The Australian Journal of
Agricultural and
Resource Economics

Journal of the Australian Agricultural and Resource Economics Society

The Australian Journal of Agricultural and Resource Economics, 56, pp. 455–474

Upstream demand for water use by new tree plantations imposes externalities on downstream irrigated agriculture and wetlands*

Thomas L. Nordblom, John D. Finlayson and Iain H. Hume†

Large-scale tree plantations in high rainfall upstream areas can reduce fresh water inflows to river systems, thereby imposing external costs on downstream irrigation, stock and domestic water users and wetland interests. We take the novel approach of expressing all benefits and costs of establishing plantations in terms of $ per gigalitre (GL) of water removed annually from river flows, setting upstream demands on the same basis as downstream demands. For the Macquarie Valley, a New South Wales sub-catchment of Australia's Murray-Darling Basin, we project changes in land and water use and changes in economic surpluses under two policy settings: without and with a policy requiring permanent water entitlements to be purchased from downstream parties, before plantation establishment. Without the policy, and given a high stumpage value for trees ($70/m^3), upstream gains in economic surplus projected from expanding plantations are $639 million; balanced against $233 million in economic losses by downstream irrigators and stock and domestic water users for a net gain of $406 million, but 345 GL lower mean annual environmental flows. With the policy, smaller gains in upstream economic surplus from trees ($192 million), added to net downstream gains ($138 million) from sale of water, result in gains of $330 million with no reduction in environmental flows. Sustaining the 345 GL flow for a $76 million (406–330) reduction in gains to economic surplus may be seen to cost only $0.22 million/GL; but this is much lower than the market value of the first units of that water to agriculture and forestry.

Key words: catchment, demand, downstream externality, entitlement, environmental services, evapotranspiration, forest, interception, irrigation, market, Murray-Darling Basin, supply, urban water, watershed, wetlands.

---

* The research project 'Developing environmental service policy for salinity and water' was supported by the NSW Department of Primary Industries (NSW DPI), Charles Sturt University (CSU) through the EH Graham Centre for Agricultural Innovation (CSU and NSW DPI), Future Farm Industries CRC, the Rural Industries Research & Development Corporation, the Murray-Darling Basin Authority, Victoria Department of Primary Industries and the University of Western Australia. The authors thank Fiona Scott, Melanie Weckert, Ron Hacker, Rajinder Singh, Peter Orchard, Jason Crean (NSW DPI) and two anonymous reviewers for critical comments. Responsibility for any errors resides with the authors alone. Assumptions, observations, results and interpretations in this study do not necessarily represent the policies of NSW DPI nor any other agency or institution.

† Thomas L. Nordblom (email: tom.nordblom@dpi.nsw.gov.au) is a Senior Research Scientist and Adjunct Associate Professor at the EH Graham Centre, Wagga Wagga, NSW. John D. Finlayson is an Assistant Professor at the School of Agricultural and Resource Economics, University of Western Australia and at the Department of Agriculture and Food, Western Australia, Perth, WA. Iain H. Hume is a Soil Scientist and Adjunct Lecturer at the EH Graham Centre, Wagga Wagga, NSW.

doi: 10.1111/j.1467-8489.2012.00593.x

1. Introduction

Interception of water by tree plantations has been flagged as important by the National Water Initiative (COAG 2004), subsequent legislation (Water Act 2007) and a recent report for the National Water Commission (SKM *et al.* 2010). The issue has taken on greater significance more recently with the possible introduction of policy settings aimed at putting a price on carbon. SKM *et al.* (2010) estimated that tree plantations on lands not directly following forest cover reduce annual river flows by 2000 gigalitres (GL) across Australia, a similar order of magnitude to the additional annual water flows proposed to sustain environmental assets in the Murray-Darling Basin (MDBA 2010).

