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Adaptive Management of Environmental Flows

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Abstract Adaptive management enables managers to work with complexity and uncertainty, and to respond to changing biophysical and social conditions. Amid considerable uncertainty over the benefits of environmental flows, governments are embracing adaptive management as a means to inform decision making. This Special Issue of *Environmental Management* presents examples of adaptive management of environmental flows and addresses claims that there are few examples of its successful implementation. It arose from a session at the 11th International Symposium on Ecohydraulics held in Australia, and is consequently dominated by papers from Australia. We classified the papers according to the involvement of researchers, managers and the local community in adaptive management. Five papers report on approaches developed by researchers, and one paper on a community-led program; these case studies currently have little impact on decision making. Six papers provide examples involving water managers and researchers, and two papers provide examples involving water managers and the local community. There are no papers where researchers, managers and local communities all contribute equally to adaptive management. Successful adaptive management of environmental flows occurs more often than is perceived. The final paper explores why successes are rarely reported, suggesting a lack of emphasis on reflection on management practices. One major challenge is to increase the documentation of successful adaptive management, so that benefits of learning extend beyond the project where it takes place. Finally, moving towards greater involvement of all stakeholders is critical if we are to realize the benefits of adaptive management for improving outcomes from environmental flows.

Keywords Environmental flows · Adaptive management · Reflection · Researchers · Managers · Local stakeholders · Decision-making · Uncertainty · Learning

Introduction

Freshwater systems are under heavy pressure from human use and are consequently highly degraded (Dudgeon et al. 2006). Governments around the world are turning to environmental flows—"the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems" (Brisbane Declaration 2007)—to reduce these impacts (Horne et al. 2017). Environmental flows will play a key role in helping to meet the United Nations' Sustainable Development Goals (SDGs; UN 2017), especially SDG 6 – 'Clean Water and Sanitation' (Sood et al. 2017), and so go well beyond the ecological focus that has dominated thinking, particularly in developed countries (e.g., Arthington 2012).

The science and implementation of environmental flows arose from, and has been dominated by, the concept of the *natural flow paradigm* (Poff et al. 1997). This states that a regulated flow regime should retain the full range of

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features of the pre-regulation flow regime if the system is to retain reasonable ecological function. This paradigm has recently been challenged by the acknowledgement that many regulated river systems today bear little resemblance to their former unregulated state, and that returning them to their original condition may be impossible or even undesirable. This has led to the concept of *designer* (Acreman et al. 2014) and *functional* (Yarnell et al. 2015) flows—flow regimes that are specifically designed to fulfill specific ecosystem functions that may or may not have been a feature of the river system in the past (Moyle 2014). There are thus several broad paradigms through which environmental flows may be conceived, along with a huge range of specific methods through which programs may be designed (Poff et al. 2017; Tharme 2003).

Implementation of environmental flows, however, remains a challenge. While environmental flows has proven an appealing concept for legislators and policy makers (Horne et al. 2017), and many countries have committed to providing water for the environment, the implementation of major environmental flows programs has lagged well behind these good intentions (Harwood et al. 2017; Le Quesne et al. 2010). One identified major barrier to implementation is the high uncertainty over costs and potential benefits of environmental flows (Moore 2004). Providing water for the environment often means removing water from traditional consumptive purposes (e.g., irrigated agriculture), either as reductions in allocations in highly-regulated systems, or restricting future development to prevent over-allocation in unregulated systems (Poff et al. 2003). It has been difficult for governments to legislate for the uncertain environmental benefits of flow provision compared to the more easily documented financial returns from consumptive uses.

