Environmental Management (2018) 61:497–505
DOI 10.1007/s00267-017-0922-4

CrossMark

Implementation of Environmental Flows for Intermittent River Systems: Adaptive Management and Stakeholder Participation Facilitate Implementation

John Conallin[1] · Emma Wilson[2] · Josh Campbell[3]

Received: 2 June 2016 / Accepted: 20 June 2017 / Published online: 2 September 2017

Abstract Anthropogenic pressure on freshwater ecosystems is increasing, and often leading to unacceptable social-ecological outcomes. This is even more prevalent in intermittent river systems where many are already heavily modified, or human encroachment is increasing. Although adaptive management approaches have the potential to aid in providing the framework to consider the complexities of intermittent river systems and improve utility within the management of these systems, success has been variable. This paper looks at the application of an adaptive management pilot project within an environmental flows program in an intermittent stream (Tuppal Creek) in the Murray Darling Basin, Australia. The program focused on stakeholder involvement, participatory decision-making, and simple monitoring as the basis of an adaptive management approach. The approach found that by building trust and ownership through concentrating on inclusiveness and transparency, partnerships between government agencies and landholders were developed. This facilitated a willingness to accept greater risks and unintended consequences allowing implementation to occur.

✉ John Conallin
j.conallin@un-ihe.org

1 IHE Delft Institute for Water Education, Westvest 7, 2601 DA Delft, Netherlands

2 NSW Office of Environment and Heritage, Level 4, Government Offices, 533 Kiewa St, Albury, NSW, Australia

3 Murray Local Land Services, 315 Victoria Street, Deniliquin, NSW 2710, Australia

Keywords Intermittent rivers · Adaptive management · Trust-building · Stakeholder engagement · Monitoring and evaluation · Environmental flows

Introduction

In areas where intensification of agriculture, industry, and urbanization has occurred, freshwater ecosystems have often been altered significantly, both physically and ecologically, resulting in highly modified, or novel type ecosystems (Acreman et al. 2014a; Hobbs et al. 2009; Moyle 2014). These modifications have affected the systems' ability to sustain ecosystem services (Arthington et al. 2010; Garcia et al. 2016; Janse et al. 2015). Presently, intermittent systems (here used as a general term for intermittent and ephemeral, or temporary rivers or waterways) are some of the most highly modified and degraded systems in the world, a trade-off for providing other important social-economic services such as agricultural and urban land (Brooks 2009; Leigh et al. 2015; Reid et al. 2017). Ecologically, intermittent rivers are an important interface between the aquatic and terrestrial ecosystems, acting as both, dependent on seasonal conditions (Acuña et al. 2014; Boulton and Suter 1986; Larned et al. 2010). In many arid areas of the world intermittent rivers make up the majority of the river network (Datry et al. 2016), and they constitute the most common type of river system in Australia (Kingsford and Thompson 2006).

Recognition of the value of intermittent rivers as important social and ecological systems, their degraded state, and the need for better management is increasing (Acuña et al. 2017; Datry et al. 2017; Meyer et al. 2007).

However, intermittent river management is challenging due to the inherent social-ecological complexity of river systems (Parrott and Meyer 2012; Patrick et al. 2014). In intermittent river systems where they are near-natural, the focus may be on preserving the present state, or finding ways to preserve the river's present (socio)ecological values, while developing the social services (Strayer and Dudgeon 2010). In areas where heavy modification has occurred, however, it is doubtful that the ecosystems could ever be returned to naturally functioning systems (Doley and Audet 2013; Hobbs et al. 2006; Kopf et al. 2015). In heavily modified systems the focus is often on returning some of the previous ecological functions to the system, while trying to maintain the majority of social services the system provides (Seastedt et al. 2008), a type of sustainable compromise scenario. Indeed, returning some of the key ecological drivers of the system, such as flow, may improve the resilience of highly modified novel ecosystems (Moyle 2014; Palmer et al. 2008).

Given the importance of intermittent rivers systems, their social-ecological complexity stakeholder-driven management actions and frameworks are needed to find sustainable compromises between the different values, or at least allow tradeoffs to be explicit (Podolak 2014). Environmental flows could provide a valuable tool in defining and reaching the social-ecologically acceptable sustainable compromises that management seeks (Arthington 2012; Poff and Matthews 2013). However, while environmental flows may provide the mechanism for determining how much water is needed for the objectives set for each system, it has limited examples of where it has provided the management framework to implement it (Acreman et al. 2014b; Brewer et al. 2016). This is problematic in countries like Australia, where many intermittent river systems are already highly modified, often crossing private land with complex legal land and water issues, and are associated with diverse social (often entrenched within status quo) and ecological values (King and Brown 2006).

Adaptive management frameworks provide a logical way forward for devising and implementing environmental flows programs in intermittent river systems (Rist et al. 2013). Adaptive management promotes "learning by doing" and is applied in situations where the impact of management interventions is uncertain (Stirzaker et al. 2011). Despite its balanced approach, incorporating both technical and social concerns, adaptive management programs are not always successful (Biggs et al. 2011; Williams and Brown 2014). In some instances of adaptive management, this may be due to a heavy focus on the science and evidence-based premise of adaptive management, at the expense of its stakeholder engagement and participatory decision-making components (Kingsford et al. 2011; Scarlett 2013). However, in complex social-ecological systems such as intermittent river systems, providing a clear emphasis and priority for effective stakeholder engagement and participatory decision-making is essential if management is to be effective, and trust and ownership developed to see long-term outcomes realized (Leahy and Anderson 2008; Walkerden 2006; Williams and Brown 2014).

