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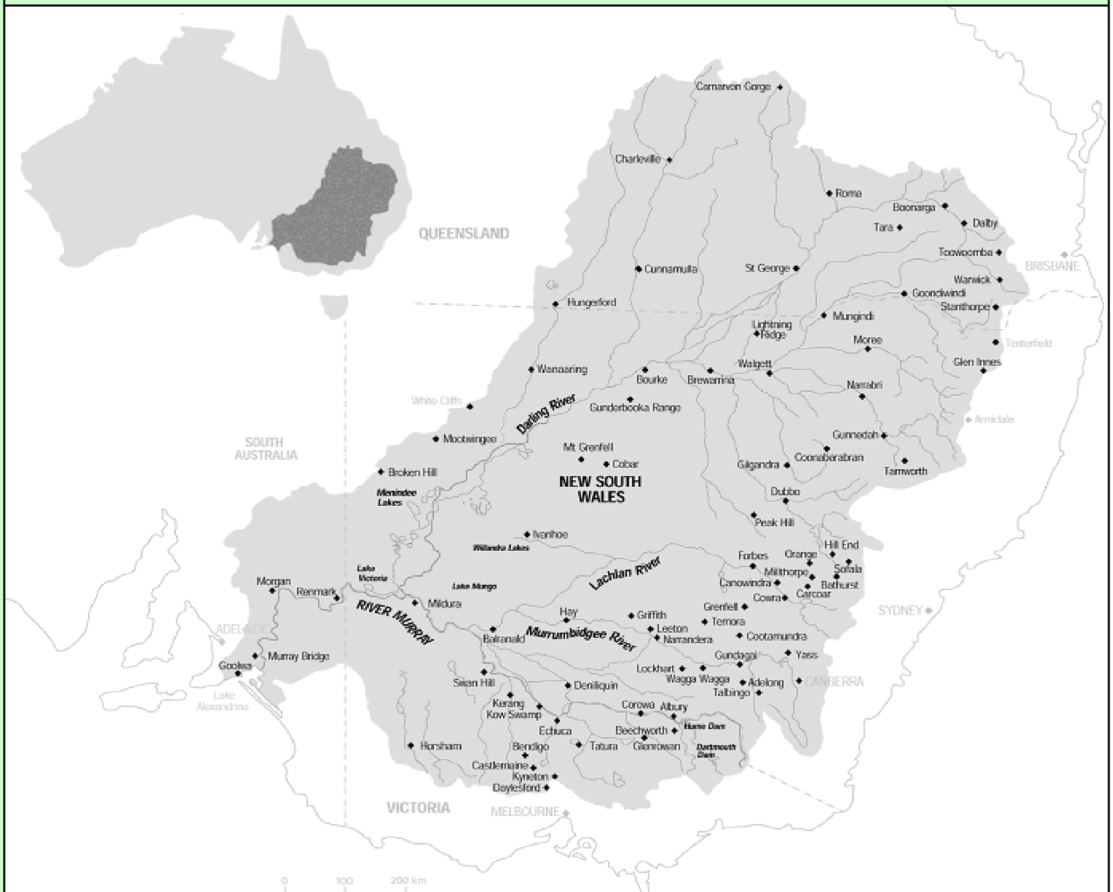

Schools of Economics and Political Science

University of Queensland

Brisbane, 4072

The University of Queensland

Australia

Turning Water into Carbon: Carbon sequestration vs. water flow in the Murray-Darling Basin

Peggy Schrobback[1 2], David Adamson[1], John Quiggin[1]

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Abstract:
Large scale forest plantations in the Murray-Darling Basin may be embraced as a carbon sequestration mechanism under a Carbon Pollution Reduction Scheme. However, increased tree plantation will be associated with reduced inflows to river systems because of increased transpiration, interception and evaporation. Therefore, an unregulated change in land management is most likely to have a dramatic impact on the water availability. This will exacerbate the impacts of climate change projected in the Garnaut Review. This paper examines the implications of unrestricted changes in land use. These results should suggest the true costs to society from carbon sequestration by determining the tradeoffs between timber production and agricultural products.

Key words:
Murray-Darling Basin, carbon sequestration, forest plantation, irrigated agriculture, water flow, trade-off

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[1] University of Queensland, School of Economics, Risk and Sustainable Management Group, St Lucia, QLD 4072, Australia
[2] Email: p.schrobback@uq.edu.au

1 Introduction

With climate change now being acknowledged as reality by the Australian Federal Government, mitigation policies in form of the Carbon Pollution Reduction Scheme (hereafter, the Scheme) are scheduled to commence in the near future. However, the suggested rules released for the Scheme leave room to continue commenting and to objectively analyse the potential intended and unintended implications these policy changes could have on society.

