The Australian Journal of
Agricultural and
Resource Economics

Journal of the Australian Agricultural and Resource Economics Society

Australian Journal of Agricultural and Resource Economics, 62, pp. 83–102

Achieving environmental flows where buyback is constrained*

David Adamson and Adam Loch†

Theory suggests that the development of common property increases national welfare, and consistent with this thinking Australia's Murray–Darling Basin (MDB) Plan uses a common property approach to recover environmental water rights in the national interest. Two water recovery instruments are used: purchasing water rights (buyback) from farmers, and saving water by subsidising irrigator adoption of technically efficient technology. A moratorium on buyback has focused environmental recovery on subsidised technically efficient technology adoption. Economists argue that national welfare is maximised via buyback and highlight the limitations of efficiency savings to recover sufficient environmental water. A risk is that water recovery targets may be reduced in future, limiting welfare gains from water reform. This article evaluates possible welfare trade-offs surrounding environmental water recovery outcomes where arbitrary limits on buyback are imposed. Results suggest that, on average, strategies which attempt to obtain >1500 gigalitres (GL) of water from on-farm efficiency investments will only provide sufficient resources to meet environmental objectives in very wet states of nature. We conclude that reliance on technically efficient irrigation infrastructure is less economically efficient relative to water buyback. Importantly, the transformation of MDB irrigation will significantly constrain irrigators' future capacity to adapt to climate change.

Key words: environmental water, optimisation, water buyback.

1. Introduction

Prior misallocation and over extraction of water resources in Australia's Murray–Darling Basin (MDB) has created social, ecological and economic welfare losses (Quiggin 2001). A possible strategy for mitigating these losses is being trialled by the MDB Plan (MDBA 2012).

The legislative basis for the Plan (*Water Act* 2007) addressed ongoing social concerns about negative water-use externalities and supply reductions

* Collaborative funding for this study was provided by the University of Queensland's School of Economics Search & Visitors Committee, and the University of South Australia's School of Commerce. Additional funding and support for Dr Adamson was provided under an ARC DECRA Grant DE160100213 *Optimising National Benefits from Restoring Environmental Water Flows,* while funding for Dr Loch was provided under an ARC DECRA Grant DE150100328 *Transaction costs in Murray-Darling Basin water reform* and Discovery Grant DP140103946 *Transitioning to a water secure future*. The full data set is available at http://www.uq.edu.au/rsmg/. The helpful comments and suggestions by two anonymous reviewers and the Editor/Associate Editor are also gratefully appreciated.

† David Adamson and Adam Loch (email: adam.loch@adelaide.edu.au) are with the Centre for Global Food and Resources, University of Adelaide South Australia, Adelaide, South Australia, Australia.

doi: 10.1111/1467-8489.12231

during the Millennium Drought (1998–2010). The Plan recognises our current understanding of water supply risk and future uncertainty is incomplete, potentially requiring future adaptation by irrigators and the environment alike (MDBA 2012). To identify the true price of water for irrigation and environmental users, an AU$3.1 billion *Restoring the Balance* (*RtB*) program sought to purchase (buyback) water rights from irrigators. Additionally, an AU$7.49 billion *Sustainable Rural Water-use and Infrastructure Program* (*SRWUIP*) sought to recover water from irrigation savings through increased water-use efficiency (DSEWPC 2012). Recovered water establishes environmental common property rights (Quiggin 2001) managed by a public trustee in the national interest (Ciriacy-Wantrup and Bishop 1975). Reducing private consumptive (irrigator) rights by between 2750 and 3200 gigalitres (GL) will provide new 'sustainable diversion limits' (SDL) on water extraction (MDBA 2012). Consistent with the concept of common property rights, the establishment of SDLs will purportedly increase national welfare gains by improving water quality, reducing social and environmental externalities, and improving identification of the true price of water (Quiggin 2001). In the Plan, SDLs describe a minimum recovery target by catchment and an additional reduction in extraction by trade zone. It logically follows that a single catchment may potentially be required to deliver both its defined reduction, plus all reductions related to that particular trade zone. However, SDLs may also be revised where water managers can achieve: environmental objectives with less water (*supply measures*), greater delivery-system efficiency savings (*efficiency measures*) or more effective environmental water delivery in future (*constraint measures*) as long as they avoid negative socioeconomic impacts (MDBMC 2014). Since September 2015, buyback recovery has been constrained at 1500 GL (DOE 2015). This prevents water from being recovered at least cost (Wheeler *et al.* 2013) and has promoted greater reliance on *SRWUIP* water recovery (up to 1900 GL – Figure 1).

During the development of the Plan, economists preferred buyback as the appropriate water recovery mechanism (Productivity Commission 2010; Crase *et al.* 2012). Buyback can: provide secure, well-defined property rights with certain spatial and temporal characteristics (Crase *et al.* 2012); identify the water resource's true price (Wittwer 2011; Wheeler *et al.* 2013); maximise welfare for different users (Loch *et al.* 2014); enable risk-management benefits during adverse climatic events (Bjornlund 2006); and offer policy flexibility from a transaction cost perspective (Marshall 2013). While public concern has been raised about the impact of buyback on rural regions, peer-reviewed assessments have failed to identify major evidence of commonly perceived negative consequences like stranded-asset impacts from ad hoc irrigation infrastructure removal (Australian Parliament 2011), rural depopulation and food/fibre production reductions (Williams *et al.* 2009) and/or widespread farmer exit (Wheeler and Cheesman 2013).

Building on Brennan's (2006) arguments, recent economic critiques of *SRWUIP* water efficiency programs have focused on six issues. First, there