Lessons learned from other natural resource management (NRM) programs have shown the benefits and challenges in involving stakeholders (Collins and Ison 2010; Cook et al. 2013; Moon et al. 2012), and steps needed to successfully engage stakeholders (Conallin et al. 2017). Stakeholder involvement may help to reduce transaction costs associated with environmental flows programs in river systems (Marshall 2013), which may be significant in highly novel ecosystems (Stringer et al. 2006). Stakeholder engagement may also minimize the need to reduce uncertainty before a program can begin, therefore increasing utility (Hurlbert and Gupta 2015). In general, it is hypothesized that stakeholders who have trust in a program and feel involved are more likely to accept more risks and higher uncertainty so their "willingness to accept" can be greater (Flitcroft et al. 2009; Hamm et al. 2016; Stern and Coleman 2015). (Flitcroft et al. 2010) describe trust as fundamental to relationships, and that trust is the power factor that essentially determines the willingness of individuals to believe the source of information (Beratan 2007; Hamm et al. 2016; Stern and Coleman 2015; Zand 2016). In this paper, we present an environmental flows management-based case study from a small intermittent creek system, the Tuppal Creek system, situated within the Murray Darling Basin, Australia. Before starting the program management agencies hypothesized that a focus on participatory decision-making to build trust and ownership would influence and support the adaptive management cycle, thus reducing conflict leading to better social and ecological outcomes. The approach combined elements from environmental flows assessment frameworks of (Richter et al. 2006), and adaptive management principles from (Kingsford et al. 2011; Walkerden 2006), tuned to the specific situation between the various stakeholders in this case study.

Methods

Study Area

The Tuppal Creek is a sixty kilometer intermittent creek system that is part of the Murray-Darling Basin, Australia. The creek flows in a north-westerly direction, departing from Murray River near Tocumwal and joining Edward River near Deniliquin in southern New South Wales (Fig. 1). The Tuppal Creek system supports a vibrant rural community, consisting of up to 35 resident landholders,

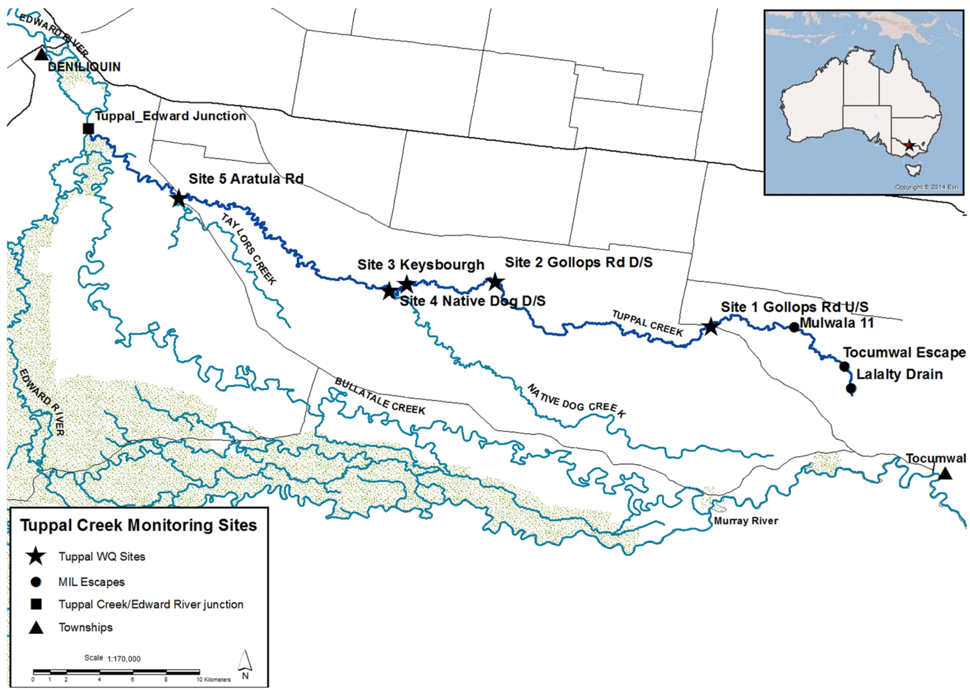

Fig. 1 Tuppal Creek System within the Murray-Darling Basin, Australia (inset). Five key monitoring sites are shown along the system, the Lalalty drain and the two channel escapes (Tocumal Escape and Mulwala 11) used to deliver environmental water. An automated water quality and water height/discharge site was situated at site 5 at Aratula Rd

where food and fiber agricultural commodities gained from the area underpin the local economy. The system is ecologically important, supporting at least twelve threatened animal species, and stands of significant remnant mature River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*Eucalyptus largiflorens*) vegetation communities (Brownbill and Warne 2010).

