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Natural capital and climate change: Possible negative sustainability impacts from 'gold plating' irrigation infrastructure

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Natural Capital and Climate Change: Possible Negative Sustainability Impacts from 'Gold-Plating' Irrigation Infrastructure

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ABSTRACT

For an individual irrigator water use efficiency increases in response to investments in on-farm capital. Sustainable river systems require sufficient flows to maintain the value and function of natural capital assets. In constrained water resource settings, federal basin managers may view on-farm capital investments as a policy objective to rebalance water shares between all users to offset negative externalities from over allocation. This paper uses a state contingent modelling approach to review an extended farm capital investment policy in Australia's Murray-Darling Basin. We examine technical efficiency gain implications for irrigation and environmental water managers under alternative states of inflow variability and the role increasing climatic uncertainty has on policy objectives. Results suggest that the incentives provided to recover environment water via on-farm capital investments could have two principal negative feedbacks given future uncertainties. First, farm capital investments may encourage inflexible production systems that fail to respond to future water scarcity, exposing that investment to increased risk. Second, technical efficiency gains may reduce return flows leading to perverse policy outcomes to achieve environmental objectives. By highlighting these ulterior policy outcomes it provides both irrigators and policy makers the capacity to adapt and increase their flexibility to develop robust policy and management solutions to help negate future uncertainty.

Keywords: technical efficiency, natural capital, Murray-Darling Basin, climate change, optimisation

JEL Codes: Q25, Q54

Natural Capital and Climate Change: Possible Negative Sustainability Impacts from 'Gold-Plating' Irrigation Infrastructure

1. Introduction

Natural capital is 'the stock which produces a flux of natural resources' (Daly, 1994, pg. 23). Natural capital is required by economic production to create manufactured capital (Costanza and Daly, 1992), but the complex interplay between economic, social-cultural and ecological systems requires preservation of critical natural capital (e.g. renewable water resources) to sustain both economic production and the biophysical environment (Chiesura and de Groot, 2003). Clarke and Munro (1994) argue natural capital must form part of national accounts, as quality and quantity changes affect future choice options. An example is the complex economic, social and ecological water demand trade-offs in Australia's Murray-Darling Basin (MDB), which have driven the implementation of costly and contentious intervention strategies to reallocate water from economic (e.g. irrigated agriculture) to ecological (e.g. basin river flow) uses. Major intervention approaches involve: i) market purchase of agricultural water rights through a $3.1 billion program known as *Restoring the Balance (RtB)*; and ii) off-farm storage/delivery infrastructure upgrades and on-farm irrigation technical efficiency improvements through a $5.8 billion program known as *Sustainable Rural Water Use and Infrastructure (SRWUI)* (Crase and O'Keefe, 2009). A target reallocation figure of 2,750GL from these intervention programs by 2019 was established through a Basin-wide Plan (MDBA, 2012). Recently, a further $1.7 billion was committed to purchasing additional water rights and addressing water delivery constraints in the MDB (DSEWPC, 2013). Consequently, reallocation targets for environmental outcomes have increased by 450GL to 3,200GL and the completion timeframe by five years to 2024.

These intervention programs constitute significant wealth transfers to agricultural water users at both farm and infrastructure operator levels. Of the two intervention programs, *SRWUI* represents the larger proportion of funding commitment (68%). However, water reallocation from this program may be limited to 40% of the 3,200GL target if historic MDB water saving outcomes can be maintained.[1] As previous policy has divided water savings equally between irrigation and environmental uses, total water reallocation from infrastructure projects may be as low as 20% of environmental needs. Further, climate change is predicted to reduce MDB surface water availability between 9% (northern MDB) and 13% (southern MDB) under the median 2030 scenario (CSIRO, 2008). If accurate, this has important implications for future water saving outcomes from any executed *SRWUI* projects between now and 2024. Finally, the MDB experiences high seasonal variability in surface water runoff into storage and delivery systems (Connor *et al.*, 2012), which must factor into environmental managers' capacity to deliver environmental objectives across a temporal scale. The uncertainties related to the *SRWUI* program include water returned from capital works, future climate change impacts and MDB seasonal inflow variability; which require flexible water management arrangements to achieve the Basin Plan's objectives. For example, the environmental flow objectives provide habitat refugia or rejuvenation, sediment or nutrient flushing from the system, and ephemeral connections between spatially diverse species populations while maintaining low levels of salinity (MDBA, 2010). Investing in fixed capital projects across the MDB may therefore be inconsistent with a flexible management approach to counter the inherent variability and uncertainty associated with future flow patterns.

The size of the budget allocated to the Basin Plan requires careful scrutiny to ensure value from such public expenditure. To examine this issue this paper reviews the *SRWUI* program objectives and models technical efficiency gain implications for agricultural water users and the environment under assumptions of increasing future water supply uncertainty. The technical efficiency gain implications are demonstrated using a modified version of the state contingent MDB model developed by Adamson *et al.* (2009), which highlights differences between variability and climate change within the basin and allows for proactive water user responses to environmental stimuli. Qureshi *et al.* (2010)

[1] The Living Murray (TLM) program invested $1 billion in market purchase and (predominantly) infrastructure upgrade projects between 2004 and 2009 to generate 225GL of water savings from technical efficiency improvements (MDBA, 2009). These savings were divided equally between agricultural, environmental and urban uses (Quiggin, 2011). With no discount factor—an unlikely outcome given an expected diminishing availability of suitable infrastructure investment projects over time (Crase and O'Keefe, 2009)—a further $6 billion investment could generate ~6 x 225 = 1,350GL water savings; or 40% of the reallocation objective.