The purpose of this study is to provide evidence of the upstream and downstream economic, social and environmental consequences of alternative policy settings concerning tree plantations and water management. Using a case study catchment, we investigate the consequences of different levels of incentives for new tree plantations under two contrasting policy settings. These are where (i) permanent water entitlements are not required for the establishment of new plantations or (ii) permanent water entitlements must first be purchased from downstream entitlement holders to compensate for expected reductions in stream flows. The former is presently the case in all Australian states and territories except for the south-east corner of South Australia (SKM *et al.* 2010, pp. 59–60).

The economic and social benefits of forest industries are described in a variety of studies (Plantations for Australia: The 2020 Vision; Gerrand *et al.* 2003; Parsons *et al.* 2007). A number of recent studies have focussed on the prospects for further expanding commercial plantations in Australia, given the capacity of trees to sequester carbon while improving water quality (Oliver *et al.* 2005; Grieve *et al.* 2008; Wood *et al.* 2008; Johnson and Coburn 2010). Two studies specifically assessed the economics of commercial forestry plantations under different carbon prices (Lawson *et al.* 2008; Sohngen 2010). All of these studies recognise that expanding tree plantations incurs opportunity costs in the form of the returns given up from existing land uses, but they make no mention of the large additional amounts of water consumed by trees or the external downstream costs this may impose.

Indeed, large amounts of water are evaporated and transpired by tree plantations (Gilfedder *et al.* 2009; Galiana and Green 2010, p. 299; Marcar *et al.* 2010). One study, which focussed on 'managed investment schemes' for carbon sequestration, noted that potential distortions in agricultural land and water use may arise where tax benefits attract expanding plantation investments that reduce water flows into streams and rivers (Ajani 2010). Crossman *et al.* (2010) explicitly estimated the opportunity costs of displaced land uses by plantations given different carbon sequestration forest options, carbon prices and commodity price scenarios across South Australia; they also calculated reductions in water yield under the various forest options and carbon prices. While noting a requirement to purchase water entitlements as foreseen by the National Water Initiative would have a negative impact on plantation expansion, Crossman *et al*. (2010) did not attempt to estimate the economic losses by downstream consumptive water users given unrestricted expansion of plantations. None of the above mentioned studies explicitly quantify the external costs that may be imposed by tree plantations on local downstream community, industry or environmental interests in water volumes.

Jackson *et al*. (2005) noted carbon sequestration strategies around the world promote tree plantations without considering their full economic, social and environmental consequences, including substantial, predictable losses in stream flow. Schrobback *et al*. (2011) reached a similar conclusion for the Murray-Darling Basin in Australia. In the *World Development Report 2010* (World Bank 2010, p. 142) we find the remark:

> 'By not properly accounting for certain uses (such as plantation forestry and natural vegetation) or for changes in user behaviour, the schemes in Australia and Chile assigned rights for more water than was available'.

The above comments refer to tree plantations in high-rainfall water-source catchments. However, in lower-rainfall areas trees have been employed to use water that otherwise leads to water-logging of soils or rising water tables, which in turn mobilise salts causing dryland salinity and/or salination of rivers (Stirzaker *et al*. 2002; Vertessy *et al*. 2003; Nuberg *et al*. 2009). Recent studies to calculate the least-cost changes in land use to reduce salt loads exported from catchments (Nordblom *et al*. 2006, 2010; Finlayson *et al*. 2010) include tree planting among the options. These 'least-cost' studies consider land use changes to decrease the annual salt loads flowing from farms to streams (Pannell and Roberts 2010), but they do not explicitly account for the external costs imposed on downstream water users from reduced water availability. The present study addresses that gap by simultaneously including water demands by upstream and downstream parties. As a starting point it was assumed all water entitlements are held by the downstream water users.

The biophysical basis of this study is provided by 'Zhang curves' which relate alternative land covers (forest, permanent pasture, rotations of permanent pastures with annual crops and continuous annual cropping or annual pasture) with mean annual rainfall to estimate water outputs (yields) of catchments (Zhang *et al*. 2001). Results of that study are briefly reviewed in Section 2.