Since the 1950s, a levee bank has blocked flows from the Murray River into the creek, altering the flow regime and disconnecting the creek's upper section (Fig. 1). Prior to the construction of the levee bank, Tuppal Creek received reconnecting flows in most years, occurring for an average of four months in spring and autumn. The lower half of Tuppal Creek still receives flows from the Murray River via the Native Dog Creek (Fig. 1) and from agricultural channel infrastructures owned and operated by a private irrigation company; Murray Irrigation Limited (MIL). Over time the ecological health of the Tuppal system has declined, impacting native fish, other animals, and plants that are accustomed to the natural wetting and drying phases of the system. The water quality was also negatively impacted, as the salt from ancient ocean sediments in the soil dissolved in the water, but could not flow out of the system, resulting in high salinity levels in residual pools and creek bed.

Due to the declining ecosystem health of the system local landholders through the Tuppal Creek Landholder Group (TCLG) together with the support of the former Murray Catchment Management Authority (now Murray Local Land Services) devised a strategic plan "Tuppal Creek Strategic Plan 2010–2020" (Brownbill and Warne 2010). A vision was created as part of the plan; "A functioning Tuppal Creek ecosystem that the current community and future generations can enjoy, use and appreciate". Flow regime (or the lack there-of) was identified as a management priority, and in 2010 the TCLG approached three government agencies, the Murray Catchment Management Authority (CMA), the NSW Office of Environment and Heritage (OEH), and the Commonwealth Environmental Water Office (CEWO), to devise an environmental flows program for the Tuppal Creek. Environmental water in New South Wales is managed by OEH. The CEWO also owns environmental water and under a Memorandum of Understanding, OEH identifies priority sites to receive environmental water, and manages and facilitates the delivery of environmental water in New South Wales. To assist in identifying priorities such as the Tuppal Creek environmental watering trial, an Environmental Water Advisory Group (EWAG) advises OEH on the use of environmental water in NSW. The EWAG consists of stakeholders that represent a range of industries, interest groups, independent scientists, government agencies, and Aboriginal organizations. The former Murray CMA's main role was to help facilitate NRM activities including environmental water within the Murray catchment. All three government agencies worked closely together in delivering environmental water in other areas of the catchment.

Three delivery points in the MIL irrigation system was identified as mechanisms to deliver environmental water to the Tuppal Creek (Fig. 1). These delivery points were designed to escape water into the Tuppal Creek when there is a risk of flooding agricultural land from the irrigation system due to high rainfall.

The TCLG advised that they must be involved, and that the co-design of an environmental flow program was a requirement for the group to support implementation. Borrowing from learnings from other programs, and highlighted in (Richter et al. 2006), four key principles would be employed;

1. Stakeholder participation; in most aspects of the project
2. Management commitment and flexibility; management objectives defined, and a willingness to change direction
3. Sound science; research and monitoring used to inform delivery and learning
4. Learning by doing; getting going and learning as you implement

Stakeholder Participation Process

Stakeholder participation was to be included in all phases of the project; planning, implementation, monitoring, and evaluation. In the planning stage it was surmised that a co-design process, (possibly with a smaller technical group) would occur through a series of meetings to plan the project, and what would be the roles and responsibilities of all stakeholders.

Management Commitment and Flexibility

Commitment would be planned in two stages, first a design stage and a trial watering, and if this was successful, a series of follow-up watering events over a short timeframe of 1–5 years. Flexibility would be shown by creating management based thresholds using easily measureable indicators that would inform water delivery and the adaptive management of the implementation stage. They would also form part of the evaluation stage to assess if the thresholds were useful in informing the adaptive management cycle.

Learning by Doing and Sound Science

Constrained by a minimal budget and small project team and aspiring for community involvement and understanding, the monitoring was kept simple, pragmatic, utility focused, and involved the local community where possible. All of the data collected was to be used to (1) to identify the optimal flow regime (frequency, timing, and duration) and any works that may be required to achieve the desired maximum flow rate and to minimize third party effects, (2) to inform long-term planning process assisting with the development of a long-term environmental water management and monitoring plan, (3) at a level that allows for making real-time decision-making, and (4) at a level of understanding suited to all stakeholders to support consultation/awareness activities. Long processing times and complicated scientific techniques were beyond budget but also avoided, so outcomes could be easily explained to all stakeholders.

Five monitoring sites were established to represent the reaches of the creek identified in the Strategic Plan (Fig. 1). At each of the sites, six parameters were measured for each watering event; electrical conductivity (EC), dissolved oxygen (DO), flow front and water level in refuge holes, frog diversity, and vegetation responses. Water quality was monitored at each site prior to a watering to establish baseline conditions for residual pools, then weekly during an event until the water reached the Edward River, then less frequently if risks such as high EC or low DO water were low. DO and EC were measured in situ at each monitoring site and at the flow front. In addition EC was continually recorded at the DPI Water hydrometric station located at the site 5, Aratula Road bridge (Fig. 1). Management thresholds were defined for water quality parameters EC (>1500 µS) and DO (<4 mg/l) and depth thresholds were based on large refuge pools remaining at approximately 1 m in the center, using site 2 as a key refuge monitoring site (Fig. 1).

Flow movement and flow front was monitored on a weekly basis until flows connected to the Edward River. Landholders were to advise OEH if the flow rates were creating any access issues. Depth of key refuge pools was measured using staff gauges and wetted perimeter recorded. Photo points were established at each monitoring site and used to identify changes in vegetation condition, and wetted perimeter. Photos were taken prior, during, and post watering.