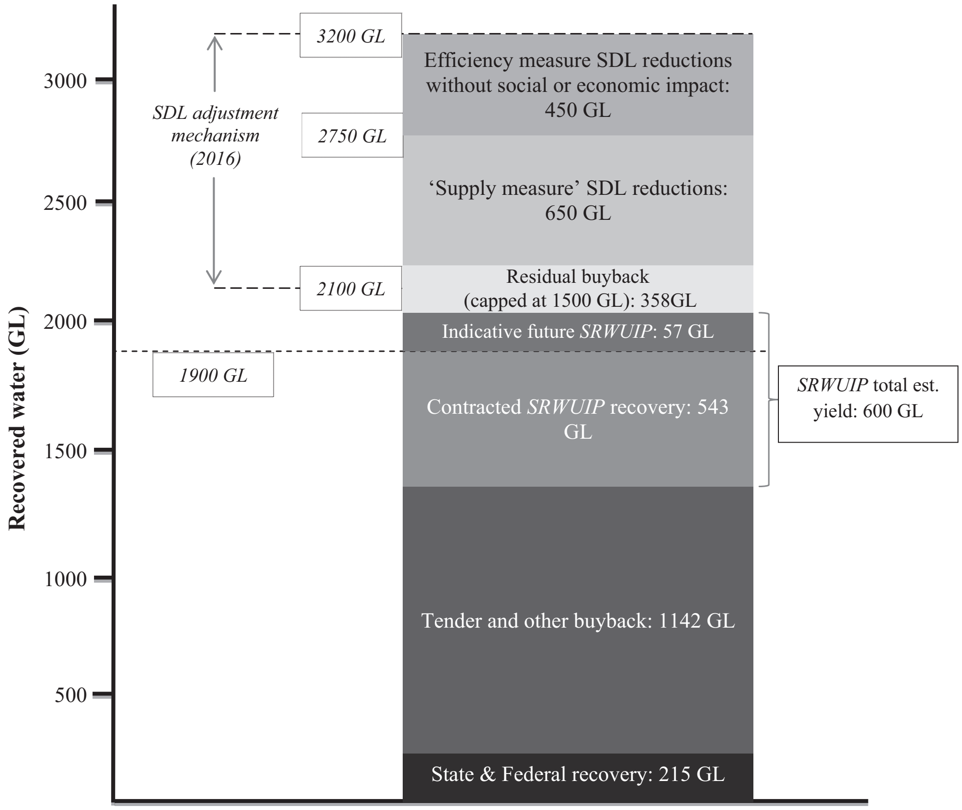

Figure 1 Environmental water recovery and adjustments (adapted from DSEWPC 2012, p. 23).

are concerns about the actual quantum of water recovered, how realised water savings will be transformed into property rights (Crase and O'Keefe 2009), and whether current seepage/evaporation losses have been fully considered (Quiggin 2006). Second, if an assumed *SRWUIP* objective is to minimise the $/megalitre (ML) cost of water recovery, the program must target areas that generate the lowest return/ML (Adamson and Loch 2014). Third, as the relatively low $/ML water is recovered, each additional ML must come at a higher price, and funding must eventually move towards upgrading already technically efficient systems (Cox and Warner 2009). Fourth, subsidised capital may encourage farmers to transition away from annuals into perennial crops; transforming on farm water use from a risk reducing to risk-increasing input of production, as water is required every year to preserve capital (Adamson *et al.* 2017). Basin-wide transitions to perennial crops may subsequently reduce volumes of water for trade during drought, increasing prices (Adamson and Loch 2014) and exposing perennial capital investments to substantial risk (Loch and Adamson 2015). Fifth, studies of water-use efficient technology adoption to obtain environmental water have consistently noted that environmental flows decrease (e.g. Gómez and Pérez-Blanco 2014) due to rebound effects resulting in greater consumptive extractions (Gomez and Gutierrez-Martin 2011), and this combination increases all water users' exposure to risk (Adamson *et al*. 2017). Sixth, irrigation efficiency investments are inferior to public spending on health, education and other services to stimulate economic growth in the Basin (Wittwer and Dixon 2013).

Political constraints on buyback, despite economic advice to the contrary, motivate our interest in evaluating the effectiveness of these two water recovery instruments. The use of a constrained welfare analysis framework allows both institutional goals (Randall 1975), the self-interests of alternative uses/users (Bromley 1990) and the constraints imposed by the Plan's SDL catchment/trade zone reduction rules to be explored. That is, by exploring the quantum of water recovered under each instrument, we can identify welfare changes and any strategic behaviour by individuals to influence those settings (Randall 1975). We test the welfare outcomes from alternative instrument settings to achieve Plan SDLs by exploring four hypotheses: (H_1) constraints on water buyback decrease economic welfare; (H_2) the non-market-based nature of *SRWUIP* reduces efficient resource reallocation, creating regional winners and losers; (H_3) subsidised irrigation technology adoption may incentivise risk-taking behaviour by irrigators; and (H_4) by relaxing instrument and institutional setting constraints on SDL/trade zones, additional welfare gains may be achieved.

2. Methodology

To test our hypotheses, we use a welfare constrained state-contingent analysis (SCA) within a directed-flow water model to examine how restrictions on buyback alter recovery outcomes. The resilience of water users is explored by modelling future shocks to MDB water supply (i.e. hydrological variability). This article builds on past modelling work utilising the SCA model constructed by Adamson *et al*. (2007). The model description, underlying assumptions and datasets are available in Adamson (2015), and discussion is limited to surface water only.[1] SCA approaches present uncertain outcomes as mutually exclusive states of nature (i.e. droughts, floods and normal) with occurrence probabilities. This allows uncertainty to be treated like certainty, and decision-makers can (re)allocate resources between risk-minimising alternatives (Chambers and Quiggin 2000).

2.1 The model and data

The model is solved from the national perspective using a constrained welfare optimisation approach. This is achieved by placing a single hypothetical

[1] Major model components are outlined herein; additional information is available at https://espace.library.uq.edu.au/view/UQ:348613/s3001062_finalthesis_phd.pdf.

socially responsible Basin manager in charge. The Basin manager's objective is to maximise net private returns (inclusive of fixed and variable costs) from irrigation water across (K) catchments (Eqns 1–4) that are constrained by the Plan's institutional goals and recovery instrument settings. The Plan's two main institutional goals are: an annual minimum 650 GL flow to the Coorong wetland area – a major ecological site near the Murray River's mouth (Eqn 6), and maintaining ≤800 electrical conductivity (EC) water salinity levels 95 per cent of the time at Morgan, an offtake for the City of Adelaide's water supply (Eqn 7).[2] The recovery instrument settings test: the quantum of water recovered by each instrument, alternative buyback implementation strategies and the limitations associated with the SDL reduction mechanisms (Eqn 5 and later 9–15). Table 1 provides the model parameter definitions.

$$\mathrm{Max}E[Y] = \sum_{K}\sum_{s\in\Omega}\pi_s(R_{s,k} - C_{s,k}) \tag{1}$$

where

$$\text{Revenue}: \; R_{s,k} = Z_{s,k}P_{s,k} \tag{2}$$

$$\text{Costs}: \; C_{s,k} = a_{s,k}x_{s,k} \tag{3}$$

$$\text{Output}: Z_{s,k} = f(x_k) \tag{4}$$

Table 1 Model parameters

Symbol	Definition
$E[Y]$	Expected [Income]
K	Catchments in the Basin (K = 1 ... 21)
S	States of Nature (S = 1 ... 3)
π	Probability of state occurrence
R	Revenue
C	Costs
Z	Output
P	Price per unit of output
a	Vector of input prices (land, fixed costs, variable costs, water)
b	Vector of input requirements (land (ι), fixed costs, variable costs, water)
B	Input constraints (land (L) and water (W)
x	Vector of activities (44 in total: 22 non-*SRWUIP* and 22 *SRWUIP*)
wx	Volume of water used derived from $b_{s,k}x_{s,k}$
wf	Volume of water flowing in the catchment
SDL	The total constraint on the water-use set by the Plan
σ	Salinity level in electrical conductivity units
w	Water used

[2] Adelaide is a major capital city located outside, and near the end of, the MDB. The city typically extracts 200 GL of drinking-water annually from the Basin.

$$\text{Subject to}: \sum_{K}\sum_{s\in\Omega} w\pi_s \leq \text{SDL} \tag{5}$$

$$\text{wf}_{s,21} \geq 650 \text{ GL} \tag{6}$$

$$\frac{\sigma_{s,20}}{0.64} \leq 800 \text{ EC} \tag{7}$$

Figure 2 outlines the key features of the model. The state of nature provides certainty by revealing the total volume of private and public water-use trade-offs. By modelling the Basin manager's objective function as a constrained dual-optimisation problem, the solution aims to maximise economic returns from irrigation while minimising the public/private costs of realising institutional goals. This is achieved by a fully aware Basin manager understanding the opportunity costs associated with the spatial use of water, return flows and conveyance losses, the impacts on water quality from its use and requirements to meet public policy objectives. By requiring the Basin manager to (not) engage in buyback before *SRWUIP* investments occur, net gains from trade and the theoretically most ambitious investment program can be determined.