It is proposed to include reforestation on a voluntary basis from Scheme's commencement in 2010 (DDC, 2008). Under the Scheme, accredited forestry entities will be issued permits for each tonne of net greenhouse gas removed from the atmosphere depending on the purpose for forest grown (DCC, 2008). Obligations, such as stand maintenance and reporting, against forest entities will apply for a defined period, e.g. 70 years following the issue of the last permit for an individual forest (DCC, 2008). As there will be competition about the limited number of permits on the emission market, forest entities will be able to sell their permits to other market participants that require permits in order to account for their greenhouse gas releases. The sale of permits will generate some kind of income for the forest entities participating in the system. Though, the income will highly depend on estimated local sequestration rates, the carbon price (DDC, 2008) and the costs of establishing and maintaining a forest. Under this climate change mitigation policy reforestation may become an attractive alternative to current production systems.

However, forests allow less surface water runoff and groundwater recharge than annual crops and pasture per unit area (Parsons *et al*., 2007). This is due to higher transpiration; interception and evaporation predominantly caused by rougher and denser canopy, longer growing periods and deeper root systems (Zhang *et al*., 2003; Farley *et al*., 2005). The effects of increased water interception are complex as reforestation impact on reduced runoff is highly depended on local characteristics such as rainfall, soil, slope, evapotranspiration as well as tree species and management, with mean annual rainfall being the dominate factor (Zhang *et al*., 2001). Research on water interception in the Murray-Darling Basin (hereafter, the Basin) due to forest plantation suggests that the runoff can decrease by up to 1.6 to 2.5 ML/ha (Young *et al*., 2009; Zhang *et al*., 2001).

Increased interception will need to be considered in water allocation regimes (Young *et al*., 2009, Zhang *et al*., 2001). Inappropriate forest planning management and regulatory measures could lead to a situation where significant amounts of water currently allocated to irrigators and the environment could be expected to be permanently removed from the system as landholders plant trees in order to gain carbon permits (Young *et al*. 2009). Under climate change scenarios as projected for the Basin in the Garnaut Review (Garnaut, 2008; Quiggin *et al*., 2008) the impact on water availability could even further exacerbate (Zhang *et al*., 2003).

The aim of this study is to investigate the carbon price signal required for turning agricultural land in the south-eastern catchments of the Basin into commercially forested land. Further, we aim to demonstrate the impact of a positive carbon price signal on land use changes when forestry is accounted for under a water allocation regime. In particular, we will investigate the impact on the Basin's overall production water yield and economic return under baseline and climate change conditions as projected by Garnaut (2008). To achieve this, section 2 outlines the data and assumptions employed to examine the profitability and spatial suitability of timber production within the Basin. The model used to simulate implications of potential carbon price signals on water availability in the Basin will be described in section 3. The results are presented and discussed in section 4 before concluding comments and the implications from the study are presented in section 5.

2 Data and Assumptions

This study examines the Basin wide impacts on water availability and economic return from potential forest plantations in the south-eastern catchments under alternative hypothetical carbon prices. The south-eastern catchments are defined as the: Murrumbidgee, Murray (1-3)[3], North East, Goulburn-Broken and North Central. These are the high rainfall catchments (see Fig.1) that predominately determine the volume and quality of water available for the environment, potable urban supplies and irrigation within the southern Basin.