Results

Stakeholder Participation

The stakeholder engagement process began with meetings between a small set of the local landholders, the OEH, Murray CMA, MIL, and CEWO representatives. Together, they formed an informal steering committee, the Tuppal Steering Committee (TSC), which was chaired by the OEH. In the first meetings stakeholders openly presented “what they wanted to see”, “what they did not want to see” and “what they were willing to accept”. Common themes for stakeholders included developing partnerships, reinstating seasonal flows, improving water quality (specifically reducing salinity), and providing water for fringing vegetation. These key themes were then used to form the basis to develop a trial watering program.

The TSC defined the following objectives for the trial environmental flows program:

To develop and establish strong partnerships between the Tuppal Creek community, other local stakeholders, and affiliated government agencies;
To reinstate an ephemeral flow regime for the Tuppal Creek;
To improve ecosystem function, in particular water quality, the condition of the fringing vegetation communities, and improving habitat and passage for native fish;
To determine if the available MIL infrastructure (escapes) are effective outlet points to deliver desirable volumes of environmental water to Tuppal Creek in order to achieve the ecological objectives.

Key risks identified by the TSC were flooding of private land, mobilization of large volumes of salt, and hypoxic blackwater entering the receiving river (in this case, the Edward River). The committee developed flow thresholds that principally focused on mitigating salinity (using ANZECC water quality guidelines) and that managed flows did not affect landholders access across the creek, especially during the crop harvesting period. Environmental flows were only to be implemented when the Edward River flows were greater than 800 ml/day (measured at the Edward River Offtake) to ensure hypoxic blackwater was effectively diluted in the receiving stream. Landholder representatives encouraged their neighbors to agree to the trial proceeding.

Evaluation was carried out through the TSC as a joint exercise in 'lessons learned' workshops. Here, data synthesized by the agencies was presented, lessons learned discussed, and decisions on setting the future objectives made collectively. Event summary documents were initially used to inform the large number of landholders associated with the Tuppal Creek. Several landholder meetings were held prior to and during the trial watering. Following the initial trial event, landholders agreed that meetings could be reduced to pre and post watering to reduce transaction costs. As a result of the trial, and the conduction of subsequent environmental watering events, trust and a strong rapport developed between the Tuppal community and the government agencies, thus removing the need for frequent face to face meetings for watering events to proceed. The environmental water managers then communicated primarily via email and telephone which suited the needs of time poor landholders.

Management Commitment and Flexibility

Water delivery to meet the desired social-ecological outcomes was divided into two phases: Phase 1—start-up flows planned to occur in spring (September–November), and Phase 2—replenishment flows that were to be initiated whenever either the depth of residual pools became critically low for native fish or water quality thresholds for salinity or dissolved oxygen were exceeded. Replenishment flows were principally delivered in autumn (March–May). Since the first year trial period, water delivery has been timed where possible, to exit the system into the Edward River coinciding with higher flow in the receiving stream to minimize salinity impacts, to maximize carbon exchange and provide connectivity for native fish. The timing and duration of the proposed event was negotiated and looked to minimize impacts to landholder access for cropping or stock management purposes, whilst still focusing on ecological needs. Environmental water was delivered through MIL irrigation infrastructure (MIL escapes; Fig. 1) at the top of the system. Depending on desired volume, one or all three release points could be utilized. A preferred hydrograph was provided to MIL, incorporating the ability for environmental water managers to adaptively manage flow rates if required, within a few days if required such as for example, if flow height were creating unforeseen access issues for landholders. The term "trial" watering was important as it signaled to both the community and the government agencies that no ongoing commitments for future watering events were planned until there was unanimous support and it was demonstrated that identified risks could be confidently managed. The outcomes of the trial were used to develop further prioritization and management decisions for the OEH and TSC.

Implementation, Water Delivery, and Monitoring

Water quality monitoring indicated that EC ranged between 50 and 1800 μS over the duration of the trial. Throughout most of the trial EC levels remained below 1500 μS however occasionally this threshold was exceeded at certain periods triggering a TSC meeting. Expert advice from scientists was sought to assist with the decision-making process. On each occasion it was determined that flows in the Edward River were at an acceptable level to receive the flows, resulting in the continuation of the environmental water delivery. High ECs were usually associated with flow fronts and were diluted quickly. Refuge pool water level monitoring was used to inform on Phase 2 flows. Using depth trigger points allowed for improved timing of Phase 2 flows to ensure large refuge pools were maintained, and allowed for easy communication to why and when a Phase 2 flow would occur.

From the onset of the project in early 2012 until end of 2016 23 gigalitres (Gl) of environmental water has been delivered to the Tuppal system. The volume of environmental water annually allocated for the Tuppal has ranged from 4 to 7 Gl. In every year a spring Phase 1 flow and an autumn Phase 2 event has occurred, except in autumn 2016, due to a blue green algae outbreak in the surrounding perennial river systems. The OEH and CEWO continue a working relationship with TSC to achieve social-ecological benefits for the Tuppal system.

Discussion

Management programs are needed that move away from managing for either social or ecological outcomes, and strive for social-ecological acceptable outcomes (Knight et al. 2011; von Korff et al. 2010; Westley et al. 2010). These programs should be supported by best available science where possible (Ryder et al. 2010; Webb et al. 2014). Such programs should not be complicated by emphasis on understanding the whole system before managing (Groffman et al. 2006; Stringer and Dougill 2013), and thus be paralyzed by uncertainty (Canessa et al. 2016; Regan et al. 2005). The adaptive management approach applied in the Tuppal Creek environmental flows program showed some of the key benefits associated with building trust and ownership through providing a platform for stakeholder participation to occur within managing a freshwater system (Nkhata et al. 2008).