However the urgency of environmental degradation of rivers (Vorosmarty et al. 2010) compels governments to act despite far from perfect knowledge about how systems will respond. In such a setting, the practice of adaptive management is an obvious way forward to enable managers to work with complexity and uncertainty (Pahl–Wostl et al. 2013). Variously defined as 'learning by doing' and 'management under uncertainty' (Webb et al. 2017), adaptive management focuses on learning about and/or within a system to improve management outcomes for all stakeholders. The learning can also improve the overall state of knowledge about that type of system, potentially benefiting management in other similar systems. Adaptive management as an overarching concept is built into several major environmental flow programs. The most notable example is the Murray–Darling Basin Plan in Australia, which seeks to return approximately 2750 GL of water to the rivers of the Murray–Darling Basin (Hart 2016), approximately 20% of the amount previously used for consumptive purposes.

There are few examples of adaptive management of environmental flows in the academic literature. A search of the citation index Web of Science in mid-2017 identified only 73 publications, with 60 of these having been published since 2010.[1] This Special Issue, therefore, offered the opportunity to bring together for the first time papers regarding adaptive management of environmental flows to assess the state of the literature and the discipline, and to identify priorities for the future.

Background to the Special Issue

The Special Issue arose from a special session of the 11th International Symposium on Ecohydraulics (ISE; Webb et al. 2016), held in February 2016, in Melbourne, Australia. Although submissions to both conference and Special Issue were open to any potential participant, the conference location created a bias towards papers from Australia.

Australia is a global leader in the implementation of large-scale environmental flows programs (Horne et al. 2017; Swirepik et al. 2016). The Murray–Darling Basin Plan, for example, is an approximate $13B AUD investment in environmental restoration and associated programs, with $3B AUD set aside for buy-backs of irrigation water alone (Hart 2016; Skinner and Langford 2013). The large number of papers from Australia therefore may reflect this high level of government investment in environmental flows. Moreover, Australia being the driest inhabited continent has prompted water managers and researchers to develop innovative approaches to environmental water decision making that make the most of the limited environmental water available (Horne et al. in review). Under such circumstances, methods that rapidly incorporate improvements in our knowledge and understanding into decision making are particularly valuable. In the Web of Science search described above, author affiliations were also dominated by Australian institutions (number of authors: Australia 37, USA 29, Europe 15, South Africa 8). We were therefore comfortable that while the genesis of the Special Issue was the ISE conference, the Australian focus of this issue is in keeping with the forefront of research on adaptive management of environmental flows.

Conceptions of Adaptive Management

Since the concept of adaptive management was formalized in the 1970s (Holling 1978), it has evolved in several

[1] Search was carried out on April 4, 2017, at the University of Melbourne. Search String: TS = ("adaptive manage*") AND ("environmental flow*" or "environmental water" or eflow*)

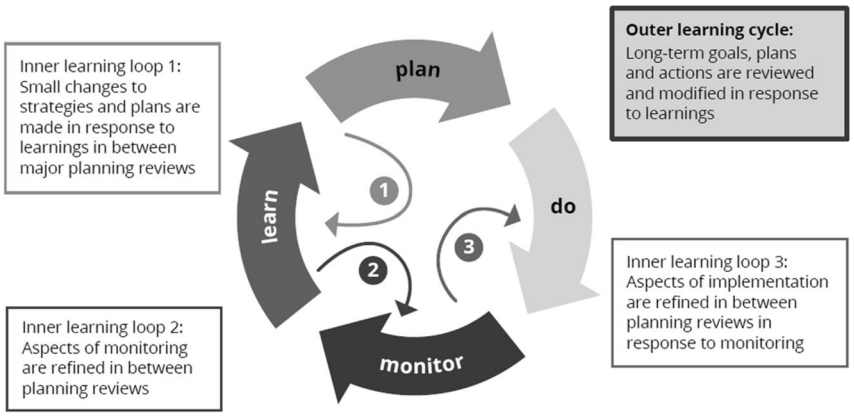

Fig. 1 The adaptive management cycle showing the outer learning cycle where lessons inform the next formal phase of planning and implementation. The inner learning loops are small changes that are made based on learnings that occur between major planning reviews. The inner loops effectively allow progress in the outer loop in both directions. Reproduced from Webb et al. (2017)

