biological responses to flow regimes (Gippel et al., 2017).

A diverse range of species and species groups (fish, birds, riparian vegetation, invertebrates) are used as indicators (Davies et al., 2010). Underpinning this practice is a broad acceptance that the presence or absence of specific organisms is a meaningful reflection of river conditions (King et al., 2009; Davies et al., 2010; Espinoza et al., 2021). The significance that is read into the presence or absence of particular organisms reflects underlying theories, frameworks and paradigms (Bouleau, 2014). While the idea of 'healthy rivers for healthy communities' shares the instrumental view of nature that is evident in the ecosystem services paradigm, river health ideas also draw on concepts of naturalness in ways that are similar to the natural flows paradigm. Species chosen as indicators of river health are usually native to a given region, while introduced species such as invasive fish are used as indicators of poor health (Davies et al., 2010). The selection and interpretation of river health indicators, objectives and targets depends on interacting scientific, technical and sociopolitical processes that co-produce riverscapes by refracting, embedding and reinforcing assumptions and concepts about rivers and what society deems to be healthy (Bouleau, 2014).

A classic indicator of poor river health (and, by implication, inadequate flow management) is blue-green algae (Cyanophyta), which is commonly used for water quality assessments. An example of this is a decision support tool that was developed to, "enable explicit prediction of the likely response of key features of the riverine environment to proposed flow management scenarios" in Australia's Murray-Darling Basin, which incorporated the abundance and distribution of native fish, bird populations and blue-green algae (Young et al., 2000: 257). There is a strong rationale for monitoring Cyanophyta to tailor flows (Atazadeh et al., 2021), since blue-green algae are toxic to animals, including humans, with severe algal blooms generating crisis conditions (Jackson and Head, 2020).

Due to the complexity of riverine ecosystems and of their responses to interventions, using biological indicators to establish causal connections between organisms and flow regimes requires wrestling with many confounding variables (Harris and Heathwaite, 2012; Acreman et al., 2014a, 2014b). Many factors determine species abundance and many factors other than flow regimes can determine riverine ecosystem health; these include catchment condition, habitat quality and connectivity (Harris and Heathwaite, 2012; Friberg et al., 2016). Flows are one of the extensively altered features of rivers (McKenna et al., 2018) and Eflows can be "used to reduce the effects of anthropogenic activities on aquatic ecosystems" (Chen et al., 2013: 1). The focus on restoring flows makes sense in many situations such as for floodplain wetlands that are impacted by irrigation extraction (Pittock and Finlayson, 2011; Kahan et al., 2021), but centering flow regimes as *the* critical variable may result in the neglect of other causal factors. For water resource managers, however, flows are often more amenable to management interventions than other determinants of river condition, such as catchment conditions, that require more extensive and complex interventions. Agricultural runoff, catchment degradation, pollution and eutrophication of rivers are examples of common and persistent problems that continue to limit the success of river restoration programmes (Harris and Heathwaite, 2012).

Anthropogenic climate change complicates Eflows for river health in myriad ways (Stein et al., 2022). In many mid-latitude regions, water demand will increase as households, businesses and governments seek to bolster water security (Palmer et al., 2008). While the push for nature-based solutions encourages integrated solutions that recognise human-environment codependencies (Seddon et al., 2021), the impetus to decarbonise the energy sector is revitalising hydroelectric generation and storage. Technologies being promoted include pumped storage hydropower (PSH) and pumped hydropower energy storage (PHES) because the latter can act as 'batteries' to enable grid stabilisation. The International Energy Agency (IEA) calls for broad support for these technologies because they are the, "reliable backbone of the clean power systems of the future" (IEA, 2022). New and proposed hydropower dams, however, pose well-known risks to rivers, reinvigorating the original impetus for compensatory Eflows (Arasteh, 2005; Moore et al., 2010). In some regions, climate change may also increase the risks and undermine the feasibility of hydropower investments by altering precipitation and runoff patterns. In 2021, for example, droughts reduced global hydropower output for the first time in 20 years, despite increased capacity (IEA, 2022). Climate change can also threaten dams and hydropower plants by increasing floods, landslides and sediment loads (Turner et al., 2017, Wasti et al., 2022), which can induce similar problems for river health (Alexandra and Finlayson, 2020).