In relation to the Tuppal Creek system, identifying trust and ownership as key processes to focus on within the adaptive management process helped facilitate planning and implementation (Binkley and Duncan 2009; Reeves and Duncan 2009). From the outset, the Tuppal project invested in stakeholder inclusion by using multiple communication methods, involving regionally based government staff with local knowledge and expertize, and creating "champions" both among landholders and government staff. A combination of one-on-one meetings, group meetings, site visits, emails, and media involvement was used to engage a diverse group of stakeholders. This allowed all stakeholders to provide input, showing that the use of different types of engagement strategies is effective (Mott Lacroix et al. 2016). The involvement of regionally based on-ground government staff allayed landholder concerns of having to deal with different people from government agencies over time who might not be up-to-date or knowledgeable of the local situation (Robinson et al. 2015). Champions (both government and local landholders) which became focal points of contact between all stakeholders was also central to the project going forward and helped reduce transaction costs for constant meetings (Hearne and Powell 2014; Straith et al. 2014).

Subsequent watering events continued to build trust and ownership by engaging landholders in the decision-making process such as the timing of the trial, flow rates, and assisting with monitoring (Mueller-Hirth 2012; Stanghellini 2010). The many ways in which stakeholders were involved resulted in both government and community having a greater willingness to engage, but also accept some uncertainty, and possible unintended consequences of the watering events (Longstaff and Yang 2008; Smith et al. 2013). Using simple monitoring parameters and methods, linked to management thresholds provided results in real-time and allowed for an increase in adaptive management. This also lead to a reduction in perceived risks as data could quickly show what was occurring, and if any actions needed taking (Ryder et al. 2010; Scott 2016).

A good example of how adaptive management occurred was how the TSC responded when EC thresholds were exceeded. Before starting the trial, there was a perceived risk from stakeholders in relation to saline water being mobilized and entering other downstream areas of the creek, or even less acceptable, the receiving water body (Edward River) close to the main drinking water source of the nearby town Deniliquin. Risk was mitigated by starting with small flows which were monitored in real-time and assessed daily. If any of the agreed upon thresholds were exceeded, the TSC would make a decision, and the flows could be ceased before any water entered the Edward River. Upon the initial trial watering, the perceived risk turned out to be just that; perceived (Bennett 2016; Hommes et al. 2008). Results showed that the environmental water helped mobilize and dilute the salinity, thus decreasing the original problem, and reaching the intended social-ecological outcomes of improving water quality within the creek, and reconnecting it with the Edward River.

Despite the initial successes of the project, sustaining the program into to the long-term has many challenges. The monitoring, although pragmatic and inclusive, is arguably not robust enough to define if some of the overall objectives set for the program are being achieved (Fazey et al. 2006; Kennett et al. 2015; Lukyanenko et al. 2016). Funding cycles, changing priorities within government agencies, and long-term commitment to reach ten-year vision cycles (as written in Tuppal Creek Strategic Plan) are rarely considered viable within single funding rounds (Benham et al. 2015; Maekawa and Aron 2016; Tennent and Lockie 2013). The future of the Tuppal project depends strongly on the continued commitment of both the local community and government agencies. Major risks to the program identified above must be explicit and part of the future planning.

To date vulnerability to changing funding and interests has been reduced through concentrating on utility and low transaction costs, but at the expense of scientific certainty. Stakeholder acceptance of outcomes has remained the focus, with an acceptance of uncertainty, and learning by doing. The longer term focus of the project, and reduced vulnerability to funding inadequacies should lead to higher resilience within the project and enable a secure relationship based on learning and dealing with unexpected events. Currently, the environmental water managers are working with the TSC and discussing setting up long-term i.e., five to ten year watering strategies for the Tuppal Creek. Environmental water managers remain focused on working with the landholders to investigate options to improve environmental water delivery to maximize social-ecological outcomes and aim to include problem-orientated, robust scientific research to improve the understanding of flow-social-ecology relationships.

Conclusion

Using trust and ownership as basis for the adaptive management approach achieved through participatory decision making and "requisite simplicity" evidence-based principles has allowed for objective-driven environmental water delivery to occur within the Tuppal Creek social-ecological system. The process of building trust and ownership occurred in steps, beginning with a co-design process for determining the delivery of environmental water initiation of a trial watering, and then follow up watering events in each year. Each step required more commitment and trust than the one before, and showed some of the strengths of stakeholder involvement in adaptive management programs. Although this is a simple case within a relevant small spatial area with a limited number of stakeholders, through applying the principles of adaptive management, concentrating on stakeholder engagement and participatory decision-making within the process, the "willingness to accept" uncertainty and unintended consequences were increased. Providing varied forms of stakeholder engagement also facilitated the participatory decision-making process, and increased inclusiveness.

