

Beguiling and risky: ‘environmental works and measures’ for wetland conservation under a changing climate

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Received: 23 February 2012 / Accepted: 19 August 2012 / Published online: 11 September 2012
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Abstract In Australia’s Murray–Darling Basin, small-scale engineering works called ‘environmental works and measures’ have been implemented as a basis for river and other wetland conservation. While implementing these, governments seem to have embraced the beguiling notion that scarce water supplies can be divided further, while conserving the environment and maintaining agricultural production. The difficulties in doing this are expected to increase in the face of extreme climate variability. With this scenario as a backdrop, the \$280 million (Monetary values (\$) in this paper are in Australian dollars (AUD). At the time of writing AUD \$1.00 = ~USD \$1.02.) Living Murray and related programmes are assessed to see whether microengineering works to manage the hydrology of wetlands make for effective

adaptation to water scarcity and climate change or whether it amounts to an overly narrow adaptation or maladaptation. Some measures were found to be substantially beneficial, such as the construction of fishways. However, under these programmes, only 0.6% of the Basin’s wetlands would be inundated and there are significant risks including desiccation of non-target wetlands and further reductions in water allocations for the environment. It is recommended that trade-offs between alternative strategies are assessed as the basis for minimising perverse impacts under changing climatic and hydrological conditions.

Keywords Climate change · Floodplain · Maladaptation · Murray–Darling · Opportunity cost · Overly narrow adaptation · River

Guest editor: C. Max Finlayson / Wetlands and climate change: ecological outcomes and adaptation as shown by Australian case studies

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Introduction

This paper considers whether the beguiling notion that humanity can re-engineer wetlands (also referred to as freshwater ecosystems in this paper) to use less water to maintain ecosystems in the face of overexploitation and change is a meritorious, adaptive strategy or is overly optimistic in failing to consider risks and trade-offs. The focus of this research is the set of management interventions known as ‘environmental water demand management’ in the international literature

(Lankford, 2003; Pittock & Lankford, 2010) and ‘environmental works and measures’ (EWM) in Australia (MDBA, 2011a) that are proposed as riverine wetland restoration measures (Palmer et al., 2005).

These issues are explored in a case study from the Murray–Darling Basin in south-eastern Australia as a place where extensive EWMs have been undertaken in response to a policy decision by the state and federal governments in 2003. In exploring these, we describe the engineering interventions that have occurred in the Basin and place the trade-offs between wetland conservation, water use and climate change in a global context.

Global context

Not just is humanity drawing increasingly heavily on the world’s water resources with more than half the world’s readily accessible freshwater diverted, but the volume required to grow food for a burgeoning population is expected to double future diversions (Shiklomanov, 1997; CAoWMiA, 2007; WWAP, 2009). Although wetlands globally provide many ecological services per unit area, contain the greatest portion of threatened species and are not well represented in nature reserves, they have also been heavily exploited, especially for water and fish (MEA, 2005, pp. 19, 39). One consequence of this level of exploitation is the growing number of river basins around the world that have become ‘closed’ with the available freshwater effectively exploited for human consumption to the extent that these rivers no longer regularly flow to the ocean (Falkenmark & Molden, 2008).

Climate change is expected to be expressed most strongly in freshwater ecosystems through changes in precipitation and flow patterns, increasing the recurrence of extreme flow events and reducing water quality, thus exacerbating the impacts of humanity on wetlands (Bates et al., 2008). Expected reductions in water availability in mid-latitude river basins and more frequent drought are anticipated to exacerbate the desiccation of wetland ecosystems (Bates et al., 2008; Cai & Cowan, 2008; CSIRO, 2008). Further, societal responses to climate change are likely to increase diversions of water and further degrade wetland ecosystems (Pittock, 2010, 2011). Under these circumstances, there is a pressing need to explore how benefits for people and for wetland

conservation can be optimised by more efficiently using available water.

The Living Murray (LM) programme and water reform

Over the past decade, the Australian government agencies and regional natural resource management institutions have developed a body of environmental water demand management practices known as ‘EWM’. (The terms environmental water demand management and EWM are often used interchangeably.) As an example, the Murray–Darling Basin Authority has stated that ‘The objective of the works and measures is to multiply the environmental benefits achievable from the water available [...] The water management structures being built at the floodplain sites are intended to enable controlled landscape-scale flooding using environmental water – often in much smaller volumes than would be required without these works’ (MDBA, 2011a, p. 56). The LM programme undertaken in the Basin provides a case study of the costs as well as the benefits and trade-offs associated with environmental interventions.

The Basin covers a seventh of Australia, over a million km², and contains the Murray–Darling river system, arguably Australia’s most important rivers (Fig. 1). Wetlands cover 5.7 million ha (as at 1984–1993), including extensive Redgum (*Eucalyptus camaldulensis*) forests on the more frequently inundated floodplains and less frequently inundated Black Box (*Eucalyptus largiflorens*) forests (Kingsford et al., 2004). Consumptive water use across the Basin has reduced average annual stream flow at the Murray mouth by 61% (CSIRO, 2008). Irrigation in the Basin uses 90% of the diverted waters to produce 70% of Australia’s irrigated agricultural output, valued at \$7 billion per year (ABS et al., 2009). Rainfall and runoff are highly variable in volume and time, and the southern portion of the Basin, which contains the River Murray, appears particularly vulnerable to reductions in water availability due to climate change (Cai & Cowan, 2008; CSIRO, 2008). Detailed assessment by CSIRO (2008) suggests that by 2030, average surface water availability in the Basin could increase by up to 7% or decline by as much as 37% with the results being magnified with progression downriver such that outflows through the wetlands of the Coorong and Lower Lakes may increase by as much