Eflows for biodiversity conservation

Biodiversity conservation is a common rationale for Eflows, with Tickner et al. (2020) arguing that Eflows are critical for addressing the freshwater biodiversity conservation crisis. In this framing, biodiversity conservation is positioned as an intrinsic social good (Nordensvard et al., 2021), an end goal of Eflows (Acreman et al., 2014b), and a means of providing ecosystem services (UNEP, 2011).

Delivering biodiversity conservation goals in riverine ecosystems is often confounded by the multiple causal factors and relationships involved (Acreman et al., 2014a, 2014b; Friberg et al., 2016). Significantly for Eflow management, flow-ecology relationships do not scale up linearly or in alignment with more ambitious river restoration policies that can have unrealistic aims or ignore warnings about scientific complexity (Harris and Heathwaite, 2012).

Biodiversity conservation requires the generation and use of knowledge using multiple techniques, theories and paradigms that draw on the diversity within the ecological sciences (Hobbs et al., 2009; Ross et al., 2015; McPhearson et al., 2016), conservation science, and ecohydrology (Acreman et al., 2014a, 2014b). Eflow research and management contributes to debates about how best to manage rivers for biodiversity conservation (Tickner et al., 2020). These debates intersect with broader discussions about what should be conserved and how. They engage with long-standing tensions between population/species-based conservation and coarser-grained approaches that aim to conserve ecological systems and their capacities to deliver ecosystem services (Boulton et al., 2016; Portela et al., 2021; for conservation of estuaries see Stein et al., 2021; for studies on the conservation of catchments, basins and eco-regions, see Daigneault et al., 2021; Pearson et al., 2022; Stuart and Gillon, 2013).

Pragmatism is evident in discussions about how Eflows can support biodiversity conservation in modified and developed rivers (Dudgeon et al., 2006; Acreman et al., 2014a), with Couvet and Ducarme (2014) calling for a form of "reconciliation ecology" that better balances freshwater biodiversity conservation and human livelihoods. Pragmatism is also evident in whole-of-river conservation methods that aim to give all river reaches differential conservation ratings (Pearson et al., 2022), and it is visible in research on using Eflows efficiently and cost-effectively to achieve conservation goals (Horne et al., 2018).

Climate change complicates biodiversity conservation, introducing additional stresses to extant problems. These include extreme heat, altered flow seasonality, altered precipitation and runoff patterns, and changing erosion rates that degrade water quality (Alexandra and Finlayson, 2020; Stein et al., 2022). Far-reaching social effects with feedbacks to biodiversity conservation outcomes include increased water demand (Palmer et al., 2008), stresses from droughts, floods and reduced institutional capacity (IPCC, 2022). Climate change also poses theoretical, practical and epistemological challenges to Eflows policies directed at biodiversity conservation, bringing greater uncertainty to established water-planning methods (Alexandra, 2021).

Eflows to enhance cultural connections

The third rationale for Eflows is that they enhance recreational, spiritual and cultural connections to rivers. While few Eflow studies focus directly on "the diversity and interdependencies of human-flow relationships – such as the linkages between river flow and human well-being, spiritual needs, cultural identity, and sense of place", this is increasingly being recognised as critically important (Anderson et al., 2019: 2). People and their relationships to rivers become central when flow planning attends to the integration of cultural and environmental needs (Anderson et al., 2019). This approach shifts thinking about Eflows as being specifically about the environment, to integrating the needs and relationships of people and nature.

More than a rationale for Eflows, relationality offers an important paradigmatic alternative to the natural flows and ecosystem management paradigms discussed in Section 3. Adopting a more relational framing of flows also has far-reaching theoretical and practical implications, including for adaptively governing river basins as socio-ecological systems (Pahl-Wostl et al., 2012; Chaffin et al., 2014).

Adopting a relational, co-evolutionary approach also positions Eflows as nourishing cultural connections and acknowledges the co-production of riverine landscapes (Bouleau, 2014). This prospect is significant in countries like Australia, New Zealand and Canada, where Traditional Owner groups actively seek greater involvement in governing rivers (Anderson et al., 2019; RiverOfLife et al., 2020; Wooltorton et al., 2022). Increased involvement remains problematic, however, while water governance institutions, "take for granted their own analytical categories (…) and do not take seriously the ontological diversity of waters" (Laborde and Jackson, 2022: 357).