Acknowledgements Funding provided through various government programs such as CMA Caring for Country and through the Office of Environment and Heritage and Commonwealth Environment Water Office environmental water programs. Landholder involvement, knowledge and time was provided as in-kind emphasizing their considerable investment in the program. Review and editorial suggestions for this paper by Paul Childs and Paula D'Santos was greatly appreciated.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

References

Acreman M et al. (2014a) Environmental flows for natural, hybrid, and novel riverine ecosystems in a changing world. Front Ecol Environ 12:466–473. doi:10.1890/130134

Acreman MC et al. (2014b) The changing role of ecohydrological science in guiding environmental flows. Hydrol Sci J 59:433–450. doi:10.1080/02626667.2014.886019

Acuña V et al. (2014) Why should we care about temporary waterways? Science 343:1080–1081. doi:10.1126/science.1246666

Acuña V, Hunter M, Ruhí A (2017) Managing temporary streams and rivers as unique rather than second-class ecosystems. Biol Conserv (in press). doi:10.1016/j.biocon.2016.12.025

Arthington AH (2012) Environmental flows: saving rivers for the third millennium. University of California Press: Berkeley, US, P 406

Arthington AH, Naiman RJ, McClain ME, Nilsson C (2010) Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. Freshw Biol 55:1–16. doi:10.1111/j.1365-2427.2009.02340.x

Benham CF, Beavis SG, Hussey KE (2015) The cost of collaboration: how caring for our country has shaped regional natural resource management in an australian river catchment australasian. J Environ Manage 22:285–297. doi:10.1080/14486563.2014.976847

Bennett NJ (2016) Using perceptions as evidence to improve conservation and environmental management. Conserv Biol 30:582–592. doi:10.1111/cobi.12681

Beratan KK (2007) A cognition-based view of decision processes in complex social-ecological systems. Ecol Soc 1–12

Biggs H, Breen C, Slotow R, Freitag S, Hockings M (2011) How assessment and reflection relate to more effective learning in adaptive management. Koedoe 53:13. doi:10.4102/koedoe.v53i2.1001

Binkley D, Duncan SL (2009) The past and future of colorado's forests: connecting people and ecology. Ecol Soc 1–14

Boulton AJ, Suter PJ (1986) Ecology of temporary streams—an Australian perspective. Limnol Aust 313–327

Brewer SK, McManamay RA, Miller AD, Mollenhauer R, Worthington TA, Arsuffi T (2016) Advancing environmental flow science: developing frameworks for altered landscapes and integrating efforts across disciplines. Environ Manage 58:175–192. doi:10.1007/s00267-016-0703-5

Brooks RT (2009) Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems of the forests of the northeastern United States. Clim Change 95:469–483. doi:10.1007/s10584-008-9531-9

Brownbill T, Warne K (2010) Tuppal Creek strategic plan 2010–2020. Report for Murray Catchment Management Authority

Canessa S et al. (2016) Planning for ex situ conservation in the face of uncertainty. Conserv Biol 30:599–609. doi:10.1111/cobi.12613

Collins KB, Ison RL (2010) Trusting emergence: some experiences of learning about integrated catchment science with the environment agency of england and wales. Water Resour Manag 24:669–688. doi:10.1007/s11269-009-9464-8

Conallin J, Dickens C, Hearne D, Allan C (2017) Stakeholder engagement in environmental water management. In: Horne A, Webb A, Stewardson M, Richter B, Acreman M (eds) Water for the environment: from policy and science to implementation and management. Academic Press, Cambridge

Cook BR et al. (2013) Interrogating participatory catchment organizations: cases from canada, new zealand, scotland and the scottish–english borderlands. Geogr J 179:234–247. doi:10.1111/j.1475-4959.2012.00492.x

Datry T, Fritz K, Leigh C (2016) Challenges, developments and perspectives in intermittent river ecology Freshw Biol. doi:10.1111/fwb.12789

Datry T, Bonada N, Boulton A (2017). Intermittent Rivers and Ephemeral Streams. Ecology and Management. Academic Press. London. P 622

Doley D, Audet P (2013) Adopting novel ecosystems as suitable rehabilitation alternatives for former mine sites. Ecol Process 2:1–11. doi:10.1186/2192-1709-2-22

Fazey I, Proust K, Newell B, Johnson B, Fazey JA (2006) Eliciting the Implicit knowledge and perceptions of on-ground conservation managers of the macquarie marshes. Ecol Soc 1–28

Flitcroft R, Dedrick DC, Smith CL, Thieman CA, Bolte JP (2010) Trust: the critical element for successful watershed management. Ecol Soc 15

Flitcroft RL, Dedrick DC, Smith CL, Thieman CA, Bolte JP (2009) Social infrastructure to integrate science and practice: the experience of the long tom watershed council. Ecol Soc 14:1–17

Garcia X, Barceló D, Comas J, Corominas L, Hadjimichael A, Page TJ, Acuña V (2016) Placing ecosystem services at the heart of urban water systems management. Sci Total Environ 563–564:1078–1085. doi:10.1016/j.scitotenv.2016.05.010

Groffman PM et al. (2006) Ecological thresholds: the key to successful environmental management or an important concept with no practical application? Ecosystems 9:1–13. doi:10.1007/s10021-003-0142-z

Hamm JA, Hoffman L, Tomkins AJ, Bornstein BH (2016) On the influence of trust in predicting rural land owner cooperation with natural resource management institutions. J Trust Res 6:37–62. doi:10.1080/21515581.2015.1108202