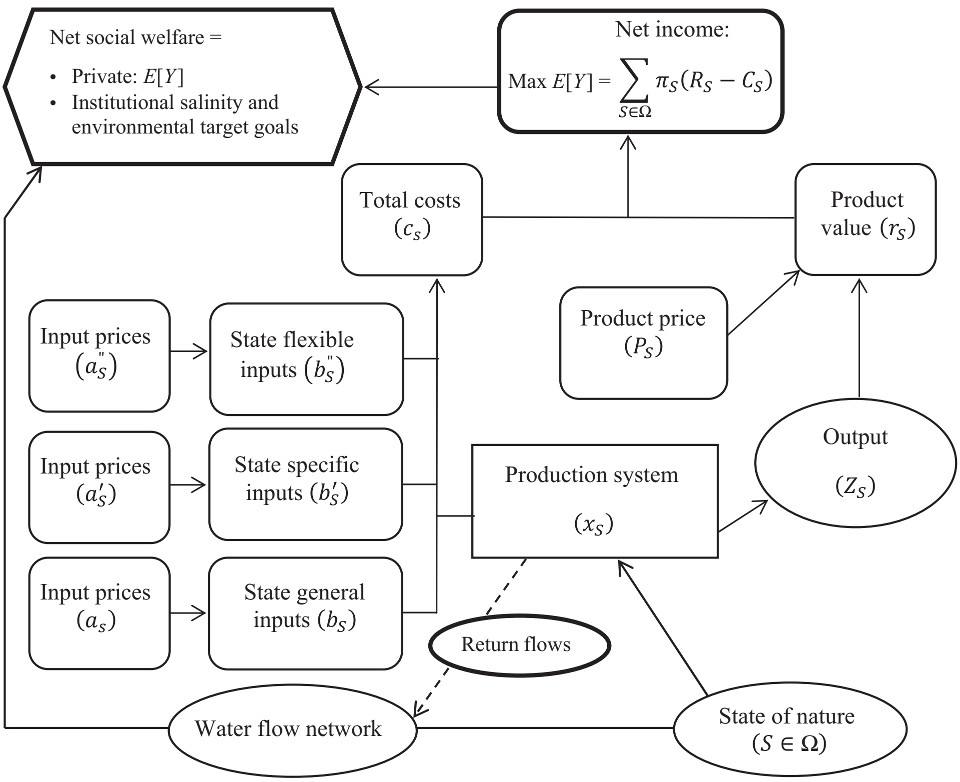

Figure 2 State-contingent analysis (SCA) model illustration.

The model implicitly assumes that all other recovered water comes from buyback, and explicitly assumes no water is recovered via off-farm efficiency projects (e.g. changes to large-scale irrigation water delivery infrastructure). This is justified under our objective of examining how on-farm land and water-use adjusts specifically in response to system-wide transformation, but imposed some limitations on the modelling. Agricultural production choices are constrained by available inputs $b_{s,k}x_{s,k} \leq B_{s,k}$, ensuring that production areas do not become negative $x_s \geq 0$ and that irrigation water volumes do not exceed river system capacity $w_{s,k} \leq wf_{s,k}$.

2.1.1 States of nature

The total volume of water available (θ) to the Basin manager varies by state of nature. Variation around the normal volume θ is defined proportionally, where drought states have 0.6θ and wet states have 1.2θ. These state of nature definitions together with the original water and salt flow data were supplied by the Murray-Darling Basin Commission, as it was then, and supplemented with data from the CSIRO Sustainable Yields Project. Production statistics were sourced from ABS Agricultural Census data organised on a Statistical Local Area basis. This process also provided the probabilities of drought, normal and wet states; 0.2, 0.5 and 0.3, respectively. Under these probabilities, the flow leaving each catchment $wf_{k,s}$ is:

$$\mathrm{wf}_{k,x} = (\theta_{k,s} \cdot wc_{k,s}) - (w_{ks} - wr_{k,s}) \tag{8}$$

where flow is determined by the impact of conveyance losses wc on water resources and includes net irrigation water w less any irrigation water lost to return flows wr. For each production system $x_{k,s}$, a defined water-use $wx_{k,s}$ and reflow variable by technology option exists. This provides capacity to model *SRWUIP* impacts on $wf_{k,s}$.

2.1.2 Production constraints

The model has two production constraints: total maximum irrigated land (L), and conjunctive water resources (W). The latter includes surface flows and inter-basin transfers to deal with controversial issues related to groundwater extraction increases. Unlike Adamson and Loch (2014), where perennial cropping was held at current land-use levels, we allow this sector to expand by 200 per cent and 300 per cent, effectively taking the model to its limits. However, water remains the binding expansion constraint, particularly the river system delivery capacity (wf) in each catchment.

2.1.3 Maximising private returns

The Basin manager operates within these constraints, but can adapt to different states by changing management strategies, altering inputs or switching production systems (outputs). Perennial crop changes are modelled as long-run investments, where only input (B) and output (Z) decisions may change to reflect their relatively more permanent cropping traits. Additionally, the Basin manager can choose to invest (with or without *SRWUIP*) between existing low (L) technology with higher rates of water-use and new high (H) technology that alters water-use along the production curve, or results in rightward shifts of the curve. The model then treats *SRWUIP* as a reduction to water-use per hectare for all technologies. It further treats capital subsidies (excluding the cost of purchasing land) as an annuity repayment, allowing for choices between commodities to be determined.

2.1.4 Modelling the investment choice with (without) SRWUIP

Capital is a state-general input, and the *SRWUIP* program is an investment in water-use efficient technology (i.e. it effectively reduces the irrigators' annual capital infrastructure cost). To represent the impact of *SRWUIP* (i.e. changes to a and b), the model uses 22 different state-contingent production systems (x) that can be produced with/without *SRWUIP* subsidies (i.e. $X = 44$, where $x = 1$–22 (without *SRWUIP*), and $x = 23$–44 (with *SRWUIP*)).