directions, and through different research traditions (Rist et al. 2013a, 2013b). In one direction lie approaches that are technically focused, relying on tight boundaries and restricted sets of possible decisions for the managed system. Statistical or mathematical models are heavily used to inform decisions, and monitoring and evaluation of the outcomes is used to update model parameters to improve the next round of decisions, and therefore ecological performance (e.g., Nichols et al. 2007; Runge et al. 2006). In the other direction lie approaches that consider the socio-ecological system, and place greatest value on the act of learning itself, and how this can help bring together the wide range of stakeholders in participatory management (e.g., Ostrom 2009; Wei et al. 2012). Both conceptions of adaptive management are valid, and most real world examples will lie somewhere along this continuum rather than being at either end.

Despite their differences, the two conceptions described above both consider adaptive management as a cyclical process consisting of the broad steps: plan, do, monitor, learn (Webb et al. 2017; Williams and Brown 2014). Within each of these major phases lies considerable complexity (Allan and Watts 2018), but this can be understood through the concept of 'mini-loops' consisting of iterative changes within the body of the adaptive management cycle (Fig. 1).

Stakeholder Contribution for Successful Adaptive Management

Volumes have been written on the 'failure' of adaptive management (e.g., Allan and Curtis 2005; Walters 2007; Westgate et al. 2013). Rather than recapitulate that literature in this paper, we bring together the papers in this Special Issue to offer some more detailed observations regarding one mechanism that is necessary for adaptive management to succeed in the long term.

Regardless of the technical/social focus of an adaptive management program for environmental flows, we argue

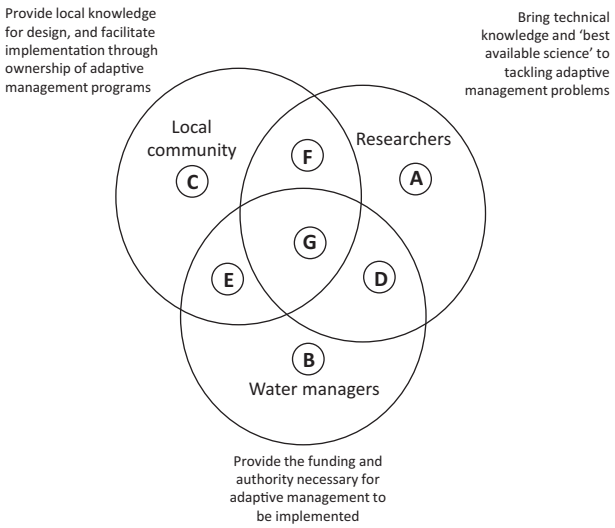

Fig. 2 Three different groups of stakeholders are essential for successful adaptive management. The figure depicts the different regions of interaction among the local community, researchers and water managers to which the papers in this special issue are mapped (Fig. 3). Also included is a brief note on what each stakeholder group brings to adaptive management, with these concepts covered more fully in the main text

that adaptive management cannot succeed in the long term without the engagement of three different groups of stakeholders: water managers, researchers, and the local community. Water managers have understanding of the relevant legislation and regulations, and have the power to make the decisions; researchers have the specific knowledge of the technical or sociological methods needed to bring knowledge together; and the local community has considerable specific knowledge and understanding that can contribute to effective implementation and acceptance long-term.

The strengths and weaknesses of different balances of stakeholder engagement are explored pictorially in Fig. 2. We suggest that an ideal example of adaptive management would lie at the intersection of all three circles, and that good examples would involve two of the three stakeholder groups.

The seven different regions of this Venn diagram represent different types of case studies that face different challenges to effective and sustainable adaptive management.