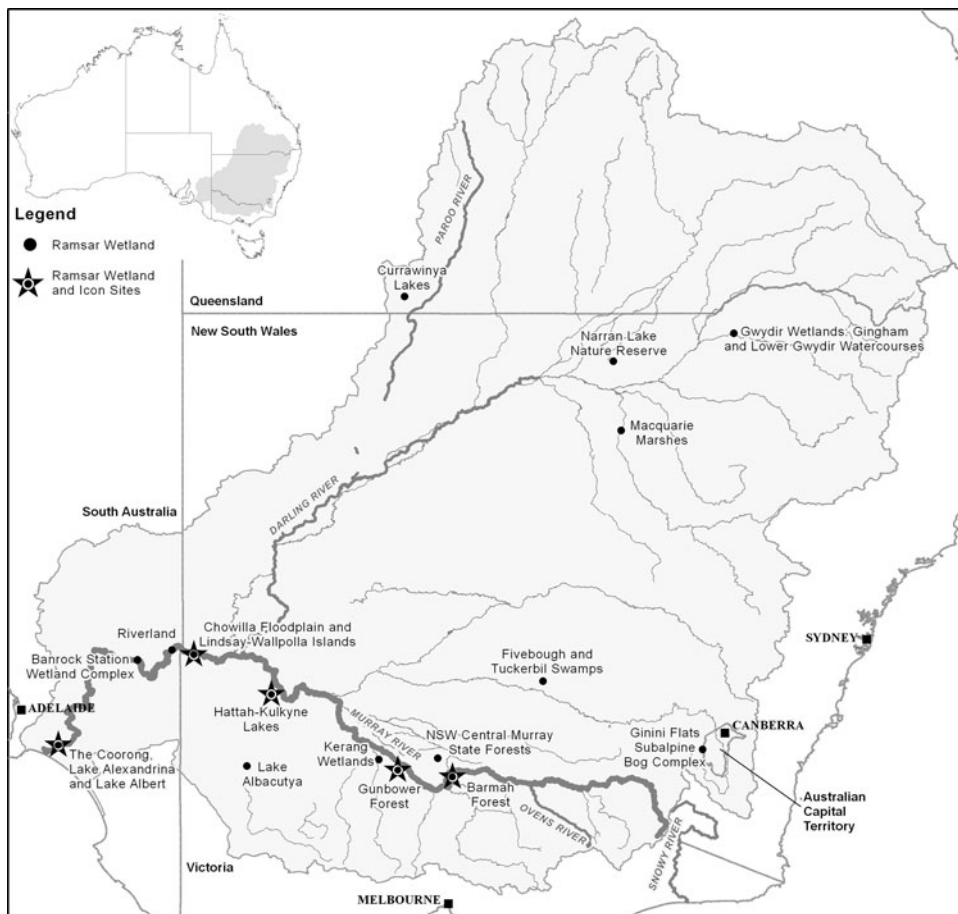


Fig. 1 Location of the Murray–Darling Basin showing major rivers, Ramsar and icon wetland sites

as 20% or decline by a catastrophic 69%. Drier conditions are expected in the southern portion of the Basin.

Extreme events are likely to be more ecologically significant than average conditions and the Basin is subject to great hydrological variability as illustrated by the drought from 2002 to 2010 when inflows declined by 40%. During the drought, a greater portion of available water was diverted to agriculture than to the environment compared to wetter years (CSIRO, 2008; WGCS, 2011). The impacts of water diversions were exacerbated in the past decade of drought with desiccation resulting in declines of some wildlife populations, the degradation of tens of thousands of hectares of floodplain forest, increased salinity and acidification (Pittock et al., 2010).

Under Australia's constitution, the state governments, not the Federal Government, have assumed

primary responsibility for management of natural resources, including water. The Federal Government has exercised increasing authority culminating in a mandate to make the final decisions on water allocations through the Murray–Darling Basin Authority and a Basin Plan under the Water Act 2007–08 (Pittock et al., 2010). In practice, the state and federal governments have reached collective decisions for managing water in the Basin. In 1994, they instigated a number of measures to limit the impact of water diversions on the environment: Surface water extractions were capped, although groundwater withdrawals were not, even in instances where links were immediate and direct (Nevill, 2009). In 2002, an independent Expert Reference Panel, formed to advise the governments on reallocation of water for the River Murray, recommended five flow options ranging from reallocation of a minimum of 350 Mm³/year that

would have a low probability of having a ‘healthy working’ river to a maximum of 4,000 Mm³/year with a higher probability (Jones et al., 2002). In 2003, the governments agreed to reallocate 500 Mm³/year through the LM programme as a ‘first step’ focussed on meeting specific ecological targets to conserve six ‘icon sites’ or ‘ecological assets’ (five of which were wholly or largely comprised of Ramsar wetland sites; Fig. 1; MDBMC, 2003; Pittock et al., 2010).

The LM included ‘realignment of a previously announced capital works program of an additional \$150 million over 7 years to effectively manage the water to the six significant ecological assets’ that became the genesis of EWM (MDBMC, 2003, p. 2). As the additional 500 Mm³/year on average of environmental water was insufficient to inundate enough of the floodplains to achieve the politically mandated targets, engineering interventions were planned to increase the benefits from the limited water available (MDBMC, 2004; MDBC, 2006a, b). The scale of the EWMs under the LM evolved with implementation being extended to 2014 and a planned total expenditure of \$280 million, including around \$45 million for the installation of fishways (ladders) on the infrastructure on the River Murray (MDBA, 2011a). High costs have seen many initially proposed measures postponed and implementation focussed on just four of the six icon sites, excluding the Coorong, Lakes Alexandrina and Albert and the Barmah–Millewa Forest (MDBA, 2011b). Nevertheless, the ambition of the programme was retained as indicated by the Authority’s boast that ‘The Living Murray [...] “works + water” – a combination that is probably unprecedented at this scale anywhere in the world. Certainly no other program to date has taken on the challenge of engineering landscape-scale flooding of multiple Ramsar-listed sites’ (MDBA, 2011a, p. 56).

Concurrently, the Australian Government in 2004 adopted the National Water Initiative (Commonwealth of Australia et al., 2004) with an emphasis on: (i) market-based instruments to promote more efficient use of water; (ii) the return of all over-allocated river systems to sustainable levels; (iii) the provision of environmental flows; (iv) sustainable management through catchment plans; and (v) complementary management of surface and ground waters. These measures were intended to be implemented through regional plans that allocated water between consumptive users and the environment and

applied in all conditions, including severe drought. Yet, during the 2002–2010 drought, the states of Victoria and New South Wales suspended many of their water sharing plans (from 2006 and 2007, respectively) (NWC, 2009). Overall, the implementation of many of the environmental components of the Initiative is seen as inadequate (NWC, 2011).

The manifest failure of previous reforms to conserve freshwater ecosystems led to the Federal Government asserting a larger, more direct role in managing the Basin’s water under the Water Act 2007 (Commonwealth of Australia, 2007). Under this Act, a Murray–Darling Basin Authority was established to prepare a Basin Plan that ensured the conservation of ‘key ecological assets’ by establishing sustainable diversion limits for water. The Authority published a *Guide to the Proposed Basin Plan* that summarised its scientific assessments and stated that meeting the Act’s ecological objectives would require the reallocation of 7,600 Mm³/year on average, but to reduce socio-economic impacts, this should be reduced to 3–4,000 Mm³/year on average (MDBA, 2010). Some quantitative system-wide ecological targets were proposed; however, the scientific and legal basis for these was not made clear and, in many cases, was less than those in the LM and unachievable with the proposed water allocations (Pittock et al., 2010; Pittock & Finlayson, 2011a). Opposition from irrigation farmers in the Basin resulted in political pressure to reduce the reallocation of water from consumptive users (Connell & Grafton, 2011) and led to a parliamentary enquiry (the ‘Windsor Inquiry’) that recommended a reorientation towards EWM and water efficiency investments to recover water (HRS-CRA, 2011).