Based on Fairweather *et al.* (2009), water-use efficiency improvements realise reductions in water consumption estimated at $0.8wx_{k,s1}$ for all $x = 23$–44. As per *SRWUIP* policy, this efficiency gain is shared equally (50/50) between the environment and the irrigator. *SRWUIP* subsidisation of capital costs by commodity is $0.1wx_{k,s1}$ * annuity per ML, where the annuity per ML options are presented in Table 2. Thus, half of the difference in water-use between subsidised and unsubsidised production systems by k determines the quantity of water recovered $wi_{k,s}$. The model assumes water diverted for irrigation is used at the farm level and does not implicitly track off-farm conveyance losses.

The model also assumes that *SRWUIP* funds are equally allocated across each unit of recovered water. This approach effectively stipulates that the federal government has no spatial preference, which in the model overcompensates some water users. Assuming that all project funds are spent, the $/ML represents maximum average prices that governments would be willing to pay under alternative recovery scenarios (see Table 2).

The $/ML is based on an annuity where interest is set at 7 per cent per annum, and the timeframe is 20 years. Over that 20-year period irrigators,

Table 2 *SRWUIP* recovery level annuity payments

SRWUIP level (GL)	Subsidy (AU$/ML)	Annuity (AU$/ML)
900	$8,411	$794
1,100	$6,882	$650
1,300	$5,823	$550
1,500	$5,047	$476
1,700	$4,453	$420
1,900	$3,984	$376

Note: *Numbers differ slightly due to rounding.

irrigation infrastructure operators and irrigation-dependent communities receive wealth transfers of approximately \$714 million to realise environmental benefits. At a *SRWUIP* recovery level of 900 GL, annuity levels are \$8411/ML – a 5.6 multiple of average buyback costs, and twice the average infrastructure prices reported in Loch *et al.* (2014). This value offsets an irrigator's annual capital cost by AU\$794 for each ML of water purchased by the government. Naturally, as recovery targets increase, the government's capacity to pay diminishes under a budget constraint, and net producer subsidies fall for each extra ML recovered. The quantity of environmental water recovered via upgrades is *wi*, which is used to achieve environmental targets RT on average (Eqn 9).

$$\sum \mathrm{wi}_k \pi_s = \mathrm{RT}\pi_s \tag{9}$$

During the analysis, Equation (9) became unsolvable for recovery targets ≥1500 GL given the original model constraints. Thus, in this case, the parameters were relaxed from (RT π_s) to (RT π_3) to obtain a solution. As such, all *SRWUIP* policy settings ≥1500 GL, according to this model, could only be achieved in wet states of nature. Further, systems that transformed to high (better) technology experienced an additional \$5/ML cost representing increased energy and delivery costs in the model.[3]

2.1.5 Including buyback in the model

The Plan requires SDL reductions by *k* and a defined recovery volume across trade zones, constraining least-cost market recovery and limiting the capacity of *SRWUIP* to obtain sufficient environmental water. The modelling work undertaken by Adamson and Loch (2014) showed that without relaxing the SDL rules, *SRWUIP* would struggle to recover sufficient environmental water. Thus, in this article, we first assumed no buyback had occurred. This allowed us to test how buyback might work in tandem with *SRWUIP* to meet recovery targets. We achieve this by implementing the buyback instrument with (without) SDL by *k*/trade zone constraints, while still maintaining environmental objectives. Alternatively, we could have adopted a two-stage modelling solution involving data of water recovered via *RtB*/*SRWUIP* in each *k* (which does not exist for *SRWUIP* (Crase and O'Keefe 2009)) and assumed parameters for future recovery investments. Instead, we assume that net private returns from reallocation are maximised via buyback through the use of relaxed trade rules, and solve both instruments simultaneously for maximum welfare.

[3] For example, see the Murrumbidgee Irrigation schedule of charges (www.mirrigation.com.au). Note that short-run variable cost increases may be entirely offset by long-run reductions to total water use bought about by efficiency gains (Ward and Pulido-Velazquez 2008). However, for Australia specifically Maraseni *et al.* (2012) and Mushtaq *et al.* (2013) identify increased energy consumption rates associated with efficient irrigation technology adoption.

Illustrating the potential benefits from buyback reallocation requires the model to be set up in two ways. First, we model all Plan constraints along the lines of Equations 10–15:

$$\sum w_k \pi_s \leq \sum \mathrm{SDL}_k \tag{10}$$

$$\sum w_{\mathrm{NTV}} \pi_s \leq 3353.9\,\mathrm{GL} \tag{11}$$

$$\sum w_{\mathrm{STV}} \pi_s \leq 2839.7\,\mathrm{GL} \tag{12}$$

$$\sum w_{\mathrm{STV}} \pi_s \leq 3373.1\,\mathrm{GL} \tag{13}$$

$$\sum w_{\mathrm{STS}} \pi_s \leq 570\,\mathrm{GL} \tag{14}$$

$$\sum w_{\mathrm{STA}} \pi_s \leq 6638\,\mathrm{GL} \tag{15}$$

where

SurfaceSDL	Total volume of surface water allowed for irrigation use
NTS	Water trading zones in the northern catchments (k = 1 ... 8)
STN	Water trading zones in the southern New South Wales catchments (k = 10, 12, 14, 16, 18)
STS	Water trading zones in the southern South Australian catchments (k = 19)
STV	Water trading zones in the southern Victorian catchments (k = 11, 13, 15, 17)
STA	Water trading zones in all southern catchments (k = 10 ... 19)

Equation 10 ensures the water used in each catchment is less than or equal to the new surface SDL. Equations 11–15 allow additional SDL reductions by trade zone, preventing any catchment from using permanent trade to increase their SDL. Finally, to examine the welfare changes from altered trade rules, we relax Equation 10. This allows water to be reallocated to maximum private returns; otherwise, based on regional comparative production advantages, any catchment may exceed its stated SDL.

2.2 Model scenarios

A total of 180 *SRWUIP* scenarios with (without) SDL by k/trade zone constraints and four base case scenarios were examined (Table 3). These included differing *SRWUIP* recovery targets (900–1900 GL), current and expected future climate conditions, impacts of 100 per cent versus 50 per cent return flows (under current climate conditions only), expansions in perennial cropping by 200 per cent and 300 per cent to test perceptions related to higher-value perennial production, and achieving SDL outcomes with (without) trade rule constraints.

The six *SRWUIP* levels reflect the range documented in the final recovery strategy. These levels constitute thresholds in the model's capacity to obtain/ deliver water in each state of nature. Climate change is expected to detrimentally impact water supply, expressed as a net reduction in water availability or increased drought frequency (Quiggin *et al*. 2010). This article utilises two shocks: a climate change scenario with reduced inflows and a scenario where water resources by state of nature do not alter, but drought state frequency is increased. Further, by adopting the strong mitigation policy of a 450 ppm (450-average) climate change scenario (Garnaut 2008), this study has selected the most benign threat to *SRWUIP* program success. The 450-average scenario predicts MDB-wide average water resource reductions of only 18 per cent by 2050.