Section 3 presents a brief summary of the physical, biological and economic conditions in the Macquarie Catchment's watersheds, and the methods used to frame the economic analysis of upstream and downstream water use. Section 4 summarises results for the cases of each of four values of tree products (stumpage values of \$40, \$50, \$60 and \$70/m^3) given two policy settings: without and with the requirement to purchase entitlements for the additional annual water use by tree plantations, in particular rainfall zones. These projections are discussed in Section 5 and conclusions presented in Section 6.

2. The role of vegetative land cover in catchment water yield

In a major review and original analysis that combined results from over 250 catchments in 28 countries, Zhang *et al.* (2001) showed there is not only a positive relationship between mean annual rainfall and mean annual water yields of a catchment, but that the type of vegetative land cover can help predict the magnitude of that relationship. Forested land yields the lowest mean stream flow for a given long run mean rainfall and cleared land the most (Figure 1).

Mean annual water yield subtracted from mean annual precipitation provides an estimate of mean annual evapotranspiration. At the drier end of the rainfall range (below 600 mm/year) Zhang *et al.* (2001) found this relationship to be less predictable than in the higher rainfall zones where commercial plantations are most profitable.

The impacts of commercial forestry on regional water resources in the south east corner of South Australia have been the subject of new legislation (DW-GSA 2010) requiring water entitlements to be obtained, before establishment of a new tree plantation is permitted. To date, no limitations on commercial tree plantation interception of water are yet in place in the other States or Territories of Australia (SKM *et al.* 2010, pp. 59–60).

3. Water sources, sinks and economy of the Macquarie catchment

3.1. Catchment characteristics

The study area is the 2.8 million ha Macquarie Catchment in New South Wales, Australia. This was represented using six upstream watersheds and

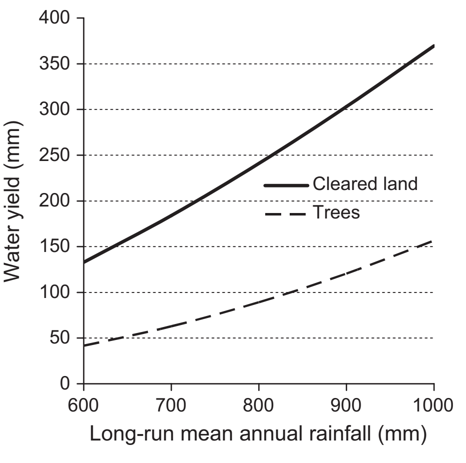


Figure 1 Catchment water yield as a function of mean annual rainfall and different vegetation types (after Zhang *et al.* 2001).

five downstream water consuming sectors (Figure 2). Detailed descriptions of the watersheds and downstream water users and wetland (WL) areas are presented in Nordblom *et al*. (2009).

3.2. Productivity of additional water use by tree plantations

We assume that tree product yield or mean annual increment (MAI) and water use, both increase approximately linearly with mean annual rainfall over the range 600–1000 mm found in the upper Macquarie catchment. We estimate the areas of new plantation that will reduce annual stream flow by 1 GL for points in this range of mean annual rainfalls (Table 1).