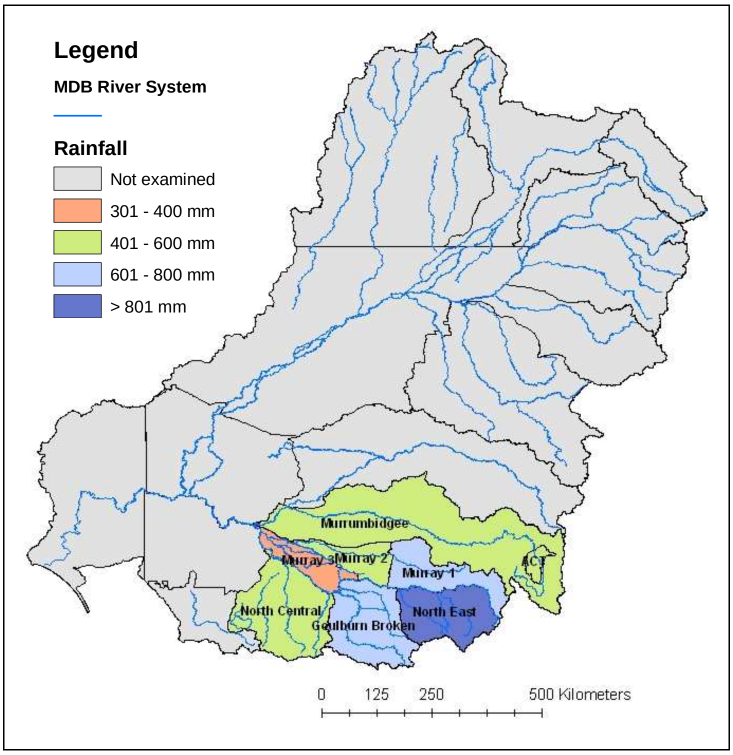

Figure 1: Average rainfall in south-eastern catchments of the Murray-Darling Basin
Source: Data based on BOM, 2008

We assume that a minimum rainfall of 600 mm per year is required as the natural threshold to grow trees[4]. Should this threshold not be met, we have assumed that supplementary irrigation of trees (either directly or indirectly via the root system) up to this threshold is required to maintain tree growth. This supplementary irrigation is then accounted for under the cap on water extractions.

The Australian government expects that most forest establishments as result of the Scheme will be not-for-harvest forests grown on marginal or less productive land, rather than plantations (DCC, 2008). However, in this study we assume that forest entities participating in the Scheme have an economical incentive to realise income from carbon and timber production rather than from carbon yield only.

Consequently, we suppose that price signals may provide an incentive for forests to be established on productive land to take advantage of increased timber growth and CO_2 absorption compared to the slower timber growth and sequestration rates from marginal land (based on Zhang *et al*. 2001). This is illustrated in Table 1 where lower rainfall is equated

[3] A subdivision of the Murray catchment has been undertaken to allow for greater accuracy of modelling water flows within the Basin.
[4] Assumption based on minimum rainfall required to grow radiate pine: 600 mm/year and for eucalyptus: 700 mm/year (VIC DPI.a, 2003; VIC DPI.b, 2008).

with reduced CO_2 absorption rates. It is likely that environmental plantings under the Scheme may take place under circumstances where opportunity costs allow for a substitution of activity; however, this is not the focus of this study.

According to the Schemes suggestions, carbon sequestration in a forest that is harvested is assumed to be lower on average than for a never harvested forest (DCC, 2008). Table 1 illustrates information about catchment based site conditions included in this study.

The estimated sequestration rates for a 30 year rotation are projected from Fortunaso's *et al*. (2007) model. This model provides us with the capacity to simulate the annual CO_2 absorption per hectare as land use changes from agricultural to commercial plantings for each catchment in the Basin. This CO_2 sequestration then defines the parameters for the number of permits issued to each forest entities per hectare as stipulated under the Scheme (DCC, 2008) where total abatement permits equals the projected net greenhouse gas removal.

Table 1: Rainfall, soil and carbon sequestration rates in the south-eastern catchments of the Basin

CMA	Ave historic rainfall (mm/year)	Soil types (mostly)	tCO_2/ha (Ave) under 30 year stand
Murray 1	654	Sodosol, Kurosol Dermosol, Chromosol	239
Murray 2	410	Sodosol	117
Murray 3	387	Sodosol, Vertosol	130
Murrumbidgee	528	Chromosol	208
North East	835	Sodosol, Chromosol	302
Goulburn-Broken	618	Sodosol	210
North Central	556	Sodosol, Chromosol	209

Sources: tCO_2/ha based on Fortunaso et al. (2008), BOM (2008) for rainfall, ASRIS (2008) for soil type (neglected salt, slope but does include soil & biomass change)

Production costs and the average timber price per hectare are based on data compiled from Private Forests Tasmania (2004). These data sets were then reviewed by PF Olsen Australia and Forestry Plantation Queensland in personal correspondence in November 2008 to bring them into line with current estimates for large scale production. Obviously production, capital and maintenance costs for forests will differ considerably between small and large scale operations and catchments and therefore should be used as a guide only. We assume that costs and timber prices will remain constant over time and scale.