In Australia and in other settler-colonial countries, wilderness concepts reinforce the myth of terra nullius, that is, of empty lands without people (Fletcher et al., 2021) with comparable essentialist naturalism reinforcing the ideals of wild rivers and natural flows. In Australia there is growing recognition that rivers, wetlands and catchments co-evolved with people over millennia (Jackson and Moggridge, 2019; Moggridge and Thompson, 2021). These natural-cultural relationships continue in heavily modified contemporary landscapes (O'Bryan, 2017). The discourse on restoring rivers and their flows is shifting from a strict settler-colonial environmental focus to gradually recognising Indigenous Peoples' rights, relationships and responsibilities (Finn and Jackson, 2011; Jackson and Moggridge, 2019; Wyborn et al., 2023). Reform challenges are conceived as less about returning rivers to some imagined natural state and more about reparative steps towards recognising cultural flows and waters' centrality in spiritual and social relations (O'Bryan, 2017; Jackson and Moggridge, 2019; Laborde and Jackson, 2022).

In many countries, calls for restorative water justice are growing that include a recognition of Indigenous Peoples' territorial and water governance rights (Boelens et al., 2016; Hartwig et al., 2018, 2020, 2022). Recognising and engaging with these fundamental issues, however, remains a challenge for water agencies that use narrow, ecologically focused, flow assessment methods (Finn and Jackson, 2011; Laborde and Jackson, 2022). Without further reforms, policy settings based on and reinforcing these methods are likely to persist (Wyborn et al., 2023).

Cultural flows and associated rights are inextricably tied to the restoration of Indigenous systems of governance and control of waters (RiverOfLife, 2020). The Echuca Declaration (MILDRIN, 2010), for example, states that, "cultural flows are water entitlements that are legally and beneficially owned by the Indigenous Nations of a sufficient and adequate quantity and quality to improve the spiritual, cultural, environmental, social and economic conditions of those Nations. This is our inherent right". Restoring flow relations thus cannot be detached from the rights to govern, use and control water. Many Indigenous People nonetheless suffer from dislocation and disconnection from their land and waters, which can be exacerbated by a narrow focus on environmental flows (Finn and Jackson, 2011; Laborde and Jackson, 2022).

Having summarised the main Eflows paradigms and rationales, we now explore Eflows assessment methods.

EFLOWS METHODS – ABUNDANCE, EVOLUTION AND DIVERSIFICATION

The abundance, evolution and diversification of Eflows methods

In this section, we provide a brief overview of Eflow assessment methods, techniques, and decision support tools and offer some possible reasons why so many methods exist.

Tharme (2003) documented more than 200 Eflow assessment methods and planning techniques. Methods have proliferated since then, based on work in diverse river basins, climatic zones and countries (Acreman, 2014a, 2014b; Poff et al., 2017; O'Brien et al., 2018). Their abundance is such that water managers are confronted (and possibly confused) by the multitude of assessment and planning options (Opperman et al., 2019).

Assessment and planning techniques need to be understood as families of methods because methods usually build on previous work that incorporates core assumptions of past platforms. King and Louw (1998), for example, define a building block methodology that enables multiple techniques to be combined. Other techniques are described as holistic (King et al., 2003); these include Downstream Response to Imposed Flow Transformation (DRIFT), which aims to cover all biotic and abiotic components of river systems. Methods are often combined into ensembles of techniques that range from hydrological and hydro-geomorphic modelling to Bayesian belief networks (Shenton et al., 2014; O'Brien et al., 2018). Horne et al. (2022) offer an example of blended flow assessment methods used to develop climate-ready flow targets, which combined adaptive management principles, future scenarios, multiple sources of knowledge, and stakeholder participation.

The abundance of Eflow assessment methods, planning tools, and techniques begs the question: what is it about the Eflows that has stimulated so much methodological work?

One somewhat cynical explanation is what Mattern (2013) calls 'methodolatry'. This neologism combines 'method' and 'idolatry', and manifests as "*the fetishisation* of method" data and models. According to Mattern (ibid), a preoccupation with methods can extend to directing research and can even drive the questions asked. While the extent to which this phenomenon is evident in Eflows research is unclear, the very notion of Eflows is rooted in an inherently methodological outlook (*how* do we manage river flows?), which generally assumes that methods such as ecological studies or ecosystem service valuations generate valuable and useful results. More broadly, Eflows are appealing as an elegant response to the complex issues of riverine degradation; however, if Eflows planning methods constrain debate to a few key variables or flow options, they risk fitting policymakers' tendency to recast complex situations as, "neatly defined problems with definite, computable solutions or as transparent and self-evident processes that can be easily optimised – if only the right algorithms are in place!" (Morozov (2013), as cited in Mattern, 2013).