We assume that *SRWUIP* investment will reduce return flows. Reduced return flows may, in turn, drive negative social, economic or environmental outcomes for downstream users (Nieuwoudt and Armitage 2004). We incorporate two return flow scenarios (50 per cent and 100 per cent) to test for these impacts. However, the partial-equilibrium nature of the model prevents examination of how modifying the area devoted to particular commodities could alter output prices. Alternatively, we refine our approach to examine how capital subsidisation may expand perennial production in two incremental steps to review any subsequent capital investment risk. These scenarios provide for a maximum expansion of irrigated areas to approximately 280,000, 560,000, and 840,500 ha, respectively. This constrains perennial expansion in the southern MDB to 1.3 million hectares, which is a parsimonious solution under current technologies and prices. Finally, our SDL by k/trade zone constraints allow us to test alternative *SRWUIP* recovery targets, and how the implementation of a buyback instrument can be used to assist recovery outcomes.

Table 3 Model scenarios

Scenario issue	Levels	Attributes
SRWUIP recovery targets (GL)	6	900, 1100, 1300, 1500, 1700, 1900
Climate change	4	Current, 450-average (Ex-ante), 450-average (Ex-post), Increased droughts
Reflows	2	100%, 50%
Perennial area	3	100%, 200%, 300%
SDL by k/trade zone constraints	2	On, off

3. Results

We first examine returns that accrue to irrigators, using the alternative scenarios for expanded perennial production (Figure 3). Once *SRWUIP* exceeds 1300 GL, the average subsidy/ML diminishes. This reflects: (i) dampening government enthusiasm to pay for water-use efficiency increases over time; (ii) the requirement for irrigators to co-invest to achieve savings; and (iii) higher operating (e.g. electricity) costs for new technology. In contrast, while returns under the unconstrained SDL/trade scenario also diminish, they do so from a higher base. The model results indicate clear net private gains when unconstrained trade occurs. As expected, perennial production increases and returns are approximately $1000/ML higher at the largest perennial area considered. This result is generally consistent with other modelled and observed economic benefits from MDB water trade, especially during drought periods (e.g. Wittwer and Griffith 2011). Our results provide support for the first hypothesis that as *SRWUIP* recovery targets increase, economic returns (welfare) decrease. Support for this hypothesis is strengthened by the fact that our calculations do not take account of the greater cost-effectiveness of buyback relative to infrastructure upgrades for recovering water.

The model also predicts *SRWUIP* investment will drive technological adjustment in response to increased water recovery requirements (Figure 4). The northern Basin transforms rapidly towards new technology above a 900 GL recovery target, while the southern Basin transforms less rapidly until reaching the 1300 GL level. This is consistent with current high irrigation water supply reliability in the southern MDB. The Basin manager is able to transform northern catchments with lower returns/ML first and maximise revenue across their portfolio. However, by 1300 GL, effectively all infrastructure is upgraded and approximately 500,000 extra hectares of agricultural production delivered. This implies eventual over-investment in new technology as the program attempts to achieve higher recovery targets; particularly in South Australian irrigation districts where a significant

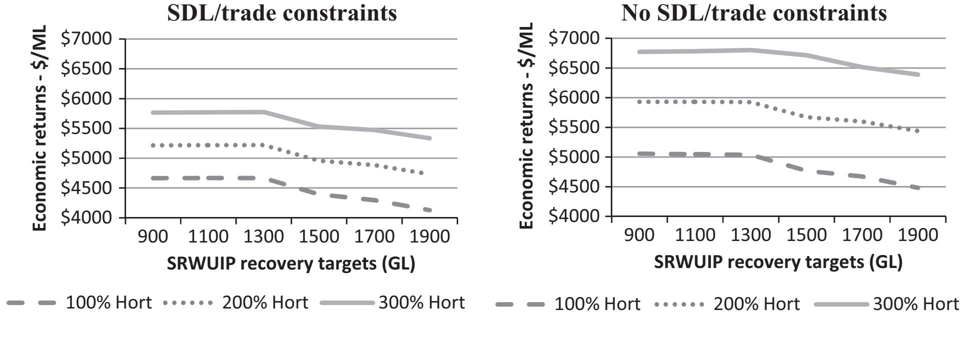

Figure 3 Economic returns by perennial area – constrained versus unconstrained SDL/trade rules.

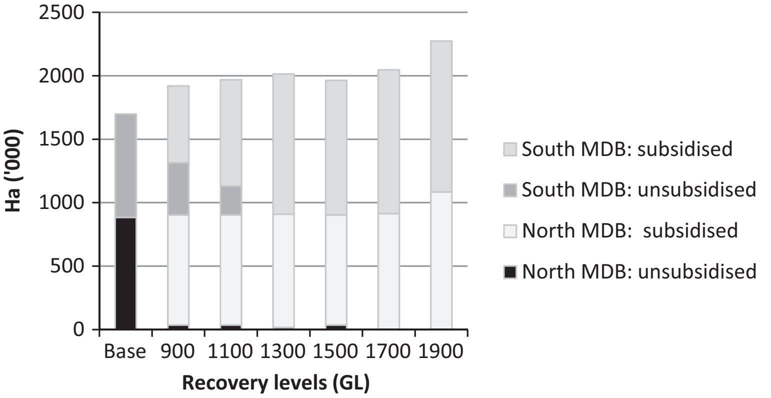

Figure 4 Land and production technology transformation (north and south).

amount of upgrade has already taken place (Loch *et al*. 2014). These results support our second hypothesis that *SRWUIP* will drive investment inequalities. This outcome is further supported in an estimation of north and south Basin technology transformations with (without) SDL/trade zone constraint scenarios (Figure 5).[4]

The relaxation of trade rules allows all irrigators to rapidly reorganise production and take advantage of *SRWUIP* opportunities to address system inefficiencies. The model suggests that *SRWUIP* funds should be allocated towards northern Basin (mainly annual production system) irrigators first, where the potential to address inefficiencies is greater. However, as recovery targets increase, the southern Basin must also transform; potentially including previously (private or publicly) upgraded perennial producers. This outcome suggests higher future technological lock-in requiring a larger volume of water in all states of nature. This ultimately reduces MDB producer capacity to adjust in the face of future climate, water supply and input uncertainty and risk.

We also examine changes to MDB production system water-use by state of nature (Figure 6). If we constrain trade, *SRWUIP* investments target the southern Basin where less recovery opportunities exist. However, while the modelled outcome is optimal in current climate settings, it is ultimately unfeasible as it requires all southern Basin irrigators to fully adopt high technology levels, and northern Basin irrigators to remain annual producers with a high reliance on water trade. Under these conditions, high levels of *SRWUIP* water recovery become unlikely, and future environmental objectives will not be met.

If these *SRWUIP* investment decisions were made, it assumes that the Basin manager has perfect foresight with regard to water requirements by

[4] Note that water flows are from the north to the south in most MDB catchments before ultimately turning west towards the Murray mouth and the sea.