With support from the Murray–Darling Basin Governments’ Ministerial Council, the Australian Government committed a further \$10 million towards the cost of investigating EWM projects (MDBLGF, 2011). The Authority then published its proposed Basin Plan with the proposed reallocation of water to the environment being reduced to 2,750 Mm³/year on average (around a quarter of water currently allocated for consumption) with an intention to reduce this reallocation with ‘savings’ from EWM and consumptive water efficiency savings, and with implementation delayed to 2019–2024 (MDBA, 2011b). The extent to which these measures would conserve wetlands in the Basin is unclear due to the absence of quantified

ecological targets and the failure to apply existing floodplain inundation and climate change models (Young et al., 2011).

Methods

In this assessment, we consider the EWMs undertaken in the LM, based on publicly accessible documents from state and federal governments. The EWMs are categorised and the water management and ecological implications of these assessed as far as possible using the publicly available information.

The intended ecological outcomes of the EWMs that are being implemented are assessed against the extent of the wetlands in the individual icon sites and in the Basin. The actual water delivery and ecological outcomes of the EWMs undertaken during the 2002–2010 drought are also assessed. This was supported by a review of the documentation submitted for six environmental impact assessment ‘referrals’ (proposals) for approval of various EWMs as required under the Commonwealth Environmental Protection and Biodiversity Conservation Act (Australian Government, 1999). The monetary cost of each EWM was determined and compared against the cost of purchasing water entitlements and wetlands as an alternative to undertaking the EWMs.

The additional measures proposed by the Windsor Inquiry and state governments for further EWMs were then reviewed to ascertain the extent to which they may contribute to the long-term conservation of significant wetlands (HRSCRA, 2011; MDBLGF, 2011). Lastly, the benefits, operational implications and ecological costs of each EWM from the preceding assessments were summarised using information obtained from the wider literature.

This assessment covers the collective effect of the LM EWM on a number of linked wetlands along the River Murray. We have not assessed the costs and benefits of alternative land purchase, water acquisition and EWM interventions at an individual floodplain wetland site because of difficulties in quantifying the effects of different water management strategies at this scale. Some of these costs and benefits can be quantified, such as the cost of works and of water and the volume of water that may fill an individual floodplain wetland. Land prices at these sites can also be inferred, but in this instance, the wetlands are

already largely publicly owned and managed for conservation (other Basin wetlands are not). The major difficulty in assessing the costs and benefits of the alternatives arises from the difficulty of predicting the marginal additional benefit of adding further volumes of environmental water to these extensive, flat and linked floodplain wetlands as the area is inundated and ecological responses vary greatly in response to many factors, including the water volume in the main river channel, the timing of water releases, the relationship to flood frequency and, in future, the consequences of climate change (CSIRO, 2008; Saintilan & Overton, 2010). Further, discharge from an upstream wetland, if conserved, may aid inundation of one or more downstream wetlands. Government-held models can be used to enumerate different scenarios for inundation patterns, but have not been applied to individual wetlands for the purpose of assessing EWMs (Saintilan & Overton, 2010; Young et al., 2011).

Results

Planned EWMs

The EWM options initially considered by the Authority for the six sites included in the LM programme are listed and described in Table 1, but implementation focused on four sites: The River Murray channel, Koondrook–Perricoota–Gunbower, Hattah Lakes and Chowilla. At the time of implementation at the Koondrook–Perricoota–Gunbower and Chowilla sites, the flows remaining in the River Murray were inadequate to create overbank flows frequently enough to sustain extensive floodplain forest wetlands, leading to efforts to transfer and pool smaller volumes of water higher up on the floodplain. At Hattah Lakes, the Chalka Creek distributary did not receive frequent enough inflows over the sill that separates it from the River Murray, resulting in attempts to divert water and accumulate it at a higher elevation in the anabranch system. In the River Murray channel, a series of weirs (low elevation dams that are also called locks) formed barriers to fish movement. Additional works and measures were also considered for the Barmah–Millewa, which is often unseasonably flooded due to irrigation water delivery, to improve flows at the mouth of the river. Measures for the Coorong and lakes Alexandrina and Albert were removed from the

LM and transferred to another programme. Research into options for intervention was also proposed for tributaries of the River Murray in New South Wales and Victoria.

Implementation of EWMs

A summary of the EWMs undertaken in the four icon wetlands that are the focus of the LM is shown in Table 2. This describes the flood frequencies before implementation and those planned afterwards, areas intended to be inundated, as well as the types of structures installed. Based on the area intended to be inundated with the EWM, 36,108 ha or around a third of the area of the three targeted icon floodplain wetlands would benefit from controlled flows (Table 2). As there are 16 designated Ramsar wetland sites, covering 636,592 ha, in the Basin, the proposed level of inundation would mean that 5.7% of the area of the Ramsar sites can be watered. Of the 5.7 million ha of wetlands in the Basin (Kingsford et al., 2004), EWM applied to 36,108 ha would enhance flows on 0.6% of the wetlands.

Management of environmental risks

Environmental risks from six proposed EWM projects were assessed by the Federal Minister for the Environment under the Environmental Protection and Biodiversity Conservation Act based on documentation provided by the state government agency proponents.¹ The Minister designated them as ‘not a controlled action’, meaning that further environmental impact assessment was not required, and approved them (in one case adding specific conditions for implementation). On average, these proposals were approved quickly by the Minister in only 23 working days after public consultation.

Of the three states which submitted proposals, only in the case of the Koondrook–Perricoota in New South Wales was a formal environmental impact assessment in preparation under state law, and in that case, it was not complete at the time of the Federal Government

approval. The EWM referral documentation cites a number of informal environmental risk assessment reports commissioned by the LM using commercial consultants; but, as these reports are not publicly available, it is not known whether they were peer reviewed and there is no indication that they were provided to the Federal Minister for the Environment to consider in his assessment.

The referral documents and a review by Authority staff cite three types of risks from the EWM (NCCMA, 2005; DWLBC, 2007; Burns et al., 2008; Jolly et al., 2008; Office of Water, 2009; GMW, 2010), namely:

Risks to fauna:

- Temporary reductions in flow velocity, disadvantaging large-bodied fish species;
- Greater mortality of fish larvae;
- Barriers to fish passage;
- Trapping of fish on the floodplain;
- Reduction of cues for fish migration and breeding due to changes in flows;
- Increased populations of invasive species, including Common Carp;
- Loss of hatched waterbirds if managed flooding is inadequate to support fledging; and
- Greater predation of turtles.

Risks to vegetation:

- Vegetation clearance to construct EWM;
- Depletion of understory vegetation;
- Inundation of vegetation intolerant of flooding through artificial diversion of flows into higher parts of some floodplains; and
- Invasion by weeds.

Water quality risks:

- Exacerbating salt loads in the River Murray;
- ‘Blackwater events’ (see below); and
- Cyanobacteria blooms.