A second explanation for why Eflows methods multiply and evolve is river system diversity, with the methods being located within this diversity. The gap between broad Eflows principles that are based on theory, and their application in practice (Arthington et al., 2006) may have caused dissatisfaction with existing methods and catalysed new methods. As Eflows policy and practice evolves, changes in objectives can trigger the need for new methods, models, data collection and monitoring (Chen and

Olden, 2018). With the co-evolution of science, policy and practice, the ecohydrological sciences continue to raise fundamental questions, with new research leading to better understanding and adding new approaches to the existing array of methods (Acreman et al., 2014b).

A third reason for the abundance is that policymakers, practitioners and research funders assess Eflow methods according to their practical relevance and their perceived legitimacy and utility (Cash et al., 2003). These criteria reflect the contextual and applied nature of Eflows methods. Acreman et al. (2014b: 434) argue that while ecohydrological knowledge has advanced, "key challenges include how to make recommendations on best evidence, build uncertainty into decision-making processes and explain this to stakeholders". Vos and Boelens (2020) also emphasise the need to engage diverse stakeholders. They argue that Eflows assessments typically apply, "standardised technological packages that use, for example, percentages of average annual discharges, status of key species, various environmental thresholds, and economic analysis". They point out, however, that determining 'key species', 'costs', and 'benefits' depends on the positions and values of the stakeholders that are consulted.

A more profound concern is how technical methods embed and reproduce their normative foundations. These techniques and methods thus should not be considered neutral or objective instruments of analysis (Vos and Boelens, 2020; Nightingale et al., 2020); instead, they should be understood as embedding numerous assumptions about society, water and the world (Lane, 2014; Laborde and Jackson, 2022). Deference to, or infatuation with, technical methods can also give rise to technical entrapment, making it more difficult to understand and address complex societal problems (Mattern, 2013; Nightingale et al., 2020).

The move to incorporate social perspectives and complexities into Eflows studies points to a broader transition in thinking about rivers (Anderson et al., 2019), one that repositions river governance on the larger stage of 'social-ecological sustainability' and 'resilience' (Pahl-Wostl et al., 2012, 2013; Poff and Matthews, 2013). By implication, this repositioning increases the scale and scope of Eflows concerns to include broader societal negotiations about preferred futures and how to achieve them. This transition is being driven not only by a shift in social sentiment or policy ideals but also by the emergence of multiple colliding risks and complexities, including climate change (Poff et al., 2016). These risks and uncertainties can undermine established notions of what works in river planning and management (Alexandra, 2021; Stein et al., 2022). Methods emerging to handle nonstationarity use greater stakeholder engagement and deliberation processes that acknowledge systemic risks and the limits to certainty and predictability (Judd et al., 2022; Horne et al., 2022).

Adaptive management approaches are widely advocated in the Eflows literature as ways of dealing with the multiple uncertainties involved in riverine ecosystems, including those driven by changing climatic conditions. The following section discusses these approaches in Eflows science and practice.

Experimentation, adaptive management and adaptive policy

Eflows science, policy and governance increasingly use techniques that are referred to as active experimentation (Davies et al., 2014), adaptive management (Richter and Thomas, 2007; Gunderson and Light, 2006; Schoeman et al., 2014), and adaptive governance (Pahl-Wostl et al., 2013; Chaffin et al., 2014).

Within the Eflows literature, there is widespread acceptance of the need for experimentation, adaptive management, learning, and operational and legal reform (Acreman, 2005; Opperman et al., 2019; Konrad et al., 2011; Owusu et al., 2021). Adaptive management and experimentation are promoted widely as framing concepts and as methodological and management frameworks that enable learning by doing (Poff et al., 2010; Poff et al., 2003; Webb et al., 2018; Opperman et al., 2019; Horne et al., 2022). Acreman et al. (2014b: 442) define adaptive management of Eflows as situations where initial estimates, "are implemented and the response of the ecosystem is monitored, and subsequently adaptations or changes to flows are made if the objectives are not met". Poff et al. (2010) also recommended adaptive management approaches that are based on monitoring ecological responses to flow alterations and adjusting management interventions accordingly.