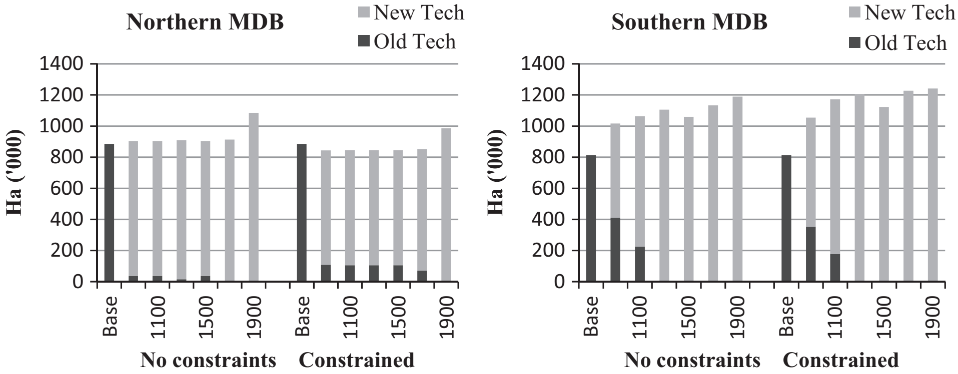

Figure 5 North and South Murray–Darling Basin (MDB) production technology transformations.

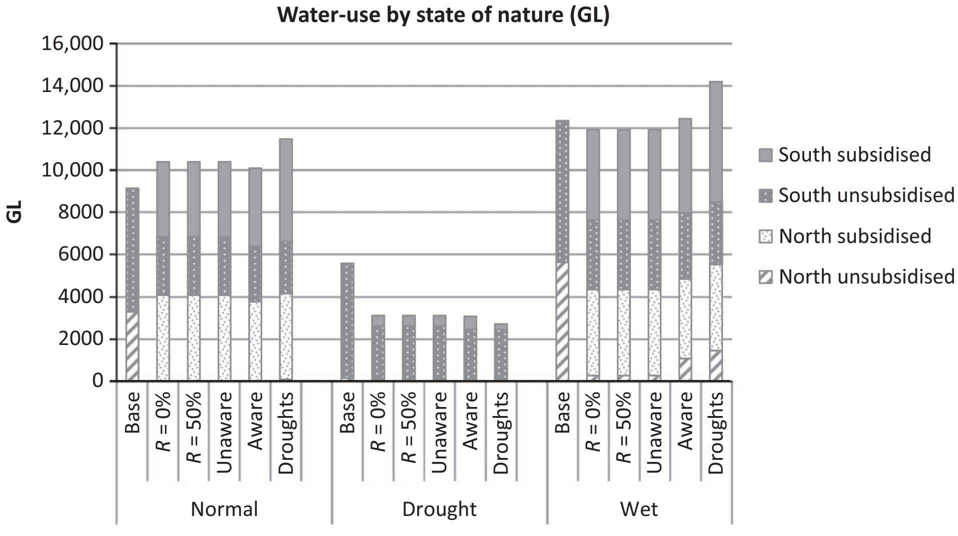

Figure 6 Changes to water-use by state of nature (900 GL target, constrained SDL/trade rules).

society, the environment and perennial producers. Under such assumptions, the model only allocates water to production systems that do not use water in a drought. In reality, perfect foresight does not exist; the heterogeneity and bounded rationality of individual decision-makers results in different resource allocations. Yet, if *SRWUIP* incentives encourage large-scale adoption of perennial production systems and reduced future opportunities for water trade, under drought or adverse realised climate states of nature these transformed areas may collapse due to a lack of water – and large perennial capital investment losses will inevitably follow (Adamson *et al*. 2017). This highlights the riskiness of a policy approach that relies heavily upon water-use efficiency investments. It also supports our third hypothesis that private water-users may engage in mal-adaptation to deal with future climate change.

Notably, *SRWUIP* water recovery levels above 1300 GL cannot be delivered on an annual basis. While water is available in normal and drought states, *SRWUIP* recovery targets are only possible in wet states of nature. This creates kinks in the supply of environmental water from the model estimates, especially under increasing drought (Figure 7). By contrast, unconstrained trade allows water-users to increase productive efficiency and mitigate future drought impacts. This also effects the strategic aim of generating 450 GL of efficiency savings with low-to-no socioeconomic impacts. The model results clearly suggest welfare is improved in the presence of trade, supporting hypothesis four.

4. Discussion

We are able to identify five implications from our modelling of the two MDB water recovery approaches:

4.1 Inflexible future production systems

The model suggests that a *SRWUIP* target of ≥1300 GL could only be achieved if the government was to transform on-farm infrastructure across the entire MDB. This is unrealistic and raises the fundamental question of how national welfare is enhanced by subsidising irrigation technology. Our modelling also suggests that sectoral transformation will encourage significant adoption of perennial production, the focus of previous infrastructure programs (MDBA 2009) and one most likely to generate higher (perceived) returns for irrigators under an assumption of future water supply stability.

However, assumptions of future supply stability are also unrealistic. Perennial production systems are relatively inflexible and highly vulnerable to future water supply shocks (e.g. drought), further reducing irrigator capacity to adjust to future uncertainty and water supply risk. Any over-investment in perennials also negates traditional risk responses to water scarcity by limiting

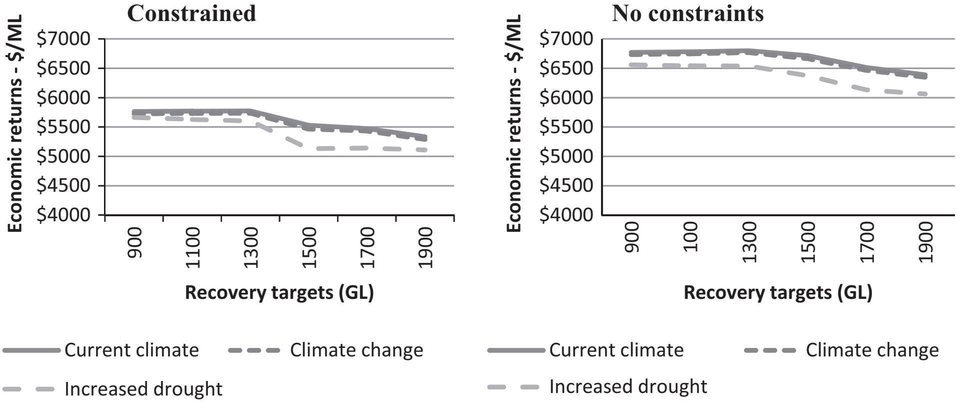

Figure 7 Economic return analysis.

