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Institutional impediments to conservation of freshwater dependent ecosystems

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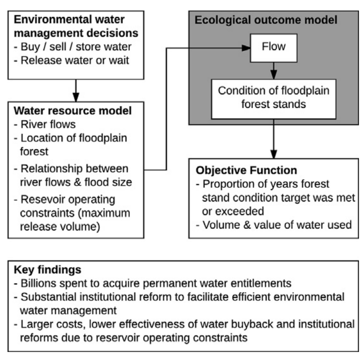
HIGHLIGHTS

- Regulation of river flows with reservoirs threatens many of the world's floodplain ecosystems.
- The decline of aquatic and floodplain ecosystems has motivated programs that return more water to the environment.
- In Australia's Murray-Darling Basin billions are being spent to return water to aquatic and floodplain ecosystems, managed by environment water holders.
- Recovery of floodplain forests by releasing water from reservoirs during periods of high flow is undermined by restrictions on river operations.
- Expensive water recovery programs can fail to achieve conservation aims without cooperation among stakeholders including reservoir operators.

GRAPHICAL ABSTRACT



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ABSTRACT

When freshwater resources become scarce there is a trade-off between human resource demands and environmental sustainability. The cost of conserving freshwater ecosystems can potentially be reduced by implementing institutional reforms that endow environmental water managers with a permanent water entitlement and the capacity to store, trade and release water. Australia's Murray Darling Basin Plan (MDBP) includes one of the world's most ambitious programs to recover water for the environment, supported by institutional reforms that allow environmental water managers to operate in water markets. One of the anticipated benefits of the Plan is to improve the health of flood-dependent forests, which are among the most endangered ecosystems globally because of river regulation and land clearance. However, periodic flooding to conserve floodplain ecosystems in the MDB creates losses to riparian landowners such as damage to fencing and temporary loss of access to flooded land. To reduce these losses reservoir operators restrict daily water release volumes. Using a model of optimal water management in Australia's southern MDB we estimate that current reservoir operating restrictions will substantially reduce the ecological benefits of investments made to recover water for the environment. The reduction in benefits is largest if floodplain forests decline rapidly without periodic inundation. In the latter

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Water entitlements
Water trading

circumstances, ecological losses cannot significantly be reduced by allowing environmental water managers to operate in water markets. Our findings demonstrate that the recovery of large volumes of water for environmental purposes and water market reforms are insufficient for conserving flood-dependent ecosystems without coordination and cooperation among multiple stakeholders responsible for water and land management.

1. Introduction

The sustainable management of natural resources often involves a trade-off between human use and ecological health (Walker et al., 2009). Competition for scarce water resources will intensify as human populations grow and climates change (Vörösmarty et al., 2000). In response to increasing pressures on limited natural resources, attempts are being made to find an improved balance between consumptive human use and environmental needs (Arrow et al., 1995). In the case of water resources, this involves finding water use strategies that minimize the costs imposed when water is transferred from agricultural and domestic uses to the environment (Horne et al., 2017).

In a growing number of settings this transfer is facilitated by institutional reforms including the establishment of water rights frameworks in which the 'environment' is treated similarly to other rights holders (Bakker, 2014). The extent to which these reforms reduce the cost of transferring water to the environment depends on how the reforms affect environmental water managers' capacity to store, trade and release water (Connor et al., 2013; Grafton and Horne, 2014). This is shown, for example, when countercyclical water trading (selling to agricultural water users when water prices are high and buying when prices are low) allows water to be used for environmental purposes when its value for consumptive uses is relatively low (Loch et al., 2011). In addition to the introduction of water trading, further reductions in the cost of environmental watering can potentially be achieved by endowing the environmental water manager with an optimal portfolio of permanent water entitlements. Water entitlements are an ongoing claim to a share of the water resource. In many water markets, security-differentiated entitlements are available that differ according to their cost and the maximum allocation that can be made against water storages each year. Low security entitlements have a lower cost than high security entitlements but are less likely to receive water allocations when water availability is low (Lefebvre et al., 2012). Increasing the holdings of low-security entitlements as a source of environmental water allocations can potentially reduce costs without preventing ecological needs being met. However, in regions experiencing a drying climate, the reliability of water allocations to low security entitlements may decline to the extent that such entitlements cannot meet environmental needs.