Despite the often-stated adoption of adaptive management approaches, evaluations indicate significant opportunities for improvement (Allan and Watts, 2018; Opperman et al., 2019; Konrad et al., 2011). Olden et al. (2014), for example, identified the need to improve experimental design and monitoring and to diversify geographical, sociopolitical and ecological contexts to increase the scientific, managerial and policy relevance of findings. These analyses suggest that enthusiasm for adaptive management principles does not always translate into execution in practice. These failings may be due to traditional command and control approaches being entrenched in water resource management practice, despite the rhetorical adoption of adaptive principles (Schoeman et al., 2014).

To encourage social learning, adaptive responses must be negotiated in transparent, open and fair processes within governing bodies and should not be obscured in scientific and technocratic complexities (Pahl-Wostl et al., 2007). Eflows tend, however, to be promoted as a social good, in a general abstract ways that brush over the sites, scales and subjects of actual benefits or the needs of particular stakeholders (Vos and Boelens, 2020; Jackson, 2021).

One significant opportunity to introduce adaptive management is the renovation and reoperation of existing dams, including renovating physical structures to better enable Eflows releases. Owusu et al. (2021) undertook a systematic international review in which they studied 69 examples of dam reoperation. They identified that changes in legislation are the primary trigger for dam reoperation, with environmental impact and Eflow studies also being important. Interestingly, both structured (rational, scientific reviews) and unstructured, opportunistic processes drove reforms to the physical structures and operations of dams (ibid). These legal and operational reforms occur at the intersection of science, policy and large-scale, long-lived infrastructure, reflecting some progress in dealing with the long-standing controversies about the impacts of dams.

A simplified form of the policy cycle (Howard, 2005) can help characterise the evolution of Eflows governance and the evolving relationships between Eflows science and policy (Acreman et al., 2014b). Public outcries and evidence from the ecological and ecohydrological sciences helped policymakers understand the impacts of altered flow regimes. Improving freshwater ecosystems became more widely accepted, with governments committing to Eflows in laws and policies. Attempts to apply Eflows in practice highlighted further deficiencies, which led to more research into flow regimes (Acreman et al., 2014b) and how to govern them (Pahl-Wostl et al., 2013).

Dealing with many contemporary flow challenges requires more profound attention to the policy, cultural and institutional dimensions of governing rivers (Pahl-Wostl et al., 2012; Hassenforder and Barone, 2019; Anderson et al., 2019; Linton and Pahl-Wostl, in press). In the next section, we examine Eflows debates as contests about resources and power. This perspective inevitably raises questions about how the actors involved in policy debates use discursive constructs to further their interests and agendas (Swyngedouw, 2009; Alexandra and Rickards, 2021).

THE CONTESTED POLITICS OF ENVIRONMENTAL FLOWS

Multiple ontologies and contested futures

In this section, we outline why attempts to understand the contested politics of Eflows need to recognise the multiple ontologies of water.

Eflows debates are enmeshed in disputes about preferred futures that include competing demands for water, food and energy security under more extreme climatic conditions (Allouche et al., 2019; Lebel et al., 2020). They are therefore also enmeshed in broader politicised debates about local and national rights, economic development, geopolitical security, and biodiversity conservation. These politicised contestations about Eflows involve clashing worldviews, with more at stake than competing values that can be traded off through some neutral optimisation process.

Middleton's (2022) examination of the disputes around hydropower development in the Mekong Basin reveals three fundamentally different ways of defining and conceiving of rivers that determine their current realities and desirable future trajectories (in the eyes of various stakeholders). In these contestations, rivers are understood variously as being:

1. Deeply interwoven with peoples' cultures, livelihoods and lifestyles and with their material, social and ritual needs;
2. Material and energy resources for economic and industrial development, including for low-carbon energy production;
3. Biodiverse ecosystems that need protection to stem the freshwater biodiversity crisis and to achieve conservation outcomes.

Negotiating Eflows when there are these fundamentally different understandings of the reality of the world requires engagement with the realpolitik of decisions about rivers and with questions about multiple ontologies. Dyson et al. (2003) and Dore et al. (2010) call for transparent and equitable negotiations between stakeholders that can surface competing positions, agendas, interests and institutionalised power relations. While this work is important, disputes are not only about competing values or political positions that can be negotiated fairly and rationally; instead, as Middleton (2022: 258) argues, "different hydrosocial networks enact multiple ontologies of water" and modern water is a, "particular assemblage of water that institutions and individuals enact". He calls for critical research into "the 'nature of water' and human-water relations" in ways that are attentive to modern water's historical, philosophical and institutional foundations and its dominant role in framing most contemporary water policy debates (see also Boelens et al., 2016; Schmidt, 2017). Recognition that multiple ontologies of water are involved in these debates is critical to understanding disputations about rivers and their flows (Middleton, 2022). Ontological tensions and ambiguities can arise from the differences in water-related ontologies; and these differences need to be recognised by researchers and by those working in water policy development and execution (Laborde and Jackson, 2022).