The White Paper suggests that production risk (e.g. fire) should be accounted for in a reversal buffer to be deducted from each permit in order to account for possible disturbances to the net greenhouse gas removed (DCC, 2008). We neglected this buffer to simplify our calculation but acknowledge that this would diminish income from carbon sequestration. Potentially in the future this could be treated as a fixed cost (i.e. annual insurance) but currently this is not available on the market.

Based on Zhang *et al*. (2001) and Young *et al*. (2009) it is estimated that each hectare of trees planted will reduce runoff by 2 ML/ha and on top of this regions that require supplementary irrigation are also accounted for in Table 2 to provide the total water requirements per hectare. To account for decreased annual rainfall in a dry state of nature, the estimated water use doubles to sustain growth.

Based on an estimated water use per tonne of CO_2 sequestered for each catchment, we briefly analysed the break-even price for water for hypothetical carbon prices. This break-even water price can be interpreted as the price at which emission policy implications are neutral in its impact on forestry relative to the case of free water and no carbon price. A water price above the calculated prices presented in Table 2 would not encourage carbon farming under the given settings. The results reveal that break-even prices vary significantly depending on the water use per catchment.

Table 2: Break-even water price

CMA	Estimated yield (tCO_2/ha)	Water use (ML/ha)	Estimated water use (ML) per $tC0_2$ sequestered	Break-even water price for $25 carbon price	Break-even water price for $50 carbon price	Break-even water price for $100 carbon price
Murray 1	7.88	2.00	0.25	$98	$197	$394
Murray 2	7.16	3.90	0.54	$46	$92	$184
Murray 3	7.16	4.13	0.58	$43	$87	$173
Murrumbidgee	7.16	2.72	0.38	$66	$132	$264
North East	10.31	2.00	0.19	$129	$258	$515
Goulburn-Broken	7.40	2.00	0.27	$93	$185	$370
North Central	7.16	2.45	0.34	$73	$146	$292

Source: tCO_2/ha based on Fortunaso et al. (2008), BOM (2008) for rainfall, ASRIS (2008) for soil type (neglected salt, slope and does include, soil & biomass change)

For this study catchment water inflow data was based on MDBC (2003) and climate change shocks to the Basin's inflows are based on atmospheric CO_2 concentrations of 550ppm (average) in 2050 as provided in Quiggin *et al*. (2008). These projections are presented in Table B in the Appendix. According to these estimates, all catchments will experience reduced inflows. It has been assumed that the cap on water extractions is proportionally changed to match reductions in inflows.

4 Model and Methodology

This analysis is a modified application of the state contingent Murray-Darling Basin Model documented in Adamson *et al*. (2007). The model simulates land and water allocations for irrigation production systems operating under alternative irrigation property rights (Adamson *et al*. 2006).

The model can be solved using a sequential model solution concept. The sequential model solution derives the allocation that maximises returns in one catchment, subject to constraints and then progresses to the next catchment. This evaluation aims to maximise the benefit of individuals in each catchment from using irrigation water as subject to a series of constraints on the use of water, land and labour.

The model uses linear programming to maximise the economic return for the Basin at a Catchment Management Authority scale for 19 catchments, Adelaide and a the Coorong and for 24 major commodities in three states of nature (normal, dry and wet). The Murray catchment was divided into three sub-catchments to achieve a smaller scale spatial resolution. The last two catchments allow for the representation of water quality arriving at Adelaide and a proxy value for environmental flows presented by the Coorong.

The model in its unmodified state optimises economic return by choosing between 23 production systems that use alternative levels of inputs and delivery differing outputs that respond to the availability of land, labour, capital, water volume and water quality (salinity) by three states of nature. In the model, salt levels are constrained by the end-of-valley salinity targets (MDBC, 2005). We introduced harvest forests as proposed under the Scheme as production system (carbon and timber) in the model using data provided in Table A in the

Appendix. We use alternative prices for carbon which demonstrate incentives for potential land use changes.

The state contingent approach chosen in this model recognises that individuals adapt to changing conditions as the season changes. Therefore, the model describes three production types (normal, dry and wet) of each major commodity under the possible states of nature.

The model assumes a directed water flow network that incorporates state contingent water flows. Water inflow in each catchment is determined by: natural runoff, any transfers to the catchment (e.g. Snowy River) and reflow from upstream water use minus natural loss and seepage. In our analysis we focus on natural inflows.

The two hypothetical scenarios for this study are set as following. First, we will simulate a base case which will reflect the current situation in which no climate change condition occurs and no additional forestry is taking place in the Basin (Scenario 1: Reference case).