Four trends are evident in the management of environmental risks in the documentation. First, there is no recognition that many of the EWMs may directly or indirectly reduce flows to and desiccate and degrade areas of non-target floodplain wetlands and that the loss of wetland structure and function is unlikely to be fully re-established through ‘restoration’ (Moreno-Mateos et al., 2012). Second, it is explicitly stated that the risk of impacts on fish passage or the occurrence of

¹ Six referrals of LM EWM project proposals to the Federal Minister between 18th February 2004 and 30th September 2010 drawn from the online database for the Environmental Protection and Biodiversity Conservation Act (accessed on 5 January 2012) at: <http://www.environment.gov.au/epbc/>.

Table 1 EWM initially proposed in the LM (MDBMC, 2004)

#	Site and measure	Types of EWM							Intended ecological benefit/s	
		Planning	Channels	Regulators	Levees & banks	Pumping	Fishways	Flood easement		Dam reoperation
<i>Barmah–Millewa Forest</i>										
1	Lake Muiwala rain rejection management	×								Prevent unseasonal flooding of the forest when irrigators upstream reject water in transit following rain
2	Rehabilitation of Tuppal and Bullatale creeks		×	×						Restore wetlands along these prior streams and prevent unseasonal flooding of the forest from rain rejection flows
3	Structural and flow options for Millewa Forest	×		×			×			Investigation and implementation of structural works and flow options and construction of fish passages
4	Barmah Forest water management plan and works	×		×			×			Better planning of flows in the forest and flow-regulating structures to better manage both seasonal and unseasonal flood events
5	Protection and enhancement of Murray Cod populations	×					×			Investigating Murray cod populations in tributaries and development of a management strategy for the operation of weirs and fishways
Sub-total										
6	Acquisition of flood easements	×						×		Investigation of acquisition of flow rights to pass regulated flows up to 45,000 ML/day to provide increased operational flexibility for flooding of the forest
<i>Gunbower, Koondrook–Perricoota Forests</i>										
7	Gunbower environmental flow management	×		×				×		Better planning of flows in the forest and construction of regulating structures
8	Structural and operational works for Koondrook–Perricoota	×		×		×		×		Means to deliver water to the forest and flow-regulating structures

Table 1 continued

#	Site and measure	Types of EWM							Intended ecological benefit/s	
		Planning	Channels	Regulators	Levees & banks	Pumping	Fishways	Flood easement		Dam reoperation
<i>Hattah Lakes</i>										
9	Hattah Lakes Implementation Project	×	×	×	×	×				Sill lowering and pumps to divert water into the Chalka Creek distributary and regulators to direct and hold waters will reduce the commence-to-flow threshold from 37,600 MI/day to 20,000 MI/day and reduce water required to fill the lakes from 106 to 41 Mm ³
<i>Chowilla Floodplain (including Lindsay and Wallpolla islands)</i>										
10	Improved flow management of the Lindsay–Wallpolla system	×		×						Better planning of flows in the forest and construction of regulating structures
11	Environmental enhancement of the Chowilla Floodplain	×		×						Better planning of flows in the forest and construction of regulating structures
12	Experimental watering of the Chowilla Floodplain							×		Pilot watering of the floodplain (completed in 2004)
13	Mallee environmental flows programme—Mulcra Island	×								Development and implementation of a water management plan
<i>The Murray Mouth, Coorong and Lower Lakes</i>										
14	Remote operation of barrage gates								×	Installation of remotely operated barrage gates to improve operational flexibility
15	Restoration and enhancement dredging of the Murray Mouth						×			Development of an optimal dredging regime for sand removal at the Murray Mouth to restore and enhance the environmental health of the Coorong and Lower Lakes

Table 1 continued

#	Site and measure	Types of EWM							Intended ecological benefit/s	
		Planning	Channels	Regulators	Levees & banks	Pumping	Fishways	Flood easement		Dam reoperation
<i>River Murray Channel</i>										
16	Hume Dam—sea fish passage programme						×			Construction of fishways on all locks and weirs between the sea and Hume Dam to support the recovery of native fish populations
17	Resnagging and riparian restoration						×			Provision of in-channel habitat through resnagging and restoration of the adjacent riparian zone to secure the long-term viability of existing native fish populations
18	Best practice wetland management	×				×				Development of a wetland management plan, construction of regulating structures and monitoring
19	Tristate weir pool project	×							×	Research on the risks and benefits of weir pool manipulation: raising and lowering water levels
20	Euston Weir Pool trial manipulation	×							×	Research on the social and economic impacts that would be associated with a weir pool drawdown at Euston Weir
21	Resnagging and riparian restoration—refuge habitat	×								Research on the role of backwaters and anabranches in the ecology of the Murray to map and prioritise suitable sites for rehabilitation
22	Identification and prioritisation of River Murray Channel works	×								Prioritised inventory of all potential river and floodplain management works to enhance the environmental health of the River Murray Channel
23	The Murray above Hume Management Plan	×								Development and implementation of a plan to improve instream and riparian habitat on the River Murray above Hume

Table 1 continued

#	Site and measure	Types of EWM							Intended ecological benefit/s	
		Planning	Channels	Regulators	Levees & banks	Pumping	Fishways	Flood easement		Dam reoperation
<i>Complementary investigations and actions</i>										
24	Adaptive management	×								Develop an adaptive management framework to be used to evaluate current or future investment performance against ecological objectives
25	Lake Victoria outlet modifications							×		Investigate the use of flows from Lake Victoria to supplement naturally occurring flood flows in the River Murray to benefits Chowilla
26	Menindee Lakes EIS							×		Assess structural options to improve operational flexibility and flows into the Darling River
27	Darling Anabranch EIS							×		Construction of a pipeline to supply users and an improved flow regime for the Anabranch
28	Terrain mapping	×								Research on high-resolution terrain mapping for the lower River Murray and Darling system
29	Salinity management—Bookpurnong Floodplain							×		Provide a model for a salt interception scheme design
30	Salinity accounting for EWM Programme							×		Investigate any potential salinity impacts of EWM projects and advise on salinity mitigation options to offset any potential impacts
31	Opportunities in major tributaries (Victoria)							×		Review the Goulburn River system for opportunities for modification of existing or new infrastructure to improve the environmental health of riverine and wetland systems

Table 1 continued

#	Site and measure	Types of EWM							Intended ecological benefit/s
		Planning	Channels	Regulators	Levees & banks	Pumping	Fishways	Flood easement	
32	Opportunities in major tributaries (New South Wales)	×							Review the Murrumbidgee river system for opportunities for modification of existing or new infrastructure to improve the environmental health of riverine and wetland systems
33	Mobile pumping infrastructure	×				×			Investigate the benefit of using mobile pumps to maintain and enhance floodplain health

‘blackwater’ events (when inundation of leaf litter results in rapid decomposition, release of nutrients and de-oxygenation due to microbial growth) will be managed by developing infrastructure operational experience. However, it is known that using small volumes of water to create slow moving inundation events is likely to increase the risk of blackwater events (Howitt et al., 2007). Third, at two icon wetland sites, the EWMs could exacerbate existing salinisation problems (Jolly et al., 2008). A range of wetlands in the Basin have been linked with acidification events (Hall et al., 2006) and links between acid sulphate sediments and salinity have been established (Whitworth & Baldwin, 2011), indicating that an increase in salinisation may have much broader impacts on water quality and wetland function. Lastly, each proposal explicitly declares that the trade-offs between additional watering of some portion of the wetlands and the impacts of EWM are overwhelmingly beneficial and that there will be no significant negative impacts on matters of national biodiversity significance (which include Ramsar wetlands and nationally threatened species at these sites).