A. Models, approaches and tools developed entirely by researchers may have potential for use in adaptive management, but without manager and local community engagement during development may not be fit for purpose or achieve the requisite degree of 'ownership' for them to become successful. Case studies in this category are at greatest risk of being ignored, and thus falling into the 'Knowing-Doing Gap' recognized in many areas of applied environmental science (Knight et al. 2008).
B. Adaptive management programs run entirely by managers are unlikely to have the level of technical (or sociological) sophistication necessary to take advantages of the latest improvements in knowledge and systems (sensu Webb et al. 2010). Moreover, such schemes risk being perceived as too 'top-down' and may not achieve eventual local community acceptance or take advantage of local knowledge.
C. Adaptive management programs developed entirely by the local community will face challenges to gain acceptance by both managers and researchers. Like programs run entirely by managers (Region B), they may suffer from not taking advantage of the latest advances in research. On top of this, the local community may not have the power to compel managers to implement an adaptive management scheme.
D. Adaptive management programs that combine researcher knowledge with management engagement have a strong chance of being implemented and thus affecting management decisions. Over time, such schemes may be embraced by the local community (moving them into Region G), but if they do not, could potentially breed ill feeling among community stakeholders whose knowledge is not being used, and who are excluded from the decision-making process.
E. Adaptive management programs co-developed by local stakeholders and managers bring together the powerful combination of ownership and engagement. Such schemes can be implemented and affect decision making, but will likely lack the latest technical advances that engagement of researchers can bring. This could lead to a perception that management decisions are not being made using 'best available science'—something of a mantra in environmental management circles (Ryder et al. 2010).
F. A direct collaboration between researchers and the local community, but without the engagement of water managers, is perhaps the most difficult stakeholder scenario to envision. The main weakness would be that the stakeholders would not be in a position to influence decision making. However, should such a combination occur, we believe that it would have a strong chance of attracting manager support (and moving into Region G) over time.
G. With true contributions and ownership by all three stakeholder groups, an adaptive management program would be able to take advantage of the subject area expertize of researchers, whilst also achieving support from the local community and the benefit of their knowledge, and would have the necessary management support to effect real differences in decision making.

How Close to the Ideal? Classifying Case Studies from the Special Issue

Where do the papers from this Special Issue fit into the conception of stakeholder involvement presented in Fig. 2? We have mapped the papers from this Special Issue onto the stakeholder diagram (Fig. 3) using an iterative process. As editors of the Special Issue, we initially mapped each paper onto one of the seven regions. The first author of each paper was then sent a copy of the diagram that included only their study, and an explanation of its purpose. They were asked to comment and/or suggest a change to the mapping. While those suggestions were not always accepted completely, this resulted in some changes to our initial mapping.

The first obvious result from this process is that the great majority (11 of 14) of papers have a heavy involvement of

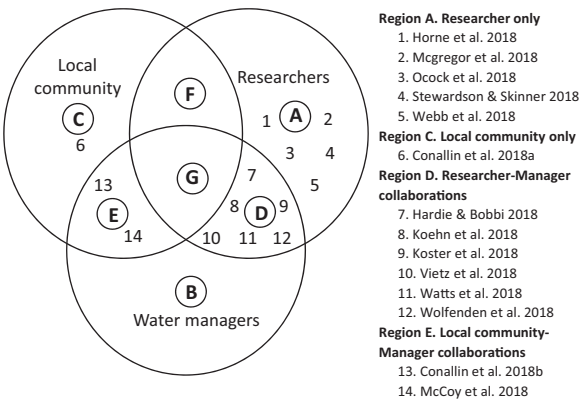

Fig. 3 Mapping the interaction of the local community, researchers and water managers for the papers in this special issue. Mapping of each paper (indicated by digits) to a region (indicated by letter) in the diagram was done in consultation with paper authors. Specific positions within regions are unimportant, with discussion of finer-scale involvement of different stakeholder groups in the main text. Paper numbers are in alphabetical order within the regions, and are the same order in which contributed papers appear in the Special Issue after this paper

researchers. This does not necessarily mean that the whole field of adaptive management is dominated by this group. Researchers are required to publish, and so case studies involving researchers are more likely to be published than those with minimal researcher involvement. Five of these 11 papers (Horne et al. 2018; Mcgregor et al. 2018; Ocock et al. 2018; Stewardson and Skinner 2018; Webb et al. 2018) are mapped to Region A (researcher only). While these papers present novel approaches to the science of adaptive management, the lack of involvement of other stakeholder groups means that they do not have a clear pathway to implementation. Most of these 11 papers have little involvement of local community stakeholders. The closest exceptions, Watts et al. (2018) and Vietz et al. (2018) have only minimal involvement of the local community, apart from local water managers.