The second scenario (Scenario 2: Reforestation accounted for in water entitlement regimes) will investigate impact of forest plantations as included in water entitlement regimes. This assumes that forest entities will need to account for water that is intercepted by trees and as well as for water that may be required for irrigation in low rainfall areas.

Under alternative carbon price signals we will be able to analyse the impacts of potential land use changes in favour of forestry on overall water availability in the Basin under baseline or current and climate change conditions. The water yields, salt projections and economic values of land and water use on a catchment and end of Basin level retrieved from these settings will be the basis for our discussion.

5 Results and Discussion

In this study, we have simulated five cases that differ in carbon prices ranging from \$25 to \$100 and compared the current baseline climate conditions to climate change impacts. These simulations allowed for quantification of the area of land changed into harvest forest under different assumptions. On this basis, we projected the CO_2 sequestration and the overall changes in water flow and in economic values expected to be observed in the chosen catchments. Subsequently, we discuss the carbon price signal required for turning agricultural land into forestry in the south-eastern catchments and subsequent effects of land change on water availability and economic return.

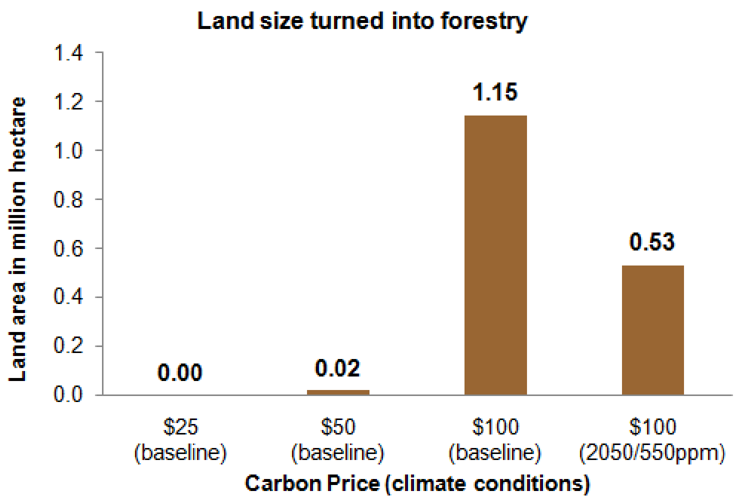

Figure 2: Land area turned in to forestry under alternative carbon prices and climate conditions.

In general, land currently used for agriculture will be turned into harvest forests when carbon prices reach a level at which profit margins from forestry exceed those from conventional farming. Our simulations show no change in land use at a carbon price of $25 per tonne of CO_2 sequestered and only very small new forestry at a carbon price of $50 per tonne of CO_2 (Fig. 2). A significant change in land use in favour of carbon forestry can be expected when assuming a price of $100 with a total of 1.14 million hectare being newly established for tree plantations in examined catchments (Fig. 2). Under climate change conditions and a carbon price of $100, the area of land converted to forestry will reach 530,000 hectares which is only half of what we see for the same price at normal climate conditions (Fig. 2). A possible explanation for the decline is that the additional irrigation under dry climate as simulated in our model considerably impairs the profitability of forestry in comparisons to alternative land use making it less attractive for land change.

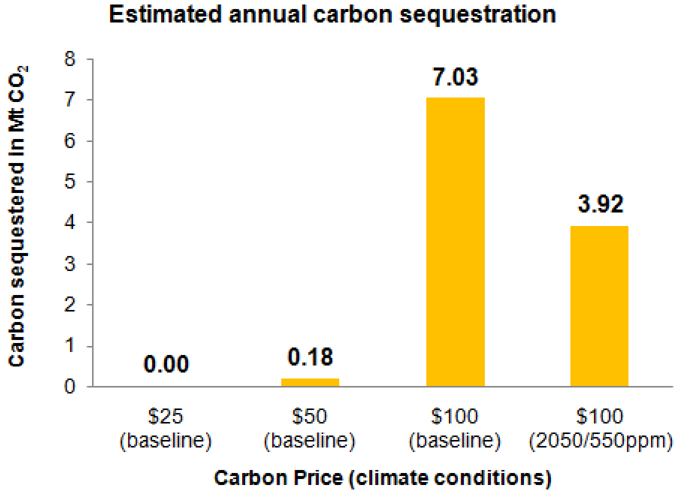

Figure 3: Estimated annual carbon sequestration under alternative carbon prices and climate conditions

Annual carbon sequestration rates are altered proportional to the area turned into forested land (Fig. 3). At a carbon price of $25 and $50 no or insignificant low amounts of greenhouse gases, respectively, is expected to be sequestered (Fig. 3). However, when forested land is established on a large scale at a carbon price of $100, total estimated sequestration rates for the examined catchments will rise to 7.03 $MtCO_2$ (Fig. 3). Sequestration rates under climate change and at $100 carbon price are expected to be below normal climate setting reaching 3.92 $MtCO_2$ (Fig. 3). Compared to Australia's total emissions in 2006 which amounted to 576 $MtCO_2$ (DCC, 2008) these sequestration results appear insignificantly small.