The EWMs being proposed seem to be conflating the concept of increasing water for environmental flows with additional interventions, microengineering works to manipulate such water. This is encapsulated by King et al. (2010, p. 27) who argue in relation to the use of a particular EWM that ‘Given the significant ecosystem benefits that can be achieved by the careful management and use of environmental flows, the risk of any negative consequences should not be considered as reasons to cease environmental water releases’.

Ecological outcomes

It could be considered premature to report in 2012 on the ecological outcomes of a EWM programme that only commenced in a drought in 2004 and when construction is planned through to 2014. Nonetheless, the Authority has reported on ‘trends in icon site health associated with environmental watering 2004-10’, as summarised in Table 3. Also contained in Table 3 is information on (i) the original conservation objectives agreed to by the governments and (ii) the portions of floodplain forest in good condition after assessments in 2006 and 2009 (MDBMC, 2003; Cunningham et al., 2007, 2009; MDBA, 2011a).

Table 2 Four icon wetlands subject to EWM under The LM illustrating flood frequencies, areas inundated and the types of structures installed (NCCMA, 2005; DWLBC, 2007; Office of Water, 2009; GMW, 2010; MDBA, 2011a)

Site	Frequency of overbank floods		Area to be inundated (ha)	Icon site area (ha)	Percentage inundated with EWM ^a	Types of structural EWM				
	Naturally	Without works				With works	Channels	Regulators	Levees/stop banks	Pump station
Koondrook-Perricoota ^a	25 in 100	<10 in 100	16,000	31,150	51.4	3.95 km new	~9	42 km	n/a	Yes
Gunbower ^b			7,250	19,931	36.4	–	4	–	–	1
Hattah Lakes	20 in 100	<10 in 100	5,358	13,000	41.2	1.31 km, natural	4	×3	1	2
Chowilla	45 in 100	12 in 100	7,500	37,700	19.9	–	–	–	–	Yes
River Murray	–	–	–	–	–	–	–	–	–	14
Total			36,108	101,781	35.5					

^a Koondrook–Perricoota and Gunbower are the New South Wales and Victorian portions of one icon site

^b Calculated as the portion of the icon site that may be inundated using EWM from the preceding columns

New EWM proposals

Following the LM and as a result of the controversy over reallocation of water from irrigated agriculture to the environment in the *Proposed Basin Plan*, further EWMs are now being proposed (MDBA, 2011c). The Windsor Inquiry listed 21 water-saving proposals derived from submissions it received for both EWMs and agricultural water efficiency projects (HRSCRA, 2011). However, in terms of EWM, these project are not new and many have been or are already being implemented, including some of the existing EWMs under the LM for the Hattah Lakes, Lindsay Island and Gunbower Forest. A number of other listed proposals are already underway, for instance the decommissioning of Lake Mokoan and reoperation of water infrastructure on the Darling Anabranch. The only new proposal, for the Nimmie-Caira system in the Lower Murrumbidgee floodplain, covers up to 84,000 ha and may help conserve wetlands constituting up to 1.5% of the Basin's wetlands.

The state governments have also received \$6 million from the Authority to assess the feasibility of 17 projects tagged as EWM. Two of the projects are directed at agricultural water efficiency, eight appear to be minor extensions of the original LM projects and one is not detailed (MDBLGF, 2011). The remaining six projects would extend research into EWM in four (of the 19) sub-Basin management areas not covered by the LM, including some large wetlands comparable in size to those that have been the focus of the LM.

Discussion

Based on the above review and analysis, the implications of the EWM approach to conserving wetlands is now considered and placed within the context of climate changes that are projected for the Basin (CSIRO, 2008). These are discussed with specific reference to the Basin to illustrate the specific costs and benefits, but conclude with comments on the wider application of each EWM.

To some extent, an analysis of the costs and benefits of EWMs could be seen as a question of whether they make riverine wetlands 'part full' or 'part empty'. Seared by drought from 2002 to 2010 and in a pragmatic response to political controversy, many researchers and government officials have not

Table 3 Ecological outcomes of EWM in 2004–2010 reported by the Murray–Darling Basin Authority (MDBA, 2011a) compared to the original conservation objectives (MDBMC, 2003), condition of Redgum stands in 2006 (Cunningham et al., 2007) and the ‘predicted mean floodplain forest stand in good condition’ in 2009 (Cunningham et al., 2009)

Site	Interim LM Redgum floodplain forest conservation objectives ^a	Redgum stands in healthy or good condition in 2006 (%) ^b	Floodplain forest ^c in ‘good’ condition in 2009 (%) ^d	Reported ‘trends in icon site health associated with environmental watering 2004–10’ ^e
Koondrook–Perricoota	30%	19	10.8	Breeding of various water bird species and sea eagles Vegetation ‘markedly healthier’ in watered areas Growth of giant rush at watered sites
Gunbower				Resilience of wetlands in dry conditions after watering Small waterbird breeding event in 2009
Hattah Lakes	Aquatic vegetation of half the lakes to be healthy	5	3.1	Diverse and abundant aquatic vegetation communities
Chowilla	100%	Lindsay & Wallpolla islands—21% Chowilla—20–60% of trees dead or nearly dead and 90% of live trees ‘stressed’	21.4	Vegetation species diversity increased with wetting and drying Understorey vegetation improved Increasing numbers of southern bell frogs Condition of floodplain forest trees improved with watering

^a Percentages represent the portion of Redgum floodplain forests to be conserved in a healthy condition. *Source* MDBMC (2003)

^b Relevant reports use ‘healthy’ and ‘good’ interchangeably. *Source* Cunningham et al. (2007)

^c Floodplain forest includes both Redgum- and non-Redgum-dominated wetland

^d *Source* Cunningham et al. (2009)

^e *Source* MDBA (2011a)

considered the risks when promoting EWMs in the Basin as overwhelmingly beneficial in partly inundating wetlands. We urge caution and point to those parts of the wetland systems that are left empty and may remain so as a result of EWM. Based on our assessment of the LM and proposed further EWMs, we point to four types of risks that an optimistic, ‘part full’ perspective may overlook in the Basin and elsewhere in the world, namely the risks that (a) the EWMs have direct, negative environmental impacts that are under appreciated; (b) that institutional failure prevents the EWMs being operated to optimise environmental health; (c) the EWMs have opportunity costs; and (d) the EWMs risk being an overly narrow adaptation to climate change, lack resilience and may fail.