Our review identifies three main kinds of ontologies that can be found in the Eflows literature. The first one, modern water, holds nature to be theoretically *a*nd practically separate from the human world. This dualistic ontology underpins the idea of management interventions 'in' and 'for' nature. Protecting natural flows and conserving biodiversity are presented as societal choices about balancing the needs of mature against the voracious demands of humans.

The second ontology sees rivers and how we know and manage them as nature-culture 'hybrids'. Efforts to place people at the heart of flow planning and to nourish cultural connections to riverine landscapes reflect this hybrid ontology (Anderson et al., 2019; Linton and Pahl-Wostl, in press). Ideas about human cultures and nature co-evolving (Geels, 2005; Kallis, 2007; Zhang et al., 2018; Macklin and Lewin, 2019) are also evident in ideas about the co-evolution and adaptive governance of socio-ecological systems (Pahl-Wostl et al., 2012; Chaffin et al., 2014). This co-evolution includes rivers in Europe for which socionatural co-construction has been underway for thousands of years (Linton and Krueger, 2020), and in Australia where the time frame is over 60,000 years (Moggridge and Thompson, 2021). This co-evolved hybrid ontology contrasts with natural flows and with imaginaries of rivers unmodified by people, which is an ecohydrological equivalent of wilderness. The second ontology is also expressed in critiques of using natural reference states for target setting in the WFD (Dufour and Piégay, 2009; Bouleau and Pont, 2015). Linton and Krueger (2020: 513) argue that the WFD is based on a fundamental ontological fallacy because it presumes a, "radical ontological distinction between nature and human beings or human society; humans are placed in a realm separate from nature and then a set of rules is constructed which is based on this separation".

A more pessimistic, historically oriented variation of the 'hybrid' ontology is the idea that Humans and Nature were once separate (as per the full dualist ontology outlined above) when nature was free of human influences. This purity and freedom were lost, however, due to planetary-scale human impacts that now make all nature a human-influenced 'hybrid'. The Anthropocene – the idea that humans are thoroughly changing the entire planet – undermines any idealised notion about the naturalness of rivers, because with global-scale anthropogenic changes, such as climate change, no river flows are natural in the sense of being unaffected by humans. This position is reflected in the growing acceptance that the restoration of natural flows maybe an impossible goal for rivers, especially those working rivers that are regulated, engineered and plumbed and that are being further disturbed by climate change (Acreman et al., 2014a). This view is evident in discussions about abandoning natural baselines, accepting humans' dominant influence over rivers (and over ecosystems more generally) and pragmatically or proactively cultivating hybrid, novel or designer ecosystems (Hobbs et al., 2009; Acreman et al., 2014a; Ross et al., 2015; Alexandra, 2022).

Critics of the dualist ontology and of its historical hybridity perspective argue against framing humans as separate and antagonistic to nature (DeLaure, 2011). Linton and Krueger (2020: 521), for example, argue against the misanthropism inherent in the idea that society only exerts pressures that are "a priori framed as harmful and degrading", with the only redemptive actions being those "dedicated responses" that aim to correct or mitigate the harmful pressures.