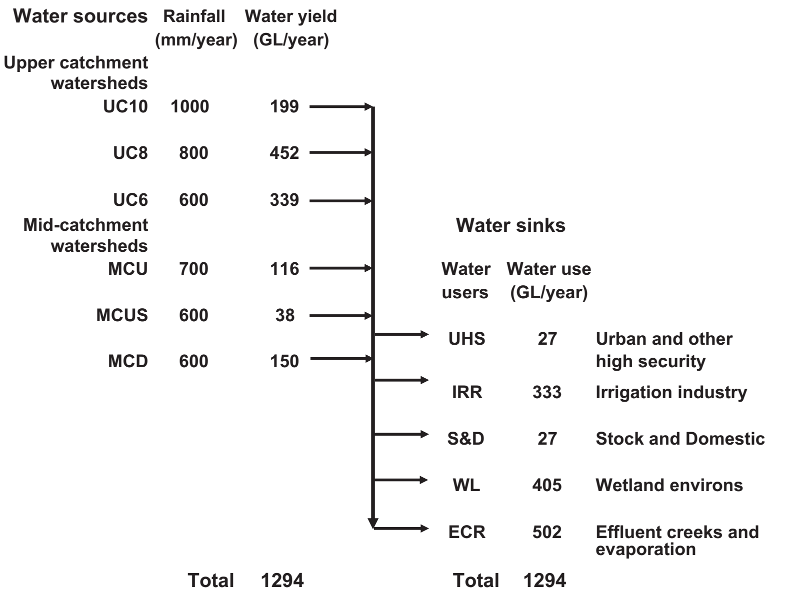


Figure 2 Schematic map of the Macquarie catchment identifying key water sources by rainfall zone and location with respect to key groups of river water users. The indicated water yields and water use levels are considered the 'initial conditions' in this study.

Table 1 Assumptions on plantation productivity and additional water use by rainfall zone

Mean annual rainfall (mm)	Mean annual increment (MAI) in wood product (m^3/ha)	Additional annual water use by new tree plantation (ML/ha)†	Plantation area to consume additional GL of water annually (ha/GL)
600	8.0	0.60	1675
700	10.5	0.78	1276
800	13.0	0.97	1031
900	15.5	1.16	864
1000	18.0	1.34	744

†600–700 mm area values are based on those in South Australia's Approval Process for Plantation Forestry, Natural Resources Management Act 2004 (DW-GSA 2010).

Tree products are assumed to have a stumpage value (i.e., \$/m^3 wood), which is income received by the plantation owner after all harvest, transport and other charges are subtracted at the mill. For a given rainfall zone, the present value (PV) per hectare of tree plantation benefits is taken to be the MAI times the stumpage value per m^3 of tree product, multiplied by a 30 year rotation length and discounted at 7 per cent annually. The PVs of tree plantation benefits are illustrated in Figure 3, given stumpage values ranging from \$40 to \$70/m^3.

In a given rainfall zone, the benefits associated with tree plantations are calculated by multiplying the above per ha benefits by the additional area of trees that reduce stream flow by 1 GL (Table 1). Establishing a plantation incurs costs of land preparation, rooted tree stock for planting, the planting operation itself, material and application costs of fertiliser, insecticide and weed control as necessary, thinning and fencing. These 'direct' costs are assumed to total \$1200/ha (Nordblom *et al.* 2009). The direct costs, plus the opportunity costs from loss of earnings of previous land uses, were subtracted from the gross PV to estimate the returns expected from new plantations.

3.3. Estimating marginal values of water for tree plantations: benefits per GL used minus opportunity costs and direct costs

'Opportunity costs' of new tree plantations are the net income losses related to foregoing the current use of the land on which a tree plantation is to be established (Crossman *et al.* 2010; Sohngen 2010). Where it is poor grazing land the opportunity cost will be lower than for good grazing land or highly productive farm land; these costs need to be considered as a newly established tree plantation excludes other productive uses (Figure 4). In this study the

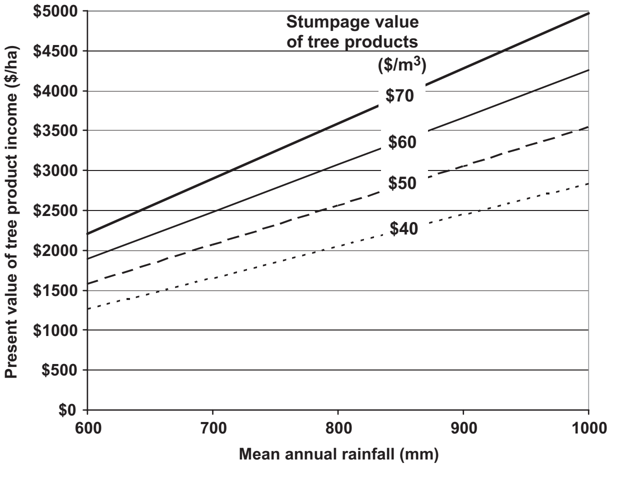


Figure 3 Present value (PV) of tree product income (\$/ha) by rainfall zone without establishment or opportunity costs or purchase costs of water entitlements.