MDB water-user capacity to trade between annual and perennial systems. As discussed, output prices in the model are fixed within the partial equilibrium approach; consequently, any adjustment in price from ‘picking’ perennial commodity winners would further expose irrigation capital to risk. A consequence of *SRWUIP* may be to reduce the resilience of the MDB irrigation sector to future climate risk or shocks. This could lead to significant irreversible capital losses, and potentially reduce future buyback water recovery under what appears to be a misunderstanding of irrigation return flow impacts (Adamson and Loch 2014).

4.2 Increased operation, maintenance and water delivery costs

Improved MDB water-use efficiency has been previously achieved through investment in new infrastructure, enhanced supply arrangements and automated scheduling or delivery measures (e.g. the northern Victoria irrigation renewal project). The operational costs associated with improved technology are usually higher than that experienced under prior arrangements. This leads to increased future water access, delivery and maintenance charges. As the total volume of recovered water grows over time, and their ownership of stored/delivered water rights increases, governments will be required to shoulder an increasing proportion of fixed and variable charges associated with water use (ACF 2014). As shown, the over-investment in infrastructure predicted for southern Basin areas also significantly increases irrigators’ future risk. If this proves unsustainable, it may lead to revenue shortfalls across irrigation districts in various regions where the capacity to pay is diminished, and/or further subsidisation of the true private costs of water storage and delivery associated with MDB irrigation.

4.3 Changes to future environmental targets

Our model predictions suggest that SDL adjustment mechanisms will be required to reduce recovery targets. If the SDL can be reduced by up to 650 GL, then total recovery from *SRWUIP* investments could be capped at around 1100 GL. Under our modelling, the probability of achieving that level of recovery is relatively high across most scenarios – subject to diminishing feasible efficiency project opportunities over time (Crase and O’Keefe 2009), accuracy in the measurement of efficiency savings outcomes and other future uncertainties. However, success of the planned SDL adjustment mechanisms remains highly uncertain due to a lack of international examples with which to compare, and uncertainty surrounding the methodology (Brookes *et al*. 2014). This increases the prospect of recovery failure at higher levels, especially where buyback continues to be constrained. As an alternative arrangement, the federal government may choose to alter the environmental targets associated with *SRWUIP*. Alterations of that nature would be inconsistent with the SDL reduction mechanism requirements, as they would reduce the certainty of consumptive users with little social or economic advantage.

4.4 High recovery costs and potential arbitrage

Higher annuity payments to recover water via efficiency investments appear likely in our model, especially where the area of perennial production increases threefold. However, MDB water users are concerned about future water supply and access (Schirmer and Berry 2014). Enabling large-scale perennial expansion requires annual capital investments that may subsequently sit idle in dry conditions. The federal government has indicated their willingness to pay annuities between 1.9 and 7.1 times greater than existing market prices (DOE 2014). This signals an intent to pay above-market prices to generate wealth transfers that may include the value of structural adjustment for rural communities and water users as they adapt to these changed policy requirements. Water users are highly likely to react to these signals and adopt new technology; but only after holding out for a subsidy. Further, technology adopters may benefit twice from this investment. This would occur under any scenario where irrigators, despite the higher input costs involved (e.g. energy costs), adopted *SRWUIP* infrastructure into their farming operation under perceptions of increased reliability and asset values for held water rights (especially in the south). These rights would, in turn, be even more expensive to purchase should there be any later reincorporation of buyback into future recovery strategies. Further investment in water-use efficiency might also result in the transformation of previously upgraded capital. The scope for strategic behaviour is large, and to our knowledge not well monitored.

4.5 Return to trade programs in MDB recovery

A return to prolonged or extreme drought is likely to trigger future debate about the portfolio of held environmental water rights (i.e. spatial and right characteristics). It may also impact on water security by state of nature where requirements to apply environmental water as emergency responses to save critical sites (e.g. specific wetlands) are accompanied by a failure to meet other prescribed salinity or environmental targets. In that scenario, a reincorporation of buyback instruments would be plausible. If this eventuates, to maximise the benefits of buyback, those irrigators still utilising lower technology water systems should be primarily targeted to avoid undermining any positive achievements from *SRWUIP*.

5. Conclusions

We test the two current instruments for environmental water recovery in the MDB. We find that an increased focus on *SRWUIP* water recovery is less economically efficient relative to water buyback and that the opportunities for lower social-cost investments will diminish over time as existing efficient water users are transformed. As many efficient water users are located in the southern MDB, this requirement also skews the distribution of subsidy outcomes resulting in regional winners and losers. Further, if *SRWUIP* investments result in production system transformations towards perennial systems that are more vulnerable to future water scarcity, large capital losses may occur in any return to drought conditions. Finally, trade reallocates water resources towards producers with a competitive advantage. While the design of the Plan SDL/trade rules distributes the requirements for change across all MDB catchments, it reduces welfare gains.

The findings from this article are useful for water managers, irrigators and policy-makers generally, with wider application. Where government programs are targeted at the management of natural resources under future resource uncertainty, or where public-policy arrangements must be carefully crafted towards suitable and feasible outcomes, then the work detailed herein provides evidence of the merit from SCA modelling. Further, the ability to capture policy detail into model scenario testing underlines the value of optimisation approaches. Here, the federal government's objective of achieving water recovery with minimal impact on irrigation-dependent communities appears feasible – up to a point – but comes at considerable public cost and future production risk. Once again, Henry Jones' comment that 'politicians in all tiers of government are talking about the environment, but they are still dreaming about more production' (Connell 2007, p. 151) comes firmly to mind. The recent Parliamentary Inquiry into water use efficiency in agriculture only serves to reinforce this point.

The model has the usual limitations associated with data availability, bounded rationality and underlying heuristics. Improvements would stem from a full description of the *RtB*/*SRWUIP* programs. This would allow us to redescribe the *RtB*/*SRWUIP* programs through new data sets that understand and represent how property rights emerge from recovered/saved water. Additional data and capacity to more accurately model whole of irrigation delivery system arrangements in the MDB (i.e. off-farm efficiency investments in line with *SRWUIP* objectives and criteria) would also provide significant modelling gains.

References

ACF (2014). *Restoring Our Lifeblood: Progress on Returning Water to the Rivers of the Murray-Darling Basin*. Australian Conservation Foundation, Carlton, Vic.

Adamson, D. (2015). Restoring the balance: water reform & the Murray-Darling Basin plan. PhD, School of Agriculture and Food Sciences, University of Queensland, Brisbane, Qld.

Adamson, D. and Loch, A. (2014). Possible negative feedbacks from 'gold-plating' irrigation infrastructure, *Agricultural Water Management* 145, 134–144.

Adamson, D., Mallawaarachchi, T. and Quiggin, J. (2007). Water use and salinity in the Murray-Darling Basin: a state-contingent model, *Australian Journal of Agricultural and Resource Economics* 51, 263–281.

Adamson, D., Loch, A. and Schwabe, K. (2017). Adaptation responses to increasing drought frequency, *Australian Journal of Agricultural and Resource Economics* 61, 385–403.