Hearne D, Powell B (2014) Too much of a good thing? Building social capital through knowledge transfer and collaborative networks in the southern Philippines. Int J Water Resour Dev 30:495–514. doi:10.1080/07900627.2014.898579

Hobbs RJ et al. (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order Global Ecol Biogeogr. doi:10.1111/j.1466-822X.2006.00212.x

Hobbs RJ, Higgs E, Harris JA (2009) Novel ecosystems: implications for conservation and restoration Trends Ecol Evol. doi:10.1016/j.tree.2009.05.012

Hommes S, Vinke-de Kruijf J, Otter HS, Bouma G (2008) Knowledge and perceptions in participatory policy processes: lessons from the delta-region in the Netherlands. Water Resour Manage 23:1641–1663. doi:10.1007/s11269-008-9345-6

Hurlbert M, Gupta J (2015) The split ladder of participation: a diagnostic, strategic, and evaluation tool to assess when participation is necessary. Environ Sci Policy 50:100–113. doi:10.1016/j.envsci.2015.01.011

Janse JH et al. (2015) GLOBIO-aquatic, a global model of human impact on the biodiversity of inland aquatic ecosystems. Environ Sci Policy 48:99–114. doi:10.1016/j.envsci.2014.12.007

Kennett R, Danielsen F, Silvius KM (2015) Conservation management: citizen science is not enough on its own. Nature 521:161–161. doi:10.1038/521161d

King J, Brown C (2006) Environmental flows: striking the balance between development and resource protection. Ecol Soc 1–22

Kingsford RT, Biggs HC, Pollard SR (2011) Strategic adaptive management in freshwater protected areas and their rivers. Biol Conserv 144:1194–1203. doi:10.1016/j.biocon.2010.09.022

Kingsford RT, Thompson JR (2006) Desert rivers of the world—an introduction. Ecol Desert Rivers 3–10

Knight AT, Cowling RM, Boshoff AF, Wilson SL, Pierce SM (2011) Walking in STEP: lessons for linking spatial prioritizations to implementation strategies. Biol Conserv 144:202–211. doi:10.1016/j.biocon.2010.08.017

Kopf RK, Finlayson CM, Humphries P, Sims NC, Hladyz S (2015) Anthropocene baselines: assessing change and managing biodiversity in human-dominated aquatic ecosystems. BioScience 65:798–811. doi:10.1093/biosci/biv092

Larned ST, Datry T, Arscott DB, Tockner K (2010) Emerging concepts in temporary-river ecology. Freshw Biol 55:717–738. doi:10.1111/j.1365-2427.2009.02322.x

Leahy JE, Anderson DH (2008) Trust factors in community–water resource management agency relationships. Landsc Urban Plan 87:100–107. doi:10.1016/j.landurbplan.2008.05.004

Leigh C, Boulton AJ, Courtwright JL, Fritz K, May CL, Walker RH, Datry T (2015) Ecological research and management of intermittent rivers: an historical review and future directions. Freshw Biol. doi:10.1111/fwb.12646

Longstaff PH, Yang S-U (2008) Communication management and trust: their role in building resilience to "Surprises" such as natural disasters, pandemic flu, and terrorism. Ecol Soc 1–14

Lukyanenko R, Parsons J, Wiersma YF (2016) Emerging problems of data quality in citizen science. Conserv Biol 30:447–449. doi:10.1111/cobi.12706

Maekawa T, Aron D (2016) Community coordination for addressing local environmental challenges: application of the Australian landcare model to Japan. Interdiscip Environ Rev 17:167–181. doi:10.1504/ier.2016.080224

Marshall GR (2013) Transaction costs, collective action and adaptation in managing complex social–ecological systems. Ecol Econ 88:185–194. doi:10.1016/j.ecolecon.2012.12.030

Meyer JL, Strayer DL, Wallace JB, Eggert SL, Helfman GS, Leonard NE (2007) The contribution of headwater streams to biodiversity in river networks. J Am Water Resour Assoc 43:86–103. doi:10.1111/j.1752-1688.2007.00008.x

Moon K, Marshall N, Cocklin C (2012) Personal circumstances and social characteristics as determinants of landholder participation in biodiversity conservation programs. J Environ Manage 113:292–300. doi:10.1016/j.jenvman.2012.09.003

Mott Lacroix KE, Xiu BC, Megdal SB (2016) Building common ground for environmental flows using traditional techniques and novel engagement approaches. Environ Manage 57:912–928. doi:10.1007/s00267-016-0656-8

Moyle PB (2014) Novel aquatic ecosystems: the new reality for streams in california and other mediterranean climate regions. River Res Appl 30:1335–1344. doi:10.1002/rra.2709

Mueller-Hirth N (2012) If you don't count, you don't count: monitoring and evaluation in South African NGOs. Dev Change 43:649–670. doi:10.1111/j.1467-7660.2012.01776.x

Nkhata AB, Breen CM, Freimund WA (2008) Resilient social relationships and collaboration in the management of social-ecological systems. Ecol Soc 1–12

Palmer MA, Reidy Liermann CA, Nilsson C, Flörke M, Alcamo J, Lake PS, Bond N (2008) Climate change and the world's river basins: anticipating management options. Front Ecol Environ 6:81–89. doi:10.1890/060148

Parrott L, Meyer WS (2012) Future landscapes: managing within complexity. Front Ecol Environ 10:382–389. doi:10.1890/110082