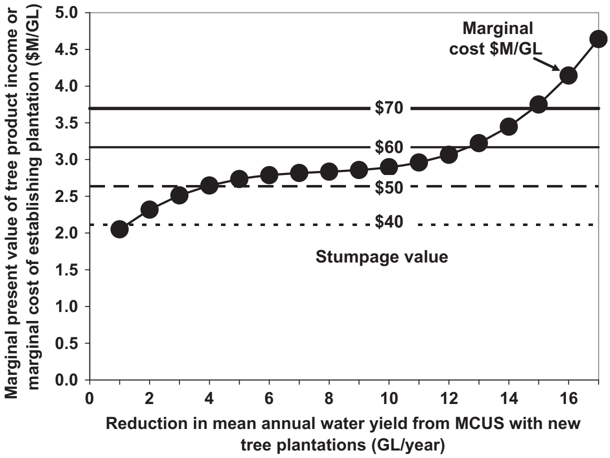


Figure 4 Marginal PV of tree product income at four stumpage values, and marginal opportunity and establishment costs (MC) of tree plantations in watershed MCUS. $M = $ million.

expression of all upstream benefits and costs of establishing plantations is in terms of dollars per GL of water used. This novel approach allows a direct connection of non-linear upstream demands for water by new tree plantations with downstream demands for water, and the supply of water entitlements held by irrigators and other water users.

The marginal opportunity cost (change in opportunity cost) may be expressed as cost to the landowner for incremental GLs of additional water used by the trees. These were derived for the saltiest sub-catchments, MCUS (acronym for 'mid-catchment upstream of urban area, salty' in Figure 2) within the Little River Catchment, considering their estimated salt-loads and water-yields (Evans *et al*. 2004; Nordblom *et al*. 2009).

A linear programming analysis of the Little River Catchment identified least-cost land use changes, which could deliver decrements in salt-loads (and water-yields) entering the river (see Nordblom *et al*. 2009). That analysis assumed existing forest areas would be retained while new forest plantations, even if not profitable in themselves, could be established to use water strategically for salinity mitigation. The associated sequence of increasing marginal opportunity costs of land use changes was smoothed by fitting a cubic function. New tree plantations established were first located where they are most profitable, followed by locations where they were less profitable because of greater opportunity costs from displacing more profitable land uses. This marginal cost curve is imposed on the marginal present values of tree products in Figure 4.

Thus the opportunity costs of tree planting depend on the land uses being displaced. Satellite images suggest the proportions of different land uses in upstream areas of the Macquarie catchment were similar to those of Little River. This allowed horizontal 'stretching' of the plantation marginal cost curve (Figure 4) to match the ranges of water yield change in the other sub-catchments, which were further adjusted downwards for the higher rainfall zones that need fewer hectares of plantation per GL of water used (Table 1).

For example, we assume only 744 ha of new plantation in UC10 (the 1000 mm rainfall zone) reduces annual water-yield 1 GL below the base levels from that area, whereas in the 600 mm rainfall zones (MCUS, UC6 and MCD), 1675 ha of new plantation would have this effect (Table 1). We have based the marginal cost curves of the higher-rainfall zones (UC10, UC8 and MCU) on that of MCUS, adjusted downwards by constant amounts (C) specific to each according to the formula, $C = \mathrm{MC}(1 - R)$, where R, in the case of UC10, is the ratio of UC10's 744 ha to MCUS's 1675 ha area for one-GL decrements in annual water yield and MC is the marginal cost of the first GL decrement from MCUS. Thus, UC10's marginal costs are assumed lower than those of MCUS by a constant \$1.21 million. Using the same logic, the marginal cost curves for the 800 and 700 mm rainfall areas (UC8 and MCU) are lower than that of MCUS by \$0.83 and \$0.51 million, respectively.