Direct, negative impacts of EWMs

The costs and benefits of the EWMs proposed in the LM (Table 1) are considered here in turn.

Enabling larger environmental flows

The purchase of flood easements and reoperation of infrastructure to enable larger and more timely environmental flows are measures that are substantially beneficial (Table 1; MDBLGF, 2011). Pittock & Lankford (2010) considered these to constitute supply-side measures rather than environmental water demand management. Despite the benefits, such measures received little focus in the LM. The lack of such measures is now being cited by the Authority in

the proposed Basin Plan as a constraint on the reallocation of more water to the environment and one reason why they cut the proposed reallocation from 3–4,000 to 2,750 Mm³/year on average (MDBA, 2011c; WGCS, 2011). Thus, there is an opportunity cost in investing in measures such as infrastructure on the floodplain rather than purchasing easements to deliver more water to better inundate wetlands.

Structures to deliver water from the river channel to floodplain wetlands

Channel and pumping infrastructure is being proposed to deliver water from the river channel to some floodplain wetlands (Table 2). These are categorised as ‘water delivery control’ methods by Pittock & Lankford (2010, Table 1, p. 81). Beesley et al. (2011, p. 11) advise that ‘Watering from depauperate sources, such as irrigation channels, or using delivery methods that limit fish passage into the wetland, such as pumping [...] will reduce the fish response’. Baumgartner et al. (2009) suggest that a modest portion of small- and large-bodied fish extracted by irrigation pumps are killed (Baumgartner et al., 2009). Depending on how the EWMs are operated, the diversion of water onto floodplains without opportunities for lateral movement back to the river channels may result in similar losses of native fish as occur with irrigation networks (King & O’Connor, 2007).

Structures for water control and ponding on floodplains

A plethora of regulators, levees and banks to control flows and pond water on floodplains have been funded through the LM (Table 2). These are categorised variously as ‘wetland size management’, ‘adjusting size’ and ‘water use and allocation’ methods by Pittock & Lankford (2010, Table 1, pp. 79, 82). None of the LM government documents recognise the consequences of these structures cutting water flows to adjacent wetland areas, perhaps under the assumption that larger flood events will eventually inundate these additional wetlands, as discussed below. Two examples illustrate this point. The Torrumbarry Cutting canal upstream and the 64-km-long levee and four regulators on the Thule and Barbers Creek systems downstream are designed to funnel water onto and hold it on more than half of the Koondrook–Perricoota

floodplain. However, there is no analysis in the government documents of the implications for lower flows and reduced inundation of adjacent floodplain forests upstream of the canal or downstream in areas like Pollack Swamp (Office of Water, 2009).

Regulators, levees and stopbanks are intended to impede water movements and in some instances could result in reduced water quality under managed conditions compared with larger, more natural flows that have a greater dilution capacity. As discussed, salinity may be exacerbated by EWM in some instances (DWLBC, 2007; Jolly et al., 2008; GMW, 2010). Blackwater events occur where inundation of floodplain leaf litter releases organic matter and nutrients, promoting bacterial growth and resulting in de-oxygenated water and the death of aquatic fauna (Howitt et al., 2007). EWM could reduce the risk of blackwater events with more frequent flooding and management of inundation to avoid the summer period, or exacerbate it by concentrating organic matter in pooled water (which may impact on the wetland and also the associated river system if released), or with more sporadic flooding on non-target wetlands. Cyanobacteria blooms are also possible if nutrient rich waters are released into rivers in warmer months (DWLBC, 2007). Pooled waters left to evaporate in wetlands may also result in the development of blooms through the concentration of nutrients as the water levels fall. By contrast, prevention of acidification may be enhanced if EWMs enable continuous inundation of sulphide-laden sediments (Hall et al. 2006).

The role of floodplains in sustaining native fish populations in the Basin is subject to ongoing research (Ballinger & MacNally, 2006). Isolation of a river reach and a managed rise in water levels can advantage non-native aquatic biota, such as Common Carp (*Cyprinus carpio*), at the expense of native species (Bice & Zampatti, 2011), although infrastructure may also enable exotic fish to be trapped (Stuart et al., 2008). There is evidence that floodplain regulators that hold water on the floodplain to improve riparian tree health can adversely impact the lateral movement of native fish (Jones & Stuart, 2008; Lyon et al., 2010). To maximise ecosystem benefits, the movement of water into floodplain wetlands and the return flows back into the main river channel have been recommended (Beesley et al., 2011). In the case of the LM EWM, return flows are envisaged in the

case of the three floodplain wetlands (NCCMA, 2005; DWLBC, 2007; Office of Water, 2009; GMW, 2010), but it is unclear whether the benefits from these will be diminished by evapotranspiration, ponding by levees or by countervailing operational requirements such as avoiding the release of black water into river channels.

Structures to enhance aquatic fauna populations

Fishways and resnagging (adding large woody debris into the rivers) to enhance aquatic fauna populations are substantially beneficial EWMs for large fish (MDBC, 2004). These are categorised as ‘wildlife navigation aids’ methods by Pittock & Lankford (2010, Table 1, p. 82). However, current fish ladders do not enable passage for smaller fish (Stuart et al., 2008). In the case of fishways, the option of decommissioning low-value weirs was not considered in the LM despite the existing and proposed investments in weir pool manipulation projects and fishways (MDBMC, 2004; MDBLGF, 2011). There is an opportunity cost in investing in expensive remodelling and day to day operations when many structures are of modest socio-economic benefit, and it may be cheaper to remove the infrastructure (Pittock & Hartmann, 2011).

Areal bias and extent

In terms of biodiversity conservation, the LM targets and EWMs are biased towards conservation of the iconic, low-lying Redgum forests rather than other wetland types higher in the floodplain, such as the Black Box forests (Pittock et al., 2010; Pittock & Finlayson, 2011a; WGCS, 2011). It could be argued that other programmes will address conservation of a representative range of biodiversity, but this is not the case if the EWMs are the primary mechanism enabling inundation of wetlands. A biased watering programme is inconsistent with national obligations under the Convention on Biological Diversity and the Ramsar Conventions to conserve a representative range of wetland ecosystems.

While the above critique of the types of EWM identifies some risks that require better management, our central criticism is that the EWMs are never likely to conserve the majority of wetlands. In the Basin, only a third of the three targeted floodplain wetland sites will be subject to managed inundation (Table 2), and this amounts to only 5.7% of the area of

designated Ramsar sites and 0.6% of all of the wetlands in the Basin. It could be said that the LM was only the first large-scale effort to apply EWM and that newly proposed programmes can do more (HRS-CRA, 2011; MDBLGF, 2011). Yet, the listed projects that have any substance are only likely to cover a similar area to those of the LM, suggesting that after a decade of work on EWM, the existing and proposed projects are unlikely to directly benefit anything more than a minor portion of the wetlands in the Basin. Given the considerable resources devoted by the Australian governments to EWM in the Basin, we question whether other countries could afford to devote more resources to cover much larger areas of their wetlands.