The third ontology is better understood as a category of diverse ontologies that share a profoundly relational and non-dualist understanding of the world. From this perspective, the dualist categories of human and its other (nature) – are powerful cultural artefacts of the Western imagination that deny the existence of many complex realities that exist across the world's peoples (Descola, 2012). Australian Indigenous Peoples provide examples of relational non-dualistic ontologies, including through the concepts entwined in the idea of *Living Waters,* which are fundamentally different to those of 'modern water' (Laborde and Jackson, 2022). It is also illustrated through the term Country, an inclusive, holistic and integrative term that is widely used to describe land, water, people, biota, place, home, landscape and territory. The term Country is commonly used in expressions, such as "this is my country". Country enfolds and enmeshes rivers, catchments and biota with people and their spiritual, ritual, material and economic connections (Jackson and Moggridge, 2019; Wooltorton et al., 2022). With these many connections, Traditional Owners' practices, responsibilities, stories and obligations have shaped Australian riverine landscapes for millennia. Examples include extensive fish traps and aquaculture systems (Humphries, 2007; Builth et al., 2008) and systematic burning regimes that cultivate vegetation patterns through 'fire-stick farming' (Fletcher et al., 2021). Calls to recognise and respect Country and Indigenous Peoples' relationships are increasingly evident in recent policy debates about cultural water and cultural rights to govern and manage water (Wyborn et al., 2023). In these debates, however, Indigenous advocates struggle against agencies and researchers that understand water in fundamentally different, 'modern' ways (RiverOfLife, 2020; Laborde and Jackson, 2022; Wooltorton et al., 2022). These differences are illustrated in the case of a managed Eflow event in the Darling River (see Box 1). Ironically, Australia is now experiencing an emerging convergence between the goals of Indigenous water justice and groups (such as some environmentalists) both of whom are seeking to return rivers to more natural flows. Despite their fundamental ontological differences, they both view the settler-colonial treatment of rivers (and their people) as profoundly damaging and in need of radical reforms (RiverOfLife, 2020; Hartwig et al., 2022).

BOX 1

The neoliberal settings of Australian water legislation institutionalise different water uses as competitors and the relations between humans and the environment as adversarial. Sue Jackson (2021) provides an insightful analysis of the compartmentalised approach to flow management. She examines the multiple river realities enacted by a large, coordinated flow event in the Darling Basin, which was managed with the aim of reconnecting riverine ecosystems during a prolonged drought. Irrigators have the right to abstract some water from the river during high-flow events caused by precipitation. Regulators therefore engaged in considerable scientific and technological effort to distinguish the regulated flow that was 'owned' by the environment from the potential additional 'natural' water flows that might be caused by a possible – albeit improbable – precipitation event. A public relations campaign funded by the river managers praised the managed flow event as a major success in rescuing the river.

When asked about the merits of this event, however, a member of the Ngemba, who have traditionally lived along the river, responded, "Connectivity? They use words that don't mean nothing [sic] to traditional owners. Every creek and billabong has gone. Those creeks and billabongs filter the river. That was their function before white man. Now, in, 200 years, they've totally devastated it and they don't care, not for their future (…). They've taken everything off us, and now they've taken the water. They've fenced off all the rivers. They've got us secluded and confined to the levee banks. Our people are on the highway to extinction" (Jackson, 2021: 13).

Australian Indigenous groups are campaigning for more rights in river management to be better able to transform relations with rivers onto a more respectful and reciprocal basis (Wyborn et al., 2023).

Power, politics and technical solutionism

To complete our review, we look at the knowledge politics of Eflows.

While there is a tendency to try to depoliticise environmental flow decisions, they need to be understood explicitly as political contests about controlling rivers, and thus controlling resources and society. In particular, debates about Eflows highlight questions about who has the power to allocate water resources, who benefits from these decisions, and whose influence, frameworks and values guide the decisions (Swyngedouw, 2009; Alexandra and Rickards, 2021). The political and self-reinforcing nature of these factors can be disguised by the apparent objectivity or neutrality of many Eflows planning and decision-making processes.

At issue here is not Eflows per se; rather, it is the political and institutional context in which they are governed. Eflows are an example of ecological modernisation (Mol et al., 2020), with hydro-technical specialists managing water resources and aquatic environments on behalf of the state. Despite well-meaning intentions, the use of selective frameworks and methods can obscure the complex value choices and socially determined objectives that are involved in governing rivers and their flows (Fernandez, 2014). Acreman et al. (2014b: 433) highlight that many countries have Eflows laws and policies and that, while science can "link hydrology to ecosystem status", there are "fundamental questions that go beyond ecohydrology, such as who decides on the target condition of the ecosystem?" Eflow policies thus raise fundamental questions about how environmental priorities and objectives are established within the broader legal and political frameworks governing rivers and water resources (Fernandez, 2014).