Six case studies mapped to Region D, the intersection of researchers and managers. These include examples of decision making regarding flow allocations for the endangered Australian grayling in the Bunyip and Tarago rivers, Australia (Koster et al. 2018); managing the geomorphology and public perceptions of river bank erosion in the Goulburn River, Australia (Vietz et al. 2018); using irrigation water to provide critical refuges for native fish during low oxygen 'blackwater' events in the Edward–Wakool system, Australia (Watts et al. 2018); and managing how return flows from wetlands are used to complement in-channel environmental flows while managing risk in the Murrumbidgee catchment, Australia (Wolfenden et al. 2018). These are four examples of adaptive management in action. Technical expertise of researchers, mixed with a willingness and ability to make adaptively informed decisions over short time scales by river managers, has resulted in real improvements for river health and environmental water outcomes. These decisions mostly correspond to the 'mini-loops' around implementation depicted in Fig. 1; there is less indication of adaptive processes being used to inform decision making at the yearly and longer scales. There are also two case studies that mapped to Region D where researchers have developed methods in collaboration with managers, with adaptive management as the ultimate goal (Hardie and Bobbi 2018; Koehn et al. 2018). Although these methods have not yet had major impacts on decision making, the collaboration of researchers and managers provides the clear pathway to implementation.

All of the above case studies are primarily based on the 'science framing' of adaptive management. Three case studies (two of which have the same primary author) mapped to the other side of the diagram, with the primary drivers being local community stakeholders, and a greater consequent focus on participatory processes and group learning.

Two case studies mapped to Region E, the intersection of managers and the local community. These include a successful example of participatory decision making in Tuppal Creek, Australia (Conallin et al. 2018b), and the Columbia Basin Water Transactions Program, which tracks the implementation and impacts of water transactions (McCoy et al. 2018). Like those case studies that map to Region D, these example have good potential for long-term effective adaptive management, but would benefit from greater involvement of researchers to take advantages of latest advances in knowledge and to provide technical input and knowledge into the decision-making process.

The case study from the Edward–Wakool Strategic Adaptive Management (SAM) program (Conallin et al. 2018a) provides a sobering example of how continued engagement of all partners is necessary for successful adaptive management. The program was originally conceived as being within Region G; the community-driven program had support from management agencies (Office for Environment and Heritage, New South Wales Office of Water, Commonwealth Environmental Water Office), and involvement of researchers. During its first years of operation, the collaboration was influential for developing flow regimes designed to benefit different fish groups, which fed into decision making (Baumgartner et al. 2014). For various reasons, however, over time the water managers shifted their focus to other approaches for implementation and evaluation of environmental flows. While the SAM program is still used by the local community, it has had little recent influence on decision-making in the Edward–Wakool system.

This example also illustrates that projects are not static; while we have mapped individual papers in this special issue to different regions of Fig. 2, those classifications could change over time, either to the benefit or detriment of adaptive management. Even successful examples of adaptive management require continued effort from all stakeholders to stay that way (Schreiber et al. 2004). From our point of view, that implies sustained effort and commitment from researchers, managers and the local community.

Informality and the Under-Reporting of Adaptive Management

Does the fact that we did not map any of the papers to the optimal Region G mean that such case studies do not exist? This brings us to the final paper in the Special Issue.

Allan and Watts (2018) does not appear on the stakeholder diagram, as this paper examines the process of adaptive management itself. The main finding is that adaptive management may manifest in multiple ways when there is commitment and trust from different stakeholder

groups involved in managing a system (see also Webb et al. 2017). Such case studies are likely to be under-reported because of the very informality of some of the adaptive management taking place. As such, the 'failure' of adaptive management may be more a failure to document and report successful examples, with those examples not necessarily conforming to preconceived ideas of what adaptive management should look like.