Subtracting the marginal cost curve from the marginal PV of benefits (see horizontal lines in Figure 4) to landowners expresses the marginal value or demand curve for additional tree plantations in terms of water (\$million/GL). For example, in Figure 5a it can be seen that given stumpage values below \$50/m^3 commercial plantations are unlikely to be attracted to MCUS. With only 600 mm of annual rainfall the MCUS sub-catchment is one of the least profitable places in the Macquarie catchment for tree plantations.

In this study, the higher-rainfall upper Macquarie catchment is of particular interest as tree plantations in these sub-catchments will be most profitable in their own right. The best example of this is UC10, an area with 1000 mm annual rainfall. Not counting the external costs of water yield reduction, but considering only the direct benefits and (direct and opportunity) costs associated with tree products, we can estimate the limits of plantation expansion (Figure 5b), where marginal values of planting more trees approach zero. For our UC10 example, this would involve consumption of up to 63 GL of 'free' water given \$40/m^3 tree stumpage values; 72 GL at \$50/m^3; 78 GL at \$60/m^3; and 83 GL at \$70/m^3. The latter would represent a 40 per cent reduction in water yield from UC10.

The aggregate demand for water by new upstream tree plantations may be expressed as the horizontal sum of the individual sub-catchment demands (as in Figure 6). The 'wavy' character of these curves is because of the different sizes and shapes of their constituent demand curves (i.e., Figure 5a,b).

3.4. Marginal values of water use by downstream irrigators and stock and domestic water users based on recent prices of permanent water entitlement trades

If new tree plantations are required to purchase water entitlements, the marginal values of water from the perspectives of downstream entitlement holders, as well as upstream land owners wishing to establish tree plantations,

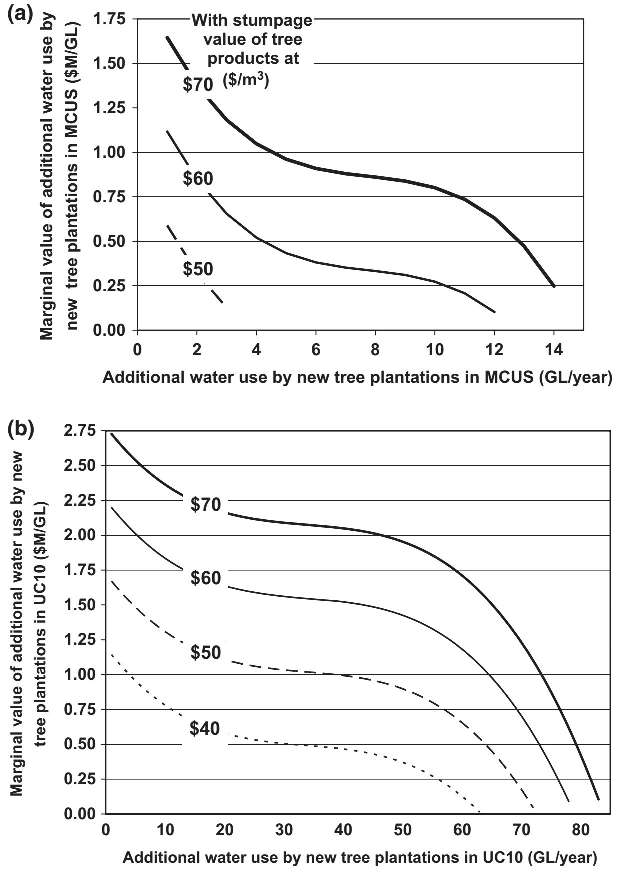


Figure 5 Demand for new tree plantation water given different values of tree products in sub-catchment MCUS with 600 mm rainfall (a) and in UC10 with 1000 mm (b).

come into play. Here we construct estimates of the marginal values of water among the downstream entitlement holders.