Underpinning much of the thinking about Eflows are administratively rational modes of problem-solving that often constrain more inclusive and adaptive frameworks (Alexandra, 2021; Wyborn et al., 2023). The dominant, managerialist approach to deeply political decisions reflects modern water's historical, philosophical and institutional underpinnings (Ahlers and Zwarteveen, 2009; Schmidt, 2017; Boelens et al., 2016; Allouche et al., 2019). Rationalist managerialism emphasises problem-solving 'out in the world'; it attempts to render complex problems technical in ways that can exclude or marginalise the social and political dimensions of problem definition and in the process shape the solutions that are deemed feasible (Allouche et al., 2019; Nightingale et al., 2020; Wyborn et al., 2023). The tendency to seek technical solutions and defer to technical approaches marginalises critical debates about the politicised nature of water allocation decisions. Vos and Boelens (2020) argue that, "the current technocratic way of establishing e-flow regimes is top-down and negates local river use and locally held nature values", marginalising local stakeholders and perpetuating inequities. Ahlers and Zwarteveen (2009: 409) also identify that the mainstream water discourse, "invisibilises, naturalises and objectifies the politics and powers involved in water re-allocation" with its, "complex distributional choices that are intrinsically political". As this review highlights, Eflows debates refract socially constructed and increasingly contested views about the rights of people and nature and the value and appropriate management of river systems.

CONCLUSIONS

Our review of Eflows makes the following main points.

Over the late 20th and early 21st centuries, Eflows have become increasingly influential in water policy, practice and research; indeed, they have become one of the dominant ways of thinking about and managing rivers.

Eflows research, policy and management have led to a greater focus on understanding and caring for rivers as ecological systems. Over these decades, the purpose, scope and foci of water resource management have shifted from treating water as a simple material resource to more profoundly recognising its ecosystem and cultural relationships.

The scope of Eflows is broadening from addressing the flow needs of specific river reaches or iconic species to broader agendas that include integrated approaches to the management of society-river relationships. Awareness of the social and environmental impacts of water resource policies is also beginning to be more widely recognised.

Many different Eflow assessment techniques and methods exist; there is a tendency, however, for them to share common underlying concepts and logics, and most draw on natural flows or ecosystem service frameworks. These paradigms are profoundly influential in shaping Eflows theory and practice, though they come from a position that humans and nature are separate and that their respective needs are thus in competition and in conflict. Increased emphasis on relationality, cultural relationships and socio-ecological systems may help bridge the divide that follows from this dualism.

Concepts of active experimentation, adaptive management, adaptive governance and social learning are prevalent in the Eflows literature; however, there are many opportunities to improve these methods and approaches and to strengthen them in practice.

Optimisation of Eflows is often the implicit or explicit goal of policies and research, but this prospect may be an illusory, unrealistic or unachievable goal due to the diversity of values involved in debates about rivers and the dynamics and complexities of riverine systems and societies' relations to them.

While valuations of the ecosystem services delivered by Eflows have been conducted, more accurate valuations may not lead to better decisions. Moreover, the political dimensions of decisions about rivers cannot be outsourced to economic or hydro-ecological experts.

The proliferation of Eflows assessment methods may indicate methodolatry and solutionism. There may also be a risk of technical entrapment, and a focus on the technical aspects of flows may divert attention from dealing with the more contentious sociopolitical difficulties of allocating water or making decisions about rivers.

Climate change fundamentally alters almost all aspects of river management, including the politics and economics of new hydroelectric dams and the assessment of ecosystem needs and environmental water requirements. Climate change is also increasing uncertainty about the use of 'natural' or pre-development benchmarks and is indicating the need for climate-ready flow targets. In 2000, the World Commission on Dams (WCD, 2000) expressed a shift in political sentiments about large dams and their impacts; however, the need for rapid decarbonisation of energy systems is leading to a reassessment of new hydropower dams and a dramatic increase in their numbers.

There is a pressing need to recognise the complex human (social, political and institutional) dimensions of governing rivers and their flows. Governing rivers involves ongoing political negotiations about purpose and priorities. More research is thus needed on how to move beyond the unproductive binary of environmental and non-environmental flows. Rivers need more-integrated planning models that recognise their inherently social, economic and ecological dimensions.

Finally, the political dimensions and social negotiations of Eflows must be made more explicit and transparent through more informed, fair and robust stakeholder engagement processes. Better processes are needed to ensure that policy debates are inclusive of diverse voices and values and are more informed about the impacts of rapidly changing Anthropocene conditions. Given that demands on rivers are shifting due to rapidly changing energy systems and their economics, it may not be possible to arrive at consensus decisions; nonetheless, it is critically important to develop ways of arriving at socially just, democratically accountable and workable agreements about rivers and their flows.

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