Overly narrow adaptation to climatic and hydrological change

Running river systems with EWM on tighter water margins risks institutional failure and reducing environmental resilience. In the Basin, proponents model the operation of EWM on floodplains in four modes (Office of Water, 2009):

- (a) Dry year with no flows.
- (b) Dry year with managed flows onto wetlands with EWM.
- (c) Year with natural flows onto wetlands that are boosted with EWM.
- (d) Wet year when EWM are drowned out and more of the floodplain is inundated.

Governments argue that the management objectives for the EWMs are only to maintain core habitats; for example, in an extreme dry period, to avoid critical loss of threatened species, avoid irretrievable damage or catastrophic events and to provide refuges to allow species to recolonise following drought (MDBA, 2011a). This strategy depends on an assumption that in wet years, at a frequency sufficient to meet wetland species’ biological requirements, there will be sufficient water to inundate more than the third of the floodplains served by the EWM structures on the three target sites (mode d above). It is questionable whether this ‘natural flooding’ will happen reliably enough if EWMs are used as a justification to reduce environmental water allocations, especially if there are predictions that such flooding will diminish with climate change impacts (CSIRO, 2008; WGCS, 2011).

The EWM have been conceived based on stationary hydrological modelling (NCCMA, 2005; DWLBC, 2007; Office of Water, 2009; GMW, 2010). There are three problems with this approach in the Basin. First, under the existing rules, as water availability declines, a greater portion is allocated to agriculture, hence diminishing the prospect of adequate water being available for use in EWM (CSIRO, 2008; WGCS, 2011). Second, it does not consider the significant potential for flows to be diminished with climate change, losses that could be counteracted in the medium term with reallocation of water from agriculture (CSIRO, 2008; Pittock et al., 2010). Inexplicably, the Authority's proposed Basin Plan does not apply existing models of climate change impacts and floodplain inundation to quantify how much of the wetlands could be conserved, and hence the likely future performance of EWM is unknown (Young et al., 2011). EWM may aid climate change adaptation for some floodplain forest habitats under some conditions, but in requiring specific volumes of water within specific, engineered limits, they fit the criteria for an overly narrow adaptation (Nelson, 2010) or maladaptation (Barnett & O'Neill, 2010). Third, success is dependent on the quality of the institutions that oversee EWM operations. Making EWM the first resort rather than the last resort wetland conservation option is risky in that they operate with narrower margins for error in terms of water supply and there may be no alternative option to conserve freshwater biota in situ should they fail.

Institutional risks

Use of EWM in the LM grew in ambition as a means of meeting government mandated ecological targets with too little water. It is now described as engineering landscape-scale flooding of a globally unprecedented scale (MDBA, 2011a). Political leaders have grasped EWM as the easy way out of the conflict of water allocations between agriculture and the environment in the Basin in funding 'projects with potential to deliver more water-efficient environmental outcomes for the Basin's rivers and wetlands, thereby reducing the need to recover water from consumptive users' (MDBMC, 2011). Rather than just being a supplementary measure for wetland conservation during extreme dry periods, EWM are now being promoted as a day to day management strategy without understanding the environmental implications.

The state and federal government's environmental assessments of the LM EWM suggest a cursory approach has been taken, as indicated by the following: lack of state government environmental impact statements in all, but one case; lack of consideration of the obvious risk of the EWM reducing watering of wetlands outside the target areas; lack of publicly available and peer-reviewed assessments of the risks that were identified; approval of the projects without the risk assessment reports being publicly included in project documentation; and rapid approval of the projects by the Federal Government without further assessment. Underlying these approvals are assumptions that any additional inundation of floodplain wetlands is ecologically positive, that risks are minimal and can be managed during ongoing operations. This highlights the dangers of adaptation options being approved without rigorous assessment of the costs and benefits.

Finally, the risk of institutional failure increases with more complicated and costly operations of the EWM. EWMs often require skilled staff to operate infrastructure. Much EWMs require rapid decision making to work effectively if flows are to be managed to achieve ecological outcomes (such as completion of a water bird breeding event); there have been many instances of failure to act in time to release stored environmental water in the Basin (Foerster, 2008, 2011). Some EWM infrastructure, such as levee banks, is relatively passive. However, most of these measures require active and costly maintenance to remain safe and operate effectively, for example clearing debris from weirs, regulators and fish ladders (Pittock & Hartmann, 2011). The energy costs for pumping are particularly high. Consequently, there is a high risk that managers will not act quickly enough or provide the recurrent funding needed to operate EWM effectively.

Path dependency and opportunity costs

Investing so much capital in renovating old and building new infrastructure is likely to establish physical and institutional path dependency, especially if lower water allocations to the environment are a consequence. Most EWM infrastructure is relatively expensive and long lived, including weirs, regulators, levees and channels. Much of this infrastructure is also expensive to decommission (Pittock & Hartmann,

2011). There are alternative options for investment to EWM that may offer different and greater environmental benefits.

The LM cost \$280 million, including \$45 million for the installation of fishways on the River Murray that could be considered essential for any effective ecological management (MDBA, 2011a). Consequently, the remaining \$235 million could have been used to purchase, at the drought-induced peak cost of \$2.37 million/Mm³ (Pittock et al., 2010), entitlements for 99 Mm³/year of water on average. This would increase average annual flows of the River Murray by 0.9 or 2.5% of the approximately 4,000 Mm³/year extra environmental water needed for a high degree of certainty of restoring the ecological health of the system (MDBA, 2010; Pittock et al., 2010; WGCS, 2011). While it is not possible to say with certainty the area of additional wetlands that could be inundated with this extra water, the ecological outcomes are likely to be different to the 0.6% of Basin wetlands watered using the highly controlled LM EWM. The main reason for not increasing water allocations to the environment is the potential socio-economic impact on agricultural communities.