The marginal values for water to the downstream IRR and S&D (irrigation and stock & domestic) sectors may be visualised as downward-sloping demand curves for permanent trades that intersect at a recent price of $1.2 million/GL with quantities corresponding to entitlement levels of 333 and 27 GL, respectively (Figure 7a) (Nordblom *et al.* 2009). This assumes IRR and S&D would be willing to purchase more water entitlements at lower prices and to sell water at higher prices.

We also account for an environmental agency offering to purchase up to 15 GL of water for the WL sector at a fixed price of $1.33 million/GL (that is, slightly above recent prices of permanent trades), but unwilling to sell any of its entitlements except at a high price ($3.8 million/GL), which could be taken as the cost of alternative approaches to securing and developing WL assets in the area. The scenarios assume all entitlements are fully allocated in an average year and that all entitlements are initially held by downstream

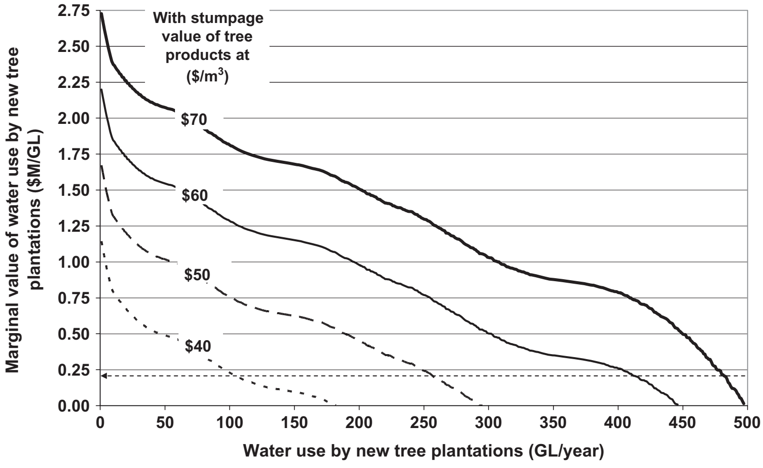
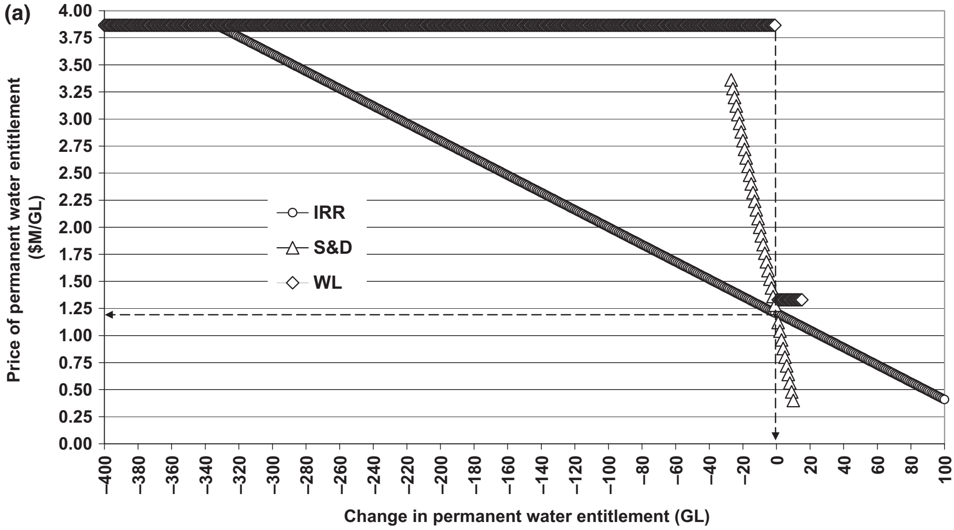


Figure 6 Aggregate demand by all six watersheds (UC10, UC8, UC6, MCU, MCUS and MCD) for extra water use by new tree plantations given different values of tree products. Each of the aggregate curves is the horizontal sum of the demand curves of