However, a carbon price of $50 represents the lower limit for a positive price signal on carbon sequestration from forestry under the current climate conditions in the catchments included in this study.

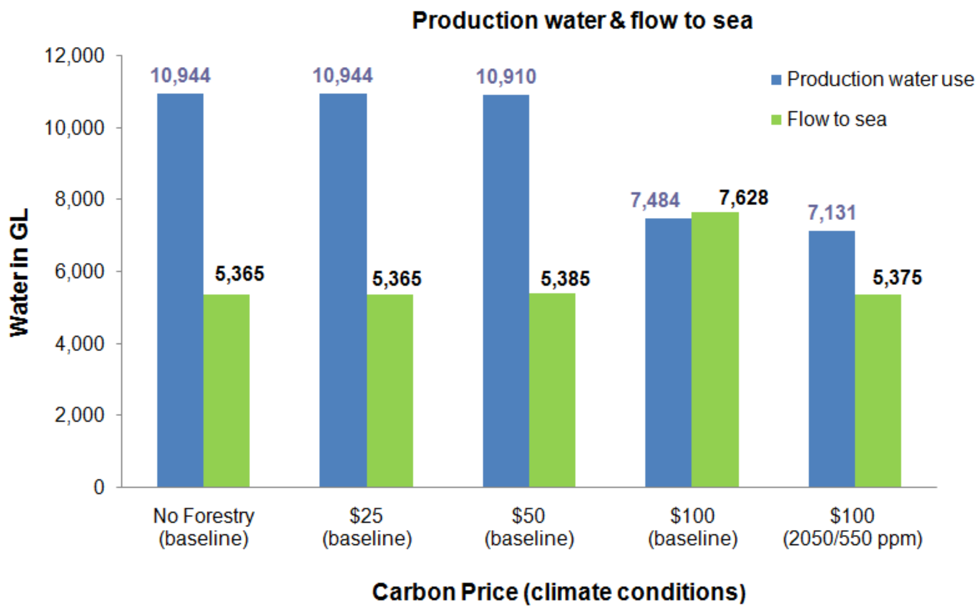

Figure 4: Production water and flow to sea under alternative carbon prices and climate conditions

Redesignation of farming land into forests ultimately affects the water flow in a river system as discussed in the introduction chapter.

In our model, production water available and environmental flows at the end of the Basin remain unchanged at 10,944 GL and 5,365 GL respectively at a carbon price of $25 compared to the reference case which sets the no forestry scenario at in baseline climate conditions (Fig. 4). Consistent with the land use data, only minor changes to the Basin's water yields occur at $50. At a $100 carbon price, the water available for irrigated production decrease significantly to 7,484 GL as a consequence of reduced run off from expanding forestry (Fig. 4). As assumed for the simulations, irrigation is required in areas that lack sufficient annual rainfall in order to sustain the timber growth. A growing number of tree plantations, hence, reduces the run off further and increases salinity violating the end of catchments thresholds. This leads to severe consequences for Mallee and SA MDB catchments as well as Adelaide in the modelling outcome. Water quality in the upstream neighbouring catchments will degrade so rigorously that no flow will be remaining available for agricultural production use (see Table C in Appendix). Accordingly, water of insufficient quality for agricultural production remains in the systems and increases water flows to the sea to 7,628 GL in the $100 simulation (Fig. 4).

The climate change scenarios at a $100 carbon price leads to a minor reduction of the production water available compared to unchanged climate conditions, leaving 7,131 GL in the system (Fig. 4). Although overall rainfall declines under climate change, a cut back in forestry dampens the negative effect of increasing drought to the production water availability. Yet, the climate change effect still accounts for the decreased environmental flows which drops to 5,375 GL compared to current climate simulations (Fig. 4).