Australian Parliament (2011). *Of Drought and Flooding Rains: Inquiry into the Impact of the Guide to the Murray-Darling Basin Plan*. House of Representatives Standing Committee on Regional Australia, Canberra, ACT.

Bjornlund, H. (2006). Can water markets assist irrigators managing increased supply risk?: some Australian experiences, *Water International* 31, 221–232.

Brennan, D. (2006). Water policy reform in Australia: lessons from the Victorian seasonal water market, *Australian Journal of Agricultural and Resource Economics* 50, 403–423.

Bromley, D.W. (1990). The ideology of efficiency: searching for a theory of policy analysis, *Journal of Environmental Economics and Management* 19, 86–107.

Brookes, J., Hillman, T., Jones, G. and Stewardson, M. (2014). SDL Adjustment Ecological Elements Method Development Report. Independent Review Panel, Murray-Darling Basin Authority, Canberra, ACT.

Chambers, R.G. and Quiggin, J. (2000). *Uncertainty, Production, Choice, and Agency: the State-Contingent Approach*. Cambridge University Press, Cambridge UK.

Ciriacy-Wantrup, S.V. and Bishop, R.C. (1975). Common property as a concept in natural resources policy, *Natural Resources Journal* 15, 713–728.

Connell, D. (2007). *Water Politics in the Murray-Darling Basin*. The Federation Press, Annandale, NSW.

Cox, J. and Warner, R. (2009). *Water trading – panacea or placebo?*, Water Leaders Congress; 6 March, IPART, Sydney, NSW, Australia.

Crase, L. and O'Keefe, S. (2009). The paradox of national water savings: a critique of 'Water for the Future', *Agenda* 16, 45–60.

Crase, L., O'Keefe, S. and Kinoshita, Y. (2012). Enhancing agrienvironmental outcomes: market-based approaches to water in Australia's Murray-Darling Basin, *Water Resources Research* 48, W09536.

DOE (2014). *Water Recovery Strategy for the Murray-Darling Basin*. Department of the Environment, Canberra, ACT.

DOE (2015). *Water Amendment Bill 2015*. Department of the Environment, Canberra, ACT.

DSEWPC (2012). *Environmental Water Recovery Strategy for the Murray-Darling Basin*. Department of Sustainability, Environment, Water, Population and Communities, Canberra, ACT.

Fairweather, H., Austin, N. and Hope, M. (2009). *Water Use Efficiency: An Information Package, Irrigation Insights No. 5*. Land and Water Australia, Canberra, ACT.

Garnaut, R. (2008). *The Garnaut Climate Change Review: Final Report*. Cambridge University Press, Melbourne, Vic., Australia.

Gomez, C.M. and Gutierrez-Martin, C. (2011). *Enhancing irrigation efficiency but increasing water use: The Jevon's Paradox*, EAAE Congress: Change and Uncertainty Challenges for Agriculture, Food and Natural Resources; 30 August–2 September 2011, Zurich, Switzerland.

Gómez, C.M. and Pérez-Blanco, C.D. (2014). Simple myths and basic maths about greening irrigation, *Water Resources Management* 28, 4035–4044.

Loch, A. and Adamson, D. (2015). Drought and the rebound effect: a Murray-Darling Basin example, *Natural Hazards* 79, 1429–1449.

Loch, A., Wheeler, S., Boxall, P., Hatton-MacDonald, D., Adamowicz, W. and Bjornlund, H. (2014). Irrigator preferences for water recovery budget expenditure in the Murray-Darling Basin, *Land Use Policy* 36, 396–404.

Maraseni, T., Mushtaq, S. and Reardon-Smith, K. (2012). Climate change, water security and the need for integrated policy development: the case of on-farm infrastructure investment in the Australian irrigation sector, *Environmental Research Letters* 7, 034006.

Marshall, G. (2013). Transaction costs, collective action and adaptation in managing complex social–ecological systems, *Ecological Economics* 88, 185–194.

MDBA (2009). Murray-Darling Basin environmental water recovery report – as at June 30 2009. Murray-Darling Basin Authority, Canberra, ACT.

MDBA (2012). *Water Act 2007* – Basin Plan. Murray-Darling Basin Authority, Canberra, ACT.

MDBMC (2014). *The Sustainable Diversion Limit Adjustment Mechanism*. Murray-Darling Basin Ministerial Council, Canberra, ACT.

Mushtaq, S., Maraseni, T. and Reardon-Smith, K. (2013). Climate change and water security: estimating the greenhouse gas costs of achieving water security through investments in modern irrigation technology, *Agricultural Systems* 117, 78–89.

Nieuwoudt, W. and Armitage, R. (2004). Water market transfers in South Africa: two case studies, *Water Resources Research* 40, W09S05.

Productivity Commission (2010). Market mechanisms for recovering water in the Murray-Darling Basin, Final report, Productivity Commission, Canberra, ACT.

Quiggin, J. (2001). Environmental economics and the Murray-Darling river system, *Australian Journal of Agricultural and Resource Economics* 45, 67–94.

Quiggin, J. (2006). Urban water supply in Australia: the option of diverting water from irrigation, *Public Policy* 1, 14–22.

Quiggin, J., Adamson, D., Chambers, S. and Schrobback, P. (2010). Climate change, uncertainty, and adaptation: the case of irrigated agriculture in the Murray-Darling Basin in Australia, *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie* 58, 531–554.

Randall, A. (1975). Property rights and social microeconomics, *Natural Resources Journal* 15, 729–748.

Schirmer, J. and Berry, H. (2014). *People and Place in Australia: The 2013 Regional Wellbeing Survey Summary Report*. University of Canberra, Canberra, ACT.

Ward, F.A. and Pulido-Velazquez, M. (2008). Water conservation in irrigation can increase water use, *Proceedings of the National Academy of Sciences* 105, 18215–18220.

Wheeler, S. and Cheesman, J. (2013). Key findings from a survey of sellers to the restoring the balance programme, *Economic Papers: A Journal of Applied Economics and Policy* 23, 340–352.

Wheeler, S., Garrick, D., Loch, A. and Bjornlund, H. (2013). Evaluating water market products to acquire water for the environment in Australia, *Land Use Policy* 30, 427–436.

Williams, J., Stubbs, T., Miller, C. and Verity, F. (2009). *Building Resilient Futures but with Less Water: Communities Can, but not on Their Own*. Wentworth Group of Concerned Scientists, Sydney, NSW.

Wittwer, G. (2011). Confusing policy and catastrophe: buybacks and drought in the Murray-Darling Basin, *Economic Papers: A Journal of Applied Economics and Policy* 30, 289–295.

Wittwer, G. and Dixon, J. (2013). Effective use of public funding in the Murray-Darling Basin: a comparison of buybacks and infrastructure upgrades, *Australian Journal of Agricultural and Resource Economics* 57, 399–421.

Wittwer, G. and Griffith, M. (2011). Modelling drought and recovery in the southern Murray-Darling Basin, *Australian Journal of Agricultural and Resource Economics* 55, 342–359.