Several of the Region D case studies (Koster et al. 2018; Watts et al. 2018; Wolfenden et al. 2018) appear to be examples of this type of informal adaptive management. In each of these cases, management programs were put in place with the expectation of involvement by researchers, but there was no a priori expectation that adaptive management would take place. It is quite possible that these case studies would not have made their way into the literature but for the session at the 2016 ISE conference and subsequent opportunity to prepare a paper for this Special Issue. Furthermore, had these case studies been published without the focus of this Special Issue, they may have concentrated more on the scientific methods and results, and less on how these processes affected management decisions. Thus, this Special Issue has facilitated the publication of several cases of informal adaptive management that may otherwise have remained hidden.

The large number of successful case studies of adaptive management, highlighted through the mechanism of this Special Issue, raises the possibility that adaptive management of environmental flows is occurring successfully in other parts of the world, but is not being reported. If this is the case, then the benefits of the learning taking place are not being shared with a wide audience. It also raises the possibility that ideal (i.e., Region G) cases of adaptive management of environmental flows exist, but are not being reported. In an April 2017 workshop on adaptive management within the Murray–Darling Basin Long-Term Intervention Monitoring Project (Gawne et al. 2013), we presented the stakeholder diagram. At least one of the programs (Warrego-Darling Rivers, NSW) claimed that adaptive management in that area fitted comfortably into Region G (P. Frazier, 2Rog Consulting, pers. comm.).

Conclusion—Documentation and Dissemination—The Role of Reflectors

In a recent work (Webb et al. 2017), we established a number of principles to underpin monitoring, evaluation and adaptive management of environmental flows. The final principle was a call for better documentation and dissemination of adaptive management programs. Better reporting of learning and outcomes would have two major benefits (Webb et al. 2017). First, it could help to counter the prevailing tone in the literature that adaptive management has failed to live up to its promise. This is important, as continued negative construction of adaptive management could serve to undermine the faith that policy makers have thus far shown in it as a guiding principle for managing environments under uncertainty. Conversely, a redoubled commitment to 'learning by doing' could see renewed interest in protecting and restoring stressed environments despite considerable uncertainty over the best way forward. Second, better reporting of learning and outcomes would increase the rate of learning overall. Rather than learning simply taking place within a narrowly defined adaptive management program or team, wider dissemination of those learnings would allow other teams and programs to benefit from this hard-won knowledge, increasing the rate at which management of imperiled environments could improve and improving outcomes for all stakeholders.

Responsibility for this increased documentation and dissemination could rest with a type of team member new to adaptive management of environmental flows—a 'Reflector' (Webb et al. 2017). The idea of reflection in and on practice is not new, and builds on the seminal work of Schön (1983) and more recent systems practitioners (e.g., Ison et al. 2011). In our model, a Reflector would be responsible for continuous self-evaluation and reflection on the adaptive management project. Rather than being responsible for managing or collecting monitoring data, they would instead examine how well the adaptive management processes were working, and if necessary take steps to improve them. We understand that funding a team member to concentrate on this reflective role might be challenging amid limited budgets for monitoring, evaluation and adaptive management, but the potential gains are enormous.

We hope this Special Issue serves as a catalyst for increased discussion of adaptive management of environmental flows, and at the very least facilitates the documentation and discussion of other successful case studies from around the world. Adaptive management of environmental flows is an extremely young field. As we move into an ever-more hydrologically uncertain future (Milly et al. 2008), environmental flows will become increasingly important for sustaining river systems (Poff et al. 2016). But with increasing demand for water for both human and environmental purposes (Vorosmarty et al. 2010), innovative and robust management of environmental flow regimes will become increasingly important. Improved communication of what does and does not work in the adaptive management of environmental flows will help us to reach this point far sooner.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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