It should be noted that the model results may not truly reflect reality as future production systems are likely to adjust to an opportunistic pattern to take advantage of irrigation supplies that will not violate the end of catchment salinity constraints. Presently these future production systems are not represented in the modelling work for the lower catchments in the Basin.

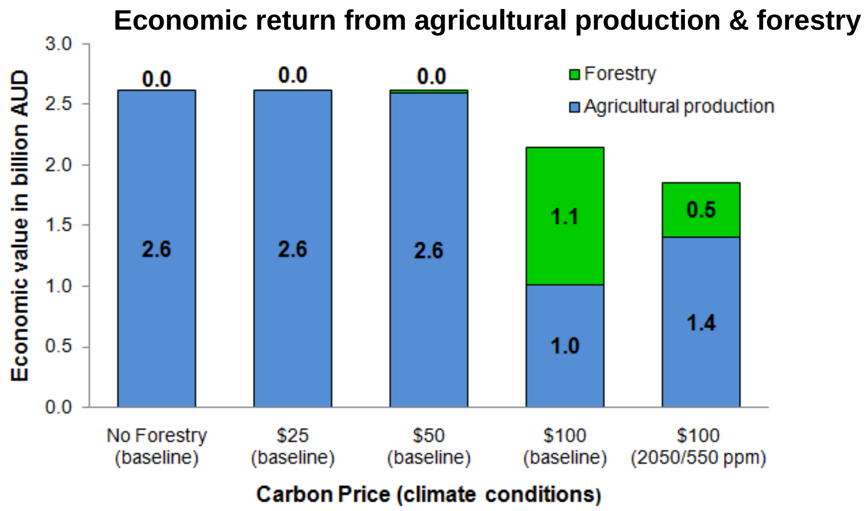

Figure 5: Economic return under alternative carbon prices and climate conditions

A land use change from current production patterns to forestry is valued as not profitable at a $25 carbon price in our model. At this price, the total economic return of the Basin consequently remains unchanged at $2.6 billion in comparison to the reference scenario (Fig. 5). The minor acre redesignations as predicted for a hypothetical $50 carbon price exhibit negligible alterations in economic values for the Basin when compared to the $25 scenario (Fig. 5). However, the economic return declines considerably to $2.1 billion at a $100 carbon price with forestry now contributing for over 50% or $1.1 billion of the total return (Fig. 5). The likely explanation for this major decrease is that catchments at the end of the Basin are forced to cut down on irrigation when confronted with reduced amounts of production water under this scenario (see Table C in the Appendix). Their contribution to the economic value will, therefore, shrink; a loss which cannot be compensated by increased income from high carbon prices.

Overall, the lowest economic return from the Basin with only $1.9 billion is estimated for a $100 carbon price under climate change conditions (Fig. 5). This result can be attributed to less inflow available initially and to forested land exacerbating water availability and quality in the Basin, even though to a lesser extend as under the current climate simulation. Forestry and agriculture account for $0.5 and $0.4 billion, respectively of the total economic value (Fig. 5). The decline in land used for forestry and the relatively high amounts of production water available despite reduced overall rainfall may explain why the contribution from agriculture is higher under climate change than in the $100 normal climate scenario.

5 Conclusion

Our analysis demonstrates the potential impacts of a voluntary inclusion of forestry in the Carbon Pollution Reduction Scheme in the south-eastern catchments for the Murray-Darling Basin under alternative carbon prices. We assumed that for-harvest forestry is only economically viable on productive land rather than on less productive land in order to achieve high carbon and timber yields.

The results of this study demonstrate that a carbon price less than $50 per tonne CO_2 will not be a sufficient price signal for land users in the examined catchments to turn from agricultural production to forested land.

Under the study's assumption, a price for carbon of $100 per tonne will result in large scale forest plantations in the Basin's south-eastern catchments. This spatial change in land use will cause increased interception in runoff with substantial impact in water availability and quality for downstream catchments in the Basin.

In a situation where the carbon price will pose a high incentive to change land use patterns in favour of forestry, a cautious management of the cap is recommended as water availability may be even further limited if reductions in runoff are not reflected appropriately in the Basin's water use restrictions. Comprehensive spatial planning on a local and regional scale is required in such a case in order to evaluate the possible impacts on water and land use availability. Furthermore, more comprehensive research is necessary to describe how a decreased runoff due to enlarged forested lands can be effectively accounted for under water entitlement regimes. Therefore, we conclude that the reforestation polices as suggested under the Scheme need to be accompanied by a comprehensive local and regional spatial planning process to ensure a social and environmental justifiable outcome.