While reduced allocations for irrigated farming will involve a period of adjustment by the associated communities, overall socio-economic impacts are widely assessed as being low. One analysis suggests that buying back irrigation water for the environment would increase economic activity in the southern Basin and there would be little effect on aggregate farm output as resources would be reallocated between activities. This analysis concludes that because farmers are owners of water rights, they would benefit from the price increase induced by the buyback (Dixon et al., 2011). Another analysis concludes that from 2001 to 2009, a water reallocation that would have given less to irrigated agriculture and more to environmental flows would have generated between half a billion and over US \$3 billion in overall economic benefits (Grafton et al., 2011). There are many negative consequences from the current level of water allocation to irrigated agriculture in the Basin when increased environmental flows may restore generation of alternative ecosystem services such as fisheries and pastures (Grafton, 2011; CSIRO, 2012). Modelling undertaken by the Australian Government for the Basin of a water reallocation of 3,000–4,000 Mm³/year (30–40 times the amounts that

could be purchased with the LM budget) resulted in the following: (a) a lowering of forgone profits in irrigated agriculture of between 6 and 9%; (b) a fall in the gross value of irrigated agriculture of between 13 and 17%; and (3) a decline in basin employment of 0.09–0.12% (ABARE & BRS, 2010). In fact, in 2000–2001 to 2007–2008, in drought irrigated surface water, diversions fell by about 70%, yet the gross value of irrigated agriculture declined by less than 1% in nominal terms (Australian Bureau of Statistics, 2010). Grafton (2011, p. 256) argues that ‘1) if large increases in environmental flows are consistent with improvements in environmental assets then increased flows have the potential to deliver multiple billions of dollars of non-market benefits in present value terms, and in excess of \$1 billion per year; 2) the annual estimated willingness to pay for improvements in riverine environmental assets in the MDB exceeds the estimated annual reduction in the gross regional product in the Basin associated with a 4000 GL/yr reduction in watercourse diversions, while having virtually no impact on the long-term employment [...]; 3) reductions in current watercourse diversions to holders of water entitlements will be fully compensated’. Further, the \$235 million spent on the LM EWM will see 36,108 ha more regularly inundated at \$679 per ha. By comparison, in expanding conservation reserves with large wetland components, the New South Wales and Federal governments spent \$35.18 million acquiring nine properties covering 136,845 ha in the Lachlan and Murrumbidgee valleys at a cost of \$257 per ha (Minister for the Environment, 2011) and \$23.75 million for the 91,383 ha Toorale Station with 14 Mm³/year of low security water entitlements at the confluence of the Warrego and Darling rivers at a cost of \$263 per ha (ABC News, 2008). While the conservation outcomes of land purchased for conservation reserves versus that from the inundation of wetlands are different, they do represent an alternative strategy to EWM that could be used to make more effective use of limited environmental funds.

While the conservation value of the alternative strategies may be partly quantified, they also entail value judgements about the benefits and risks. An outline of the costs, benefits and risks, with examples, of the three alternatives for wetland conservation discussed in this paper, namely, EWM, the purchase of larger environmental water allocations and the purchase of land for reserves, is presented in Table 4. We

Table 4 Benefits and risks of alternative wetland conservation strategies in the Murray–Darling Basin

Strategy	MDB example of cost (AUD)	Benefits	Risks
Environmental works and measures	\$679 per ha under the LM, 0.6% of Basin wetlands for \$235 million	Enables more regular and controlled watering of targeted wetlands May diminish reallocation of water from consumptive users	To flora, fauna and in diminishing water quality and reducing connectivity Diminished frequency of inundation of non-target wetlands Institutional failure due to higher management costs, required expertise and timely decision-making More expensive
Purchase of water entitlements	At \$2.37 million/Mm ³ (drought-induced peak cost), could purchase entitlements for 99 Mm ³ /year and increase average annual flows of the River Murray by 0.9% (or 2.5% of the ~ 4,000 Mm ³ /year estimated as providing a high degree of certainty of restoring the ecological health of the system)	Enables larger environmental flows to maintain wetlands	Water entitlements insufficient to inundate the floodplain without intervention Institutional failure in managing environmental flows
Purchase of wetlands	\$257–263 per ha based on purchase of 228,228 ha in western New South Wales	Enables deployment of a broad range of wetland conservation measures	Insufficient environmental water to enable inundation Ongoing management costs

propose that further investments for wetland conservation should consider these alternatives and an informed decision made to maximise the benefits and reduce the risks. This could include using different, but complementary, strategies (Pittock and Finlayson, 2011b).

The five criteria for measuring the success of river restoration projects proposed by Palmer et al. (2005) could be extended to these floodplain wetland EWM. First, they proposed that interventions should be guided by the image of a more dynamic, healthy ecosystem, but ecological dynamism is the opposite outcome of the engineering works deployed in EWM. Second, they proposed that the ecological condition must be measurably improved, which we question in this assessment as an outcome of the EWM. Thirdly, they say that the ecological system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed, which is the antithesis of the EWM deployed in the LM. Fourthly, they say that pre- and post-assessment must be completed and data made publicly available, which we found was not the case in the LM. Finally, they say that no lasting harm should be inflicted on the

ecosystem during the construction phase, which is not the case with structures like inoperable stop banks and levees that block flows to wetlands.

Conclusions

In the Murray–Darling Basin, EWM began as an expedient means of meeting politically mandated ecological targets with insufficient water and to sustain ecological refugia for short periods in extremely dry conditions. However, in the rhetoric of the government agencies, EWM has morphed in ambition from merely a realignment of the capital works programme to a means of supporting landscape-scale flooding. The beguiling notion that we can take the same, limited water supply and divide it for more and more uses has captured the imagination of political leaders as an easy way out of a tough dilemma by funding ‘projects with potential to deliver more water-efficient environmental outcomes for the Basin’s rivers and wetlands, thereby reducing the need to recover water from consumptive users’ (MDBLGF, 2011).

Yet, the aspiration has not been matched by the performance. Wetland ecosystems comprise more than the floodplain trees addressed by the LM. They include other types of vegetation, fauna, healthy soils and clean water. Far from ensuring landscape-scale flooding, only a third of the three targeted LM icon wetland sites can be regularly inundated using EWM. This is not consistent with meeting Australia's obligation under the Ramsar Convention to maintain the 'ecological character' of all of the listed Ramsar wetlands. The LM EWM will enhance management of only 0.6% of the Basin's wetlands, and even with the proposed new projects, is unlikely to benefit more than a small minority of these habitats. Worse, the EWM is contributing to wetland degradation directly through local diversions of water flows and indirectly by justifying reduced allocation of water to wetlands in the Basin. Only large environmental flows can conserve the majority of the Basin's wetlands, especially when considering the increased water scarcity expected over the southern Basin under climate change.

The alternatives to a strategy based on EWMs include larger environmental flows. Socio-economic research in the Basin suggests that the purchase of water for larger environmental flows is cheaper than water efficiency measures. A broader range of biophysical interventions to conserve free-flowing and regulated rivers in the Basin have also been recommended to spread the risk of failing to inundate the wetlands and to increase ecological resilience in the face of water abstraction and climate change (Koehn et al., 2011; Pittock & Finlayson, 2011b). Unless more effective measures are implemented, it is unlikely that the wetlands in the Basin will be conserved, especially under climate change, an outcome that, given the legal foundation that is in place (Pittock et al., 2010), could leave the water planning process for the Basin open to legal challenge.

There are a number of global lessons for conservation of wetlands with climate change. Key amongst them is that any intervention has risks and costs as well as benefits that require rigorous consideration for better wetland conservation. In this case, investment in EWM has been costly, appears to benefit small areas of wetlands at the expense of others, has a number of operational risks and may not be sustained with greater climate change. Given the shortcomings in existing EWMs, we recommend that alternative adaptation and

conservation strategies, such as the acquisition of wetlands and of water to inundate them, need to be costed and considered.

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