provide an archetypal examination of the interaction between MDB intervention approaches and return flow outcomes. This paper expands that study in three ways. First, a full-Basin model is optimised rather than focusing on a single-catchment example. Second, while the two studies share similar state of nature constraints this study considers future risk and adaptation to both climate change and extended drought conditions. Third, where Qureshi *et al.* concentrate on return flow impacts from intervention this paper assesses the outcome of capital works on MDB Plan objectives (environmental, social and economic) to determine the net value of this approach. Results suggest that increasing farm technical efficiency via capital investment may encourage production systems with reduced adaptive capacity to future water scarcity, thus exposing sunk capital to unacceptable risk. Further, the modelling suggests that rather than freeing natural capital for environmental use the proposed technical efficiency investment creates second-best options for the MDB environment, if changes to return flow are ignored. Finally, during climate change or drought-induced water scarcity this approach results in significant reductions of water supply to achieve environmental, social and economic outcomes across the MDB.

The remainder of this paper outlines: general issues associated with technical efficiency improvement in the MDB; the modified state contingent MDB model and its application in this context; results from the modelling process; and implications for water managers. We conclude that federal basin water managers at multiple governance scales should avoid reallocation policy options that ignore requirements to flexibly manage the inherent variability and uncertainty associated with their systems.

2. Technical efficiency issues

The reallocation of natural capital to the environment via investment in on-farm capital is based on an assumption of technical efficiency gains. In this paper, technical efficiency is expressed as both a reduction in the volume of water required to produce (at least) similar original technology outputs, and a reduction in the rate of return flows (Cummins and Watson, 2011). Irrigation water is applied to support plant growth and yield. The difference between applied water and plant uptake (return flow) contributes water to the hydrological system from irrigation runoff, seepage or evaporation, which provide a basis for a variety of downstream water rights (Nieuwoudt and Armitage, 2004). Thus, more efficient water use may result in reduced irrigation water use as well as less 'excess' water availability as return flows to the hydrological system (Grafton and Hussey, 2007). Negative impacts from reduced return flows include less surface water runoff and groundwater recharge (Young, 2010), water quality impacts from increased pollutants (e.g. salt or phosphate) or turbidity (Grafton and Hussey, 2007), and magnified consumptive irrigation use (Connell and Grafton, 2008) reducing water for the environment. Extended drought, drainage collection improvements and altered on-farm water use practices have reduced MDB return flows since the early 1990s (URS Australia Pty Ltd., 2010). Return flow reductions from changed water use practices to manage variable water supply conditions under climate change are also reported by Connor *et al.* (2012).

The technical efficiency impacts explored herein are best highlighted through example. Figure 1 illustrates expected perennial crop water use changes following subsidised capital investments. The original production function generated an output per hectare (Z) from water use *WU*. With farm capital investment the new production function generates the same *Z* from a reduced water volume (*WU'*). For simplicity it is assumed that neither the operational or maintenance costs increase. Under drought (climate change) conditions the available water will decrease proportionally for each production function to *WUd/WUd'* such that the reduction is equivalent (*WU-WUd* = *WU'-WUd'*). Farm output also falls from Z to *Zd/Zd'*, where Z*d'* < *Zd*.

Figure 1: The Murray-Darling Basin and its hydrological catchments

During drought supply conditions we assume all saved water from capital transformation has been applied to perennial horticulture production, resulting in a higher capital level exposure to risk than in the original production function context. Further, where the capital transformation has not increased water supply security, or where the water savings are not used to improve flexibility in farm risk management, then subsequent droughts will result in additional negative capital returns (e.g. the perennial crop asset may be lost). Young *et al.* (2002) suggest that, over 20 years, water efficiency savings following capital transformation could reduce net (return) flows by as much as 723GL per annum—or 23% of reallocation objectives under the 3,200GL target. Climate change could have further impact on return flows in the southern MDB especially. Quantifying the impacts of changes to land and water use, and the subsequent return flow implications, under inherent basin water supply uncertainties motivates our application of a modified state contingent model.

3. Model methodology and data

Incorporating risk and uncertainty is paramount to decision making. The literature in allocating water resources in the Basin abounds with studies (e.g. Grafton et al., 2011; Qureshi et al., 2010) where risk and uncertainty is encapsulated within an expected value framework using errors terms to provide a stochastic representation of outcome. This approach dominates the literature despite its ability to provide “inefficient and biased results” (Just and Pope, 1978). The state-contingent approach tackles the allocation of resources differently. Instead of passively describing the producers’ response within an error term it assumes that producers actively respond to environmental signals by altering inputs to produce outputs that are defined by that signal. By viewing all possible future outcomes into a set of mutually exclusive states of nature (i.e. droughts, floods and normal) you can then adopt the approaches developed for allocating resources under certainty (Chambers and Quiggin, 2000).

To represent the *SRWUI* program the model had to be modified to examine the policy signals of reducing the cost of capital, the change in water use and associated variable costs, and the impacts of increasing water use efficiency by manipulating the volume of water returning to the river system after irrigation use. The following assumptions have been made for the *SRWUI* program. Only 50% of the water efficiency gained from capital expenditure goes to the environment. A total budget of $7.6 billion exists (MDBA 2012) to recover 971GL and the program only occurs in the Southern Basin.[2] This then provides an annuity per ML of $367 at 7% over a 20 year period. By assuming that capital is subsidised by the total volume of water returned to the environment per hectare the reduced capital

[2] The 971 GL figure is based on the volume of water to be sourced from the Southern trading zones (NSW, VIC and SA) as detailed in Table 1. Other options in regards to the total volume to be obtained from the *SRWUI* were examined but violated constraints and have not been reported.

by commodity by catchment is determined. The reduction in variable costs is determined by the total water efficiency gain multiplied by the price of water.