Other aspects that demand consideration are the risk to investment in harvest forests (such are fire, pest and disease outbreak) and the obligations against forest entities which could diminish future land value. Moreover, the robustness and reliability of accreditation and monitoring system established need to be thoroughly tested before the commencement of the Scheme in order to avoid leakage and, thus, undermining the Scheme. Further research would also be required in assessing potential costs associated with managing and maintaining a sequestration permit registry as they will provide information to the emission market and land users considering reforestation. However, potential transaction costs related with the forest entity's participation in the Scheme, such as reporting and management expenses are currently hardly analysed. If too high, these costs will pose disincentives for participation.

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Appendix

Table A: Estimated yields, productions costs and prices for forestry in south-eastern catchments of the Basin

CMR	Timber yield (m^3/ha/yr)	Timber price (\$/m^3)	Carbon yield (tCO_2/ha/yr)	Casual labor costs (hr/ha/yr)	Labor price (\$/hr)	Water use (ML/ha)	Machinery (hr/ha/yr)	Machinery costs (\$/ha/yr)	Chemical costs (\$/ha/yr)	Other variable costs (\$/ha/yr)	Establishment costs (\$/ha)
Murray 1	9.79	31.31	7.88	17	15.52	2.00	5	7.05	16.67	50	3,200
Murray 2	8.00	31.31	7.16	17	15.52	3.90	5	7.05	16.67	50	3,200
Murray 3	8.00	31.31	7.16	17	15.52	4.13	5	7.05	16.67	50	3,200
Murrumbidgee	8.00	31.31	7.16	17	15.52	2.72	5	7.05	16.67	50	3,200
North East	15.83	31.31	10.31	17	15.52	2.00	5	7.05	16.67	50	3,200
Goulburn-Broken	8.60	31.31	7.40	17	15.52	2.00	5	7.05	16.67	50	3,200
North Central	8.00	31.31	7.16	17	15.52	2.45	5	7.05	16.67	50	3,200

Source: Assumptions are based on Private Forests Tasmania (2004), PF Olsen Australia (November 2008), Forestry Plantation Queensland (November 2008), BOM (2008), Fortunaso *et al*. (2008), Young *et al*. (2009) and Zhang *et al*. (2001)

Table B: Total current and future projected inflows

Catchment	Total current (GL)	550ppm Average			
		2020	2030	2040	2050
Condamine	803	91%	86%	81%	77%
Border Rivers, QLD	735	91%	86%	81%	77%
Warrego-Paroo	419	91%	86%	80%	76%
Namoi	1,076	93%	89%	84%	81%
Central West	1,748	93%	89%	85%	82%
Maranoa-Balonne	1,328	91%	86%	80%	76%
Border Rivers-Gwydir	1,652	93%	89%	85%	82%
Western	0	92%	88%	83%	80%
Lachlan	1,186	93%	89%	84%	81%
Murrumbidgee	4,958	93%	89%	85%	82%
North East	4,796	93%	90%	86%	83%
Goulburn-Broken	3,877	91%	86%	81%	77%
Wimmera	530	89%	83%	77%	73%
North Central	736	91%	85%	80%	76%
Murray	2,476	92%	87%	83%	79%
Mallee	13	90%	85%	79%	75%
Lower Murray Darling	115	92%	87%	82%	78%
SA MDB	161	89%	82%	75%	71%

Source: MDBC (2003), Quiggin *et al*. (2008)

Table C: Estimated water availability in the Basin under $100 carbon price

CMA	GL under $100 (baseline)	GL under $100 (2050/550ppm)
Condamine	279.8	237.2
Border Rivers, QLD	209.0	160.9
Warrego-Paroo	47.0	35.7
Namoi	507.4	460.1
Central West	533.5	496.1
Maranoa-Balonne	148.3	148.3
Border Rivers-Gwydir	707.9	669.1
Western	147.2	98.2
Lachlan	585.0	473.9
Murrumbidgee	1,213.7	2,078.7
North East	60.2	65.2
Murray 1	39.1	46.1
Goulburn-Broken	608.1	745.9
Murray 2	859.8	742.6
North Central	740.6	**0.0**
Murray 3	662.5	568.0
Mallee	**0.0**	**0.0**
Lower Murray Darling	135.0	105.3
SA MDB	**0.0**	**0.0**
Adelaide	**0.0**	**0.0**
Total prod. water	**7,484.3**	**7,131.3**
Flow to Coorong	**7,627.5**	**5,374.5**