One of the main potential impediments to cost-effective environmental water management is institutional fragmentation, in which uncoordinated actions are taken by different water stakeholders (Daniell et al., 2014; Daniell and Barrateau, 2014). This problem is particularly acute when there are conflicting aims of different stakeholders. In Australia's Murray-Darling Basin a source of conflict is the need for periodic flooding to conserve floodplain ecosystems, reflecting that floods create losses to riparian landowners such as damage to fencing and temporary loss of access to flooded land. These losses are often mitigated by reservoir operators through imposing restrictions on daily reservoir releases to reduce the likelihood of a flood event. In turn, these operating restrictions can potentially reduce the cost-effectiveness of environmental water recovery programs and institutional reforms to facilitate efficient environmental water management. In extreme circumstances, such restrictions can make it infeasible for an environmental water manager to create or prolong floods to conserve flood dependent ecosystems. This would make floodplain ecosystems wholly dependent on the frequency of natural flood events or necessitate costly investments in pumps and infrastructure to facilitate water delivery to those ecosystems (Pittock et al., 2013).

Substantial research has been undertaken on the potential benefits of institutional reforms to conserve freshwater dependent biota (see Hart, 2016a for a comprehensive review). Research has also been conducted on the potential for river operation restrictions to undermine institutional reforms (Hart, 2016a, 2016b). There is a need for quantitative estimates of the impact of such restrictions on the cost and feasibility of floodplain conservation. This information would usefully inform decisions on whether to relax those restrictions or invest in infrastructure that would allow water to be delivered to floodplain ecosystems without requiring large floods.

The primary aim of this study is to provide early empirical evidence on the extent to which river operation restrictions can reduce the benefits of water recovery programs and institutional reforms aimed at conserving floodplain biota. This requires a method for determining efficient water management strategies. If river operation restrictions substantially increase conservation costs or reduce conservation effectiveness despite water being managed efficiently, this would strengthen the case for a detailed assessment of options to mitigate such losses. Here, we define a water management strategy to be efficient if it minimizes the total volume of water required to achieve a specified ecosystem health target. We determine efficient water management rules using genetic programming (Potvin et al., 2004).

We apply the method to a case study focusing on a catchment within Australia's Murray-Darling Basin system, where one of the world's largest institutional reform programs to recover water for the environment has been implemented (Hart, 2016a, 2016c; Hart and Davidson, 2017). The water recovery program has been supported by the creation of an environmental water holder endowed with a portfolio of permanent water entitlements and the capacity to store and trade water. One of the primary anticipated ecological benefits of the Plan is the conservation of floodplain forests, which are among the most endangered ecosystems globally, threatened primarily by river regulation. Approximately half of the wetlands and floodplain habitats in the MDB could potentially be watered with releases from reservoirs in the absence of constraints on daily release volumes (Bunn et al., 2014; MDBA 2012). The ecological asset we consider is a floodplain forest of river red gum (*Eucalyptus camaldulensis* Dehnh) that requires periodic flooding to be maintained at a high level of health. The forest occupies discrete land parcels within the floodplain. In our analysis, parcels were defined by their distance from the edge of the river-bank. Distant parcels are inundated only with larger floods. An efficient water release strategy trades off immediate gains from small floods that inundate only part of the floodplain with potential future gains from waiting to inundate extensive areas. The likelihood of creating a larger flood later depends on future river flows, dam release capacity, and the extent to which environmental water holdings can be increased over time through storage and water trading.

2. Study area

We focused on 150 km of the lower Goulburn River Floodplain (Fig. 1), which lies between the Goulburn Weir (36.717 °S 145.170 °E) and its junction with the Murray River (36.103 °S 144.830 °E) in northern Victoria, Australia.

Detailed hydrological data and spatial data on river red gum stands were available for the study area. The hydrological data included a long-term dataset of simulated flows and dam-storage levels between