Table 1:
Net reduction in extractions, by trade zone

K	Catchment (k) Name	Surface Diversion Limits		Water already returned	Water from Capital Investment
		Current	Proposed		
1	Condamine	586.8	526.8	16.8	
2	Border Rivers QLD	404.0	396.0	5.0	
3	Warrego Paroo	168.9	159.9	9.0	
4	Namoi	508.0	498.0	10.0	
5	Central West	734.0	669.0	65.0	
6	Maranoa Balonne	391.2	351.2	11.2	
7	Border Rivers Gwydir	753.0	704.0	5.0	
8	Western	198.0	192.0	0.0	
9	Lachlan	618.0	553.0	*65.0*	
10	Murrumbidgee	2,553.5	2,233.5	173.0	
11	North East	329.9	297.0	32.9	
12	Murray 1	54.4	46.5	7.9	
13	Goulburn Broken	1,915.7	1,546.4	369.3	
14	Murray 2	906.0	775.0	131.0	
15	North Central	1,441.6	1,247.1	194.5	
16	Murray 3	815.4	697.5	117.9	
17	Mallee	204.8	174.5	30.4	
18	Lower Murray Darling	96.7	83.5	13.2	
19	SA MDB	459.0	358.0	101.0	
20	Adelaide	206.0	206.0		
21	Coorong				
	TOTAL	13,344.9	11,714.9	**1,358.0**	
Reduction in Surface Extractions (A)			**1,630.0**		
Other Adjustments Zone					
Northern (k = 1 to 8)			143.0		
Southern VIC (k = 11, 13, 15, 17)			425.3		425.3
Southern NSW (inc ACT) (k =10,12,14,16,18)			462.9		462.9
Southern SA (k =19)			82.8		82.8
All Southern (k = 10 to 19)			450.0		450.0
Total Shared Reduction (B)			**1,564.0**		**1,421.0**
TOTAL Reduction in Surface Flows (A+B)			**3,194.0**		

Notes differences to Basin Plan are due to:

- Reduction in the SDL to Basin Plan is due to the Wimmera not being modelled
- Lachlan's propped SDL reduction is 48 GL but already 65 GL has been returned

Source: (MDBA, 2012)

The *SRWUI* program is compared to the Base solution. The Base solution assumes that water use is constrained to the Basin Plan Sustainable Diversion Limits (SDL) and all adjustment occurs via trade within the defined regions (see below). Consequently the model documentation has been written as modifications to the Base solution and only discusses changes made to the model. For the full documentation see Adamson *et al.* (2007). The climate change impacts are modelled in two different ways, and this is discussed in the appropriate section below. The complete data sets and results can be obtained from the corresponding author.

For this paper the model is solved from the national good perspective where a single individual can allocate all resources throughout the Basin to achieve the maximum possible return (Equation 1) subject to a set of constraints (Equations 5 to 10).

$$MaxE[Y] = \sum_{K} \sum_{s \in \Omega} \pi_s \left(R_{s,k} - C_{s,k} \right) \quad (1)$$

Where:

Revenue: $$r_{s,k} = z_{s,k} p_{s,k} \quad (2)$$

Costs $$c_{s,k} = a_{s,k}{}' x_{s,k} \quad (3)$$

Output $$z_{s,k} = f(x_k) \quad (4)$$

Subject to:

$$b_{s,k} x_{s,k} \leq B_{s,k} \quad (5)$$

$$x_s \geq 0 \quad (6)$$

$$w_{s,k} \leq wf_{s,k} \quad (7)$$

$$\sum_{K} W \pi_s \leq SDL \quad (8)$$

$$wf_{s,21} \geq 650\ GL \quad (9)$$

$$\sigma_{s,20} / 0.64 \leq 800 \text{ EC} \quad (10)$$

Symbol:	**Definition:**
$E[Y]$	Expected [Income]
K	Catchments in the Basin ($K = 1 \dots 21$)

S	States of Nature ($S = 1..3$)
π	Probability of state occurrence
R	Revenue
C	Costs
Z	Output
P	Price per unit of output
x	Vector of activities
a	Vector of input prices (land, fixed costs, variable costs, water)
b	Vector of input requirements (land (l), fixed costs, variable costs, water)
B	Input constraints (land (L), water)
w	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 Basin Plan
σ	Salinity level in EC units

3.1. Production Systems

The model has 23 state contingent production systems; there are 21 choices in irrigated activities, a dryland production and water to be diverted for Adelaide, as illustrated by the first column in Table 2. These production systems are derived from a set of commodities ($M = 1 \dots 17$). The transformation of commodities to state contingent production systems occurs by mixing and matching commodities, transitioning commodities between dryland and irrigated activities, altering inputs and outputs, and two technology settings, L & H. Low (L) defines production systems with low technology, for example furrow or overhead irrigation. While High (H) defines a high technology setting for example drip irrigation. Columns 2, 3 and 4 illustrate how managers can alter commodity selection by state of nature. As illustrated once a perennial crop (e.g. grapes) is selected that commodity must always be produced in each state of nature. The manager's response for perennials in alternative states is to alter inputs b to produce alternative outputs Z. For modelling *SRWUI* program, x increases to 30 commodities by modifying production systems ($x = 1 \dots 7$) to illustrate changes to vectors a and b (as per Table 3).

Table 2:
Equation symbol definitions (1)

Symbol:	**Definition:**
$E[Y]$	Expected [Income]
K	Catchments in the Basin ($K = 1 \ldots 21$)
S	States of Nature ($S = 1..3$)
π	Probability of state occurrence
R	Revenue
C	Costs
Z	Output
P	Price per unit of output
x	Vector of activities
a	Vector of input prices (land, fixed costs, variable costs, water)
b	Vector of input requirements (land (l), fixed costs, variable costs, water)
B	Input constraints (land (L), water)
w	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 Basin Plan
σ	Salinity level in EC units

Table 3:
The state contingent production system

x	Production System Name	State Contingent Crop		
		Drought	**Normal**	**Wet**
1	**Citrus-H**	Citrus-H	Citrus-H	Citrus-H
2	**Citrus-L**	Citrus-L	Citrus-L	Citrus-L
3	**Grapes**	Grapes	Grapes	Grapes
4	**Stone Fruit-H**	Stone Fruit-H	Stone Fruit-H	Stone Fruit-H
5	**Stone Fruit-L**	Stone Fruit-L	Stone Fruit-L	Stone Fruit-L
6	**Pome Fruit**	Pome Fruit	Pome Fruit	Pome Fruit
7	**Vegetables**	Melons	Vegetables	Fresh Tomatoes
8	**Cotton Flex**	Dryland Cotton	Cotton Flex	Cotton Flex
9	**Cotton Fixed**	Cotton Fixed	Cotton Fixed	Cotton Fixed
10	**Cotton/Chickpea**	Chickpea	Cotton Flex	Cotton Flex
11	**Cotton Wet**	Dryland Cotton	Dryland Cotton	Cotton Flex
12	**Rice PSN**	Rice PSD	Rice PSN	Rice PSW
13	**Rice Flex**	Dryland Wheat	Rice PSN	Rice PSW
14	**Rice Wet**	Dryland Wheat	Dryland Wheat	Rice PSW
15	**Wheat**	Wheat	Wheat	Wheat
16	**Wheat Legume**	Wheat Legume Dry	Wheat Legume	Wheat Legume Wet
17	**Sorghum**	Sorghum	Sorghum	Sorghum
18	**Oilseeds**	Oilseeds	Oilseeds	Oilseeds
19	**Sheep Wheat**	Sheep Wheat Dry	Sheep Wheat	Sheep Wheat Wet
20	**Dairy-H**	Dairy-H	Dairy-H	Dairy-H
21	**Dairy-L**	Dairy-L	Dairy-L	Dairy-L
22	**Dryland**	Dryland	Dryland	Dryland
23	**Adelaide Water**	Urban Water	Urban Water	Urban Water

Due to a lack of data it was assumed that the new capital intensive horticultural crops would experience a net reduction in water use of 20-30% depending on their existing technology settings. Importantly some state contingent annual cropping systems include a multiple crop rotations and limits on production consistent with production systems.

The total land L constraint in B is derived by increasing the area reported to be irrigated in 2001 (ABS, 2004). This version of the model allows for total area to increase by 50%, with the exception of *k1, k6 & k11*, where the total area dedicated to irrigation has been allowed to increase by 150%, 200% and 100% to bring data into line with known capacities. To prevent unrealistic expansion of horticultural commodities ($x = 1 \ldots 7$) in the Base model the area reported to be under horticulture in the above data set is constrained to only increase by 50%. This then prevents horticulture dominating the landscape, in the Base model due to lack of capital. This separation also allows for the model to treat the expansion in perennial and broad acre separately. Any land not allocated to an irrigation activity then transitions to R_{23}, dryland production. However, this constraint was relaxed in the *SRWUI* runs to deliberately illustrate perverse policy outcomes of how cheap capital could alter investment patterns.

Unlike the previous versions the constraints concerning operator labour have been relaxed on the assumption that labour would enter the market to take advantage of opportunities. This then helps illustrate the story of horticultural expansion in the southern Basin.

3.2. Interaction between water & salinity

The Basin is modelled as a directed flow network across 21 catchments. Conjunctive exogenous water resources θ include surface flows, ground water extractions and net inter-basin transfers. However, due to complexities with the Basin Plan ground water resources are not examined in this model. The states of nature are defined by a proportional change to the normal state's θ, where the drought state is $0.6\theta$and the wet state is 1.2θ. The model assumes that the probability of a drought, normal and wet states is 0.2, 0.5, 03 respectively. The flow leaving each catchment $\mathrm{wf}_{\mathrm{k,s}}$ is derived from equation 11. Here the flow is determined by the impact that conveyance losses wc have on water resources and include the net water used from irrigation less the water return flows wr from its use.

$$wf_{k,s} = \left(\theta_{k,s} \cdot wc_{k,s}\right) - \left(w_{ks} - wr_{k,s}\right) \tag{11}$$

For each production system $x_{\mathrm{k,s}}$, a defined water use and reflow variable by technology option exists. This provides the capacity to model the *SRWUI* and the impacts of the spatial location of investment. Water quality is simplified to reflect salinity σ (see Equation 12) as it is a binding policy constraint to ensure that the Basin Plan's requirement for the City of Adelaide's water quality is achieved (Equation 10). Herein, σ is a ratio of the salt load G and f where:

$$\sigma_{\mathrm{k,s}} = \mathrm{G}_{\mathrm{k,s}}/\mathrm{wf}_{\mathrm{k,s}} \tag{12}$$

$\mathrm{G}_{\mathrm{s}}^{\mathrm{k}}$ is a combination of the naturally mobilised exogenous tonnes of salt that enters with θ_{ks} less the exogenous tonnes of salt removed via the salinity mitigation program, plus the endogenous salt transported with reflow determined by $\theta_s w_{ks}$. Without a detailed environmental plan in the Basin Plan Equation 9 provides the only environmental target for this model. This simply ensures that 650 GL of water arrives to the Coorong in all states of nature.

3.3. The Bain Plan & Capital Infrastructure

Water used for irrigation is constrained by $wf_{k,s}$ (Equation 7) and the Basin Plan's exogenous sustainable diversion limits (Equations 8). However to model the Basin Plan, Equation 8 has to be transformed into Equations 13 to17. The current plan stipulates both a reduction by k and a defined volume to be sourced from within interconnected or state based trading regions (Table 1). Of the two,' termed' unconnected systems only the Lachlan (k = 9) is included within the model. Within the identified trading zones the Base model has assumed free trade to obtain water at least cost for the environment. The model considers all water diverted for irrigation is used on farm and does not track conveyance losses in built capital infrastructure. These equations allow irrigation water can to be carried over between states of nature by only requiring water on average to equal the specified SDL. For the *SRWUI* program Equation 19 replaces Equations 15 to 17 to allow the model to find the best places within the Southern connected system to undertake capital works to get 971 GL for the environment.

$$\sum w^k \pi_s \leq \sum SurfaceSDL^k \tag{13}$$

$$\sum w^{NTV} \pi_s \leq 143\ GL \tag{14}$$

$$\sum w^{STV} \pi_s \leq 425.3\ GL \tag{15}$$

$$\sum w^{STN} \pi_s \leq 462.9\ GL \tag{16}$$

$$\sum w^{STS} \pi_s \leq 82.8\ GL \tag{17}$$

$$\sum w^{STA} \pi_s \leq 450\ GL \tag{18}$$

$$\sum w^{CTZ} \pi_s = 971\ GL \tag{19}$$

Symbol:	Definition:
$SurfaceSDL$	Total volume of surface water allowed for irrigation use
$GroundSDL$	Total volume of ground water allowed for irrigation use
NTS	Water trading zones in the northern catchments ($k = 1 \dots 8$)
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 ($k = 10 \dots 19$)
CTZ	Water from capital programs in southern trading zones ($k = 10 \dots 19$)

3.4. Water Resources and Climate Change

This study uses data from the Garnaut Climate Change review and Quiggin *et al.* (2010), which describes the data and the assumptions for converting climate variables into changes in runoff to re-parameterise θ. From that study, the best case, climate change scenario (450 Average) was chosen in to make this article comparable with other published material. This is described as the strong mitigation scenario, in which CO2 equivalents are stabilised at 450 ppm by 2100. At this point mean global temperature is expected to increase by ~1.5°C. This scenario uses 50th percentile projections for rainfall, relative humidity and surface temperature across Australia. This study examines the impact on water resources in two time periods 2050 and 2100, which equates to approximately an average decline in water resources of 10% and 20% respectively.

The second approach to modelling climate change is undertaken by changing the frequency of the droughts. In this case the data for the Base model where the normal, drought and wet states occur with a frequency of 0.5, 0.2 and 0.3 respectively are altered to 0.5, 0.3 and 0.2.

4. Results

Table 4 summarises the model runs under taken in this paper. The Base model assumes what would occur if the SDL was achieved by simply trading the water away from irrigators. All other runs examine the *SRWUI* and assume that 971 GL of water must come from water savings via capital works. In the southern trade zones the base full-trade model converged in all states of nature without violating the imposed water use, flow to Coorong or salinity constraints. Average annual capital investment required to achieve this outcome was $1,674 million (Table 5). We then also relaxed strict return flow constraints across these trade zones. This model (WRF-100) optimised, providing a basis for further model comparisons. WRF-100 assumed that return flows rates did not alter in response to capital works investment (i.e. 100% return flows).

Table 4:
How Capital Investment has been modelled to influence water use, return flow rates and subsidised capital expenditure in the Murrumbidgee only

x	Production System Name	Reduction Water Requirements			Return flow Rates			Reduction in Capital
		Drought	Normal	Wet	Drought	Normal	Wet	
24	**Citrus-H**	2.3	2.3	2.7	0.05	0.15	0.15	$828
25	**Citrus-L**	2.0	2.0	2.4	0.05	0.15	0.15	$736
26	**Grapes**	1.8	1.8	2.2	0.05	0.15	0.15	$677
27	**Stone Fruit-H**	0.9	0.9	1.1	0.05	0.15	0.15	$331
28	**Stone Fruit-L**	1.3	1.3	1.5	0.05	0.15	0.15	$474
29	**Pome Fruit**	2.1	2.1	2.5	0.05	0.15	0.15	$773
30	**Vegetables**	0.0	2.5	1.8	0.05	0.15	0.15	$904

Note: Half of the water reduction is estimated to go to the environment by state of nature

The reduction in water costs is reflected in the changes to variable costs under constant $/ML

Table 5:
Equation symbol definitions (2)

Symbol:	**Definition:**
$SurfaceSDL$	Total volume of surface water allowed for irrigation use
$GroundSDL$	Total volume of ground water allowed for irrigation use
NTS	Water trading zones in the northern catchments ($k = 1 \ldots 8$)
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 ($k = 10 \ldots 19$)
CTZ	Water from capital programs in southern trading zones ($k = 10 \ldots 19$)

The WRF-100 results provided Coorong flows of 867GL under drought conditions while salinity was maintained at 308EC, meeting important constraints. By comparison, in the model where it was known that capital works would result in 50% return flow reductions (WRF-50 *ex-post*) constraints were still able to be met. That is, Coorong flows of 650GL were achieved in drought conditions with a moderate increase in salinity (348EC); providing a feasible outcome from the capital works program (see italicised Coorong flow volumes in Table 5). In the normal state agricultural water use remained reasonably consistent between the Base and WRF-100/WRF-50 (*ex-post*) models, but economic returns increased dramatically (from $2,436 to ~$7,760 million) as the subsidisation of capital investment transformed the southern Basin towards increased production of citrus and grape perennials. This transformation naturally involved corresponding increases in farm capital exposure to risk under different states of nature. However, to achieve this increased income the annual cost of capital would need to be $5,755 million.

In all further models we now treated capital investment as a sunk-cost. Interest turned to what may occur during future periods of water scarcity under climate change and/or prolonged drought conditions, similar to those experienced in the MDB between 2000/01 and 2009/10. Climate change impacts on achieving 450GL average recovery outcomes in the *southern All* trade zone were modelled using MDB scenarios out to 2050 (2050 CC) and 2100 (2100 CC). Although not optimized, the models showed decreasing return flows in northern Basin catchments in normal and wet states, and large southern Basin catchment return flow reductions in the drought state of nature. In both models Coorong flows are reduced to zero, and salinity impacts range between 1,750EC (2050 CC) and 2,371EC (2100 CC). This suggests that any early environmental benefits derived from a MDB capital works program could be entirely undone by 2100 under climate change impacts. It also suggests a significant requirement for future MDB structural adjustment under a capital works intervention approach.

The increased frequency of MDB drought states model (i.e. probability of drought increases to 0.3, while wet state probability falls to 0.2) also produced some interesting capital works outcomes. While the model did optimise, meeting the 650GL Coorong flow and (largely) salinity constraints, water and land use actually increased across the Basin. Setting return flows at 50% allows an additional 492GL of water use during the drought state and—as the model seeks to be as flexible as it can be under the constraints—another 79,000 hectares of land use. In this case, southern Basin production mainly transforms toward annual vegetable crops, consistent with expected agricultural water use under drought conditions and assumed irrigator risk aversion. However, in line with our technical efficiency discussion above perennial crop production also decreases, suggesting negative capital returns for the Basin as a whole. Overall the model estimates an increase in economic returns under the drought state; rising from $957 million (Base) to $4,935 million (Drought). Notably, the annual capital repayment required to achieve this needs to increase to $6,109 million.

Our findings indicate that full agricultural water reduction requirements cannot be achieved through capital works models, particularly in southern MDB catchments without significant relaxation of existing flow, trade and zone constraints. The use of capital works as a policy instrument appears to: i) expose agricultural water users to increased economic risk under production transformations; ii) decrease social wealth through large wealth transfers to achieve capital investment (relative to Base trade model results); and iii) where capital investment result in return flow reductions, undermine Basin Plan environmental flow objectives. The implications of these results are discussed in the following section.

5. Implications for water managers

The capital works models performed according to a priori expectations of water user behaviour, within the context of severely relaxed Basin constraint parameters. Irrigators adopt subsidised capital works readily and adjust their water and land use to accommodate changed availability. However, this clearly has a number of implications for irrigators, water managers and projected MDB governance arrangements.

5.1. Production transformation

Transformation of production toward perennial cropping in response to capital works programs, possibly as a consequence of perceived water supply increases from efficiency, may drive a number of perverse outcomes. Reliability of supply will not be improved via capital works. During a return to reduced supply conditions increased on-farm capital investment will raise perennial irrigator exposure in the form of subsidised (public) or individual (private) risk. Where irrigators more generally choose to expand their irrigated cropping area through capital investment (i.e. shifts from IA to IA' in Figure 2), such that all 'saved' water is applied on-farm, they will also be exposed to increased levels of risk during adverse states of nature.

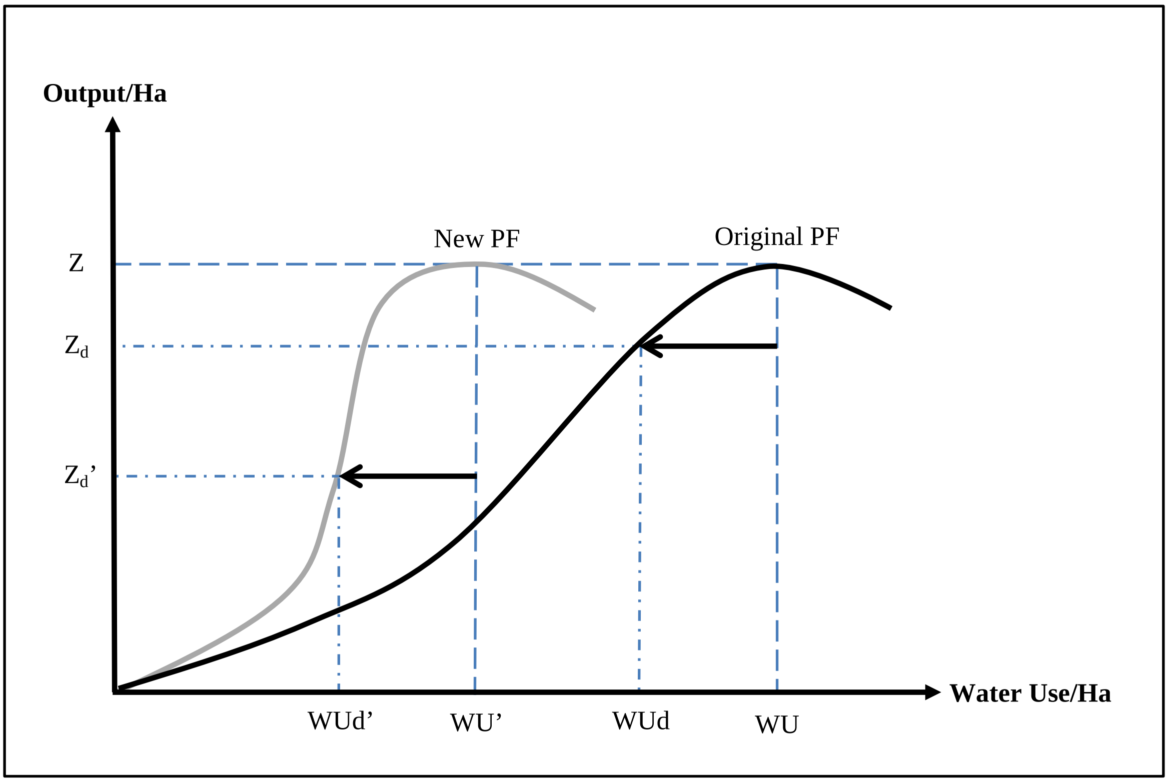

Figure 2: Capital transformation and inflexibility

This risk exposure is underlined in the climate change and drought models, where any future reductions in water supply will logically need to be borne by irrigators, the environment and society as a consequence of the capital works subsidy incentives. An example helps illustrate the link between efficiency improvements from capital works and possible perverse contributions to environmental flow objectives (Table 6).

Table 6:
Summary of model assumptions

Model	Intervention	Return Flow	State probability	Climate assumption
Base	Full trade	100%	(0.5,0.2,0.3)	Current
WRF-100	Capital works	100%	(0.5,0.2,0.3)	Current
WRF-50 *ex-ante*	Capital works	50%	(0.5,0.2,0.3)	Current
WRF-50 *ex-post*	Capital works	50%	(0.5,0.2,0.3)	Current
2050 CC scenario	Capital works	50%	(0.5,0.2,0.3)	450GL average, 2050
2100 CC scenario	Capital works	50%	(0.5,0.2,0.3)	450GL average, 2100
Droughts	Capital works	50%	(0.5,**0.3,0.2**)	Current

In this example, a 30% efficiency improvement from the adoption of new technology reduces water use per hectare from 10ML to 7ML/Ha. Originally, return flows contributed 3ML/Ha in normal and wet states of nature, and 1ML/Ha in the drought. Saving is generated from capital works lower return flows by 50%—but since water use is also reduced this has a proportional impact on return flows. Consequently, return flows fall to 1.05ML/Ha in the normal and wet states, and 0.35ML/Ha in drought. If savings are shared on a proportional basis between irrigators and the environment then irrigators effectively receive 1.5ML/Ha for existing or increased use. While this use contributes to return flows it does so at a reduced rate, resulting in 0.22ML/Ha relative environmental flow reductions during normal and wet states of nature. Note that in the drought state environmental return flow increases by 0.93ML/Ha as a consequence of the capital works, which may be considered positive. However, if MDB environmental watering plan objectives seek to mimic natural conditions (Kingwell, 2006) then increased flows during dry periods may be at odds with management goals.

5.2. Wealth transfer misallocation

The limited public data on proposed MDB capital works projects suggests wealth transfers are to be (unequally) shared between irrigator and irrigation infrastructure operators (IIOs) in the MDB—with attendant environmental benefits from improved flow access. However, interpretation of our model results suggests water savings are predominantly created by conveyance system improvements, not on-farm efficiencies. As capital works programs would likely not reduce the volume required to irrigate (Table 6), total farm equity growth to offset debt (private or public) requited to obtain efficiency improvements would not eventuate (Adamson, under review).[3] Thus, although the policy intent may be to allocate wealth transfers across irrigators, IIOs and the environment actual intervention conclusions may heavily favour IIOs by ‘gold-plating’ the MDB delivery arrangements. As a consequence irrigators, in particular, and environmental water managers will be adversely impacted through exposure to higher infrastructure operating costs over time. Economically marginal irrigators may be forced to exit sub-systems, thus increasing the cost-burden for remaining water users. This in turn may produce a cycle of reducing economic margins for remaining irrigators, forcing further exit.

In addition, our state of nature analysis highlights the importance of considering climate change impacts. Wealth transfers to capital works programs constituting sunk costs across the MDB may be significantly misallocated if future climate trends force southward shifts of irrigated agriculture (e.g. in temperate zones a 3°C mean annual temperature increase may correspond to an isotherm shift of approximately 300-400km in latitude towards the poles, or 500 meters in altitude (Kingwell, 2006)). Such results can be observed in our CC 2050 and CC2100 models, where irrigated land use trends toward catchments closer to the Coorong in response to capital works. Further delivery infrastructure and on-farm transition costs to accommodate climate change outcomes would be of significant magnitude, and result in further wealth transfers toward irrigators and IIOs.

Importantly these irrigation water delivery schemes were originally public assets, which were increasingly privatized (New South Wales) or corporatized (Victoria) to meet reform requirements (Cummins and Watson, 2011). Generally, if the economic benefits from water savings were obvious to MDB IIOs we might expect them to finance capital works investments themselves. Since they are no longer public assets, private incentives to invest appear limited, and industry privatization no longer enjoys the political support afforded it in previous periods (Sirasoontorn and Quiggin, 2007) questions should be raised about why public wealth transfers are being undertaken to ‘gold-plate’ these assets where economic capital investment losses are likely in future. Therefore, affecting a

[3] Contrary to the buyback recovery program, capital works creates net debt; whereas Cheesman Wheeler (2012) show reduction of farm debt via buyback investment.

substantial wealth transfer (i.e. $7.75 billion) to not achieve Basin Plan outcomes—as suggested in our models—indicates that capital works investment does not provide an appropriate economic intervention approach, as discussed below.

5.3. Inconsistency with Basin Plan environmental objectives

Our model results show that, if water recovered for environment benefit is not fully stipulated, the short-term gains of the program will be potentially be undone through significant natural capital losses; especially via climate change impacts. Importantly, no capital works model is able to achieve the required Basin Plan full trade zone water reduction target. Further, if return flows reduce as a consequence of this investment then we also jeopardize Basin Plan environmental objectives. This is because return flow reductions diminish supply reliability for downstream users, particularly the environment (Table 6). Within a reduced return flow context failure to fully consider states of nature and climate change in Basin Planning may result in overinvestment in capital programs, leading to additional diminution of environmental gains from other policy approaches (e.g. buyback).

Finally, if we persist with previous proportional water saving sharing arrangements (50/50) we will likely reduce environmental flows even further. This implies that such arrangements may have to reviewed to either alter share proportions to account for this imbalance (e.g. 75% environment, 25% irrigation), or scrap proportional sharing arrangements altogether.

6. Conclusion

The intended MDB capital works program is at odds with the Basin Plan objectives—in terms of economic, social and environmental outcomes. By subsidising capital irrigation farmers in the MDB will take the opportunity to modernise their water use arrangements; in turn increasing farm debt levels and reducing their flexibility to future water supply shocks. Further, the process of 'gold-plating' MDB irrigation infrastructure will not increase the reliability or security of water assets owned by irrigators or IIOs. This mixture of increasing risk exposure and overinvestment in capital works will compound losses under a future return to drought states of nature, or climate change impacts. In that eventuality irrigators (and IIOs) will: still have to cover the costs of maintaining that capital; and when the face value of entitlements is re-discovered under drought the pressure to meet new use charges and debt liabilities will likely require governments to again act as the final insurer.

Where climate change or, more realistically perhaps, drought-induced water scarcity presents management issues for federal basin water managers at multiple governance scales we would recommend avoiding reallocation policy options that ignore requirements to flexibly manage the inherent variability and uncertainty associated with such systems.

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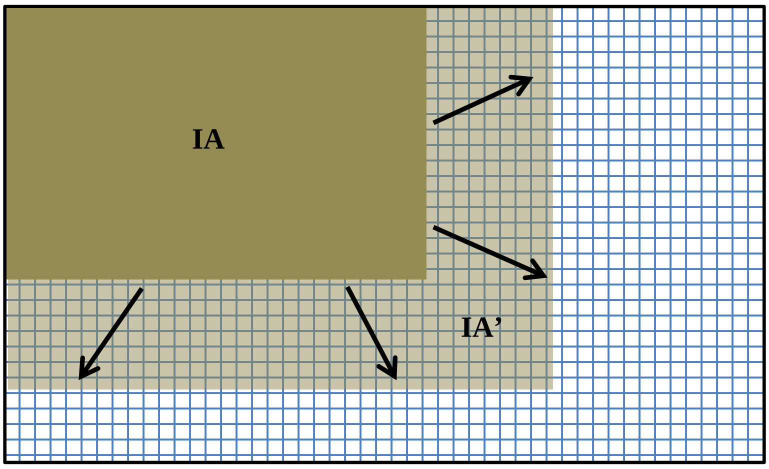

Fig. 3. Possible efficiency gain effects on total irrigated area (IA)

Table 7:
Summary of model outcomes

Model	**Normal water use (GL)**	**Normal Coorong flows (GL)**	***Drought Coorong flows (GL)***	**Normal Salinity (EC)**	**Normal $ returns ($million)**	**Area under production (‘000 Ha)**	**Annual Capital Repayments ($’m)**
Base	10,127	5,546	*1,164*	282	$2,436	1,800	$1,674
WRF-100	10,120	5,565	*867*	243	$7,762	1,269	$5,755
WRF-50 (*ex-ante)*		4,841	*582*	277			
WRF-50 (*ex-post)*	10,133	4,832	*650*	280	$7,763	1,269	$5,756
2050 CC scenario		2,524	*0*	474			
2100 CC scenario		2,374	*0*	497			
Droughts	11,365	3,894	*650*	353	$8,336	1,348	$6,109

Note: Full outcome sets were not always calculated for each model where they involved minor alterations to previous runs (e.g. 2050 CC scenario effects based on WRF-50 ex post). This accounts for any missing values above.

Table 8:
An example of potential capital work reductions to exiting environmental flows

	Existing technology	**New technology**
Water use/Ha	10ML	7ML (= 3ML saving)
Return flows by state (normal, drought, wet)	100% return flows (0.3, 0.1, 0.3)	50% return flows (0.15, 0.05, 0.15)
Return flow outcomes	3.0ML, 1.0ML, 3.0ML	1.05ML, 0.35ML, 1.05ML (extra water)
Water saving split (50/50)		1.50ML (increased use)
Increased farm water use		2.55ML, 1.85ML, 2.55ML
Environmental supply	3.0ML, 1.0ML, 3.0ML	2.55+(0.15*1.5)=-2.78, 1.85+(0.05*1.5)=1.93, -2.78
Difference:	3.0ML-2.78ML=**-0.22ML(N)**, 1.0ML+1.93=**0.93ML(D)**, 3ML-2.78ML=**-0.22ML(W)**	

Table 9:
Land allocated (‘000 Ha) by model run

Production System Name	WRF-100, 250 CC, 2100CC	Drought Run
Citrus-H	402	366
Citrus-L		
Grapes	867	790
Stone Fruit-H		
Stone Fruit-L		
Pome Fruit		
Vegetables		193

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