Patrick MJ et al. (2014) Building bridges between the sciences and the arts of water co-operation through collective action. Reflect Aquat Proc 2:48–54. doi:10.1016/j.aqpro.2014.07.008

Podolak CJP (2014) A visual framework for displaying, communicating and coordinating a river restoration monitoring project. River Res Appl 30:527–535. doi:10.1002/rra.2651

Poff NL, Matthews JH (2013) Environmental flows in the anthropocence: past progress and future prospects current opinion in environmental. Sustainability 5:667–675. doi:10.1016/j.cosust.2013.11.006

Reeves GH, Duncan SL (2009) Ecological history vs. social expectations: managing aquatic ecosystems. Ecol Soc 1–14

Regan HM, Ben-Haim Y, Langford B, Wilson WG, Lundberg P, Andelman SJ, Burgman MA (2005) Robust decision-making under severe uncertainty for conservation management. Ecol Appl 15:1471–1477. doi:10.1890/03-5419

Reid MA, Thoms MC, Chilcott S, Fitzsimmons K (2017) Sedimentation in dryland river waterholes: a threat to aquatic refugia? Mar Freshw Res 68:668–685. doi:10.1071/MF15451

Richter BD, Warner AT, Meyer JL, Lutz K (2006) A collaborative and adaptive process for developing environmental flow recommendations. River Res Appl 22:297–318. doi:10.1002/rra.892

Rist L, Campbell BM, Frost P (2013) Adaptive management: where are we now? Environ Conserv 40:5–18. doi:10.1017/S0376892912000240

Robinson CJ, Bark RH, Garrick D, Pollino CA (2015) Sustaining local values through river basin governance: community-based initiatives in Australia's Murray–Darling basin. J Environ Plan Manage 58:2212–2227. doi:10.1080/09640568.2014.976699

Ryder DS, Tomlinson M, Gawne B, Likens GE (2010) Defining and using 'best available science': a policy conundrum for the management of aquatic ecosystems. Mar Freshw Res 61:821–828. doi:10.1071/MF10113

Scarlett L (2013) Collaborative adaptive management: challenges and opportunities. Ecol Soc. doi:10.5751/ES-05762-180326

Scott DN (2016) 'We Are the Monitors Now': experiential knowledge, transcorporeality and environmental justice. Soc Leg Stud 25:261–287. doi:10.1177/0964663915601166

Seastedt TR, Hobbs RJ, Suding KN (2008) Management of novel ecosystems: are novel approaches required? Front Ecol Environ 6:547–553. doi:10.1890/070046

Smith JW, Leahy JE, Anderson DH, Davenport MA (2013) Community/agency trust and public involvement in resource planning. Soc Nat Resour 26:452–471. doi:10.1080/08941920.2012.678465

Stanghellini PSL (2010) Stakeholder involvement in water management: the role of the stakeholder analysis within participatory processes. Water Policy 12:675–694. doi:10.2166/wp.2010.004

Stern MJ, Coleman KJ (2015) The multidimensionality of trust: applications in collaborative natural resource management. Soc Nat Resour 28:117–132. doi:10.1080/08941920.2014.945062

Stirzaker RJ, Roux DJ, Biggs HC (2011) Learning to bridge the gap between adaptive management and organizational culture. Koedoe 1–6

Straith D, Adamowski J, Reilly K (2014) Exploring the behavioral attributes, strategies and contextual knowledge of champions of change in the Canadian water sector. Can Water Resour J 39:255–269. doi:10.1080/07011784.2014.942576

Strayer DL, Dudgeon D (2010) Freshwater biodiversity conservation: recent progress and future challenges. J N Am Benthol Soc 29:344–358. doi:10.1899/08-171.1

Stringer LC, Dougill AJ (2013) Channeling science into policy: enabling best practices from research on land degradation and sustainable land management in dryland Africa. J Environ Manage 114:328–335. doi:10.1016/j.jenvman.2012.10.025

Stringer LC, Dougill AJ, Fraser E, Hubacek K, Prell C, Reed MS (2006) Unpacking participation in the adaptive management of social-ecological systems: a critical review. Ecol Soc 11: 1–22

Tennent R, Lockie S (2013) Vale Landcare: the rise and decline of community-based natural resource management in rural Australia. J Environ Plan Manage 56:572–587. doi:10.1080/09640568.2012.689617

Von Korff Y, d'Aquino P, Daniell KA, Bijlsma R (2010) Designing participation processes for water management and beyond. Ecol Soc 15:1–29

Walkerden G (2006) Adaptive management planning projects as conflict resolution processes. Ecol Soc 1–11

Webb JA, Miller KA, de Little SC, Stewardson MJ (2014) Overcoming the challenges of monitoring and evaluating environmental flows through science–management partnerships. Int J River Basin Manage 12:111–121. doi:10.1080/15715124.2014.901332

Westley F, Holmgren M, Scheffer M (2010) From scientific speculation to effective adaptive management: a case study of the role of social marketing in promoting novel restoration strategies for degraded dry lands. Ecol Soc 15: 1–16

Williams BK, Brown ED (2014) Adaptive management: from more talk to real action. Environ Manage 53:465–479. doi:10.1007/s00267-013-0205-7

Zand DE (2016) Reflections on trust and trust research: then and now. J Trust Res 6:63–73. doi:10.1080/21515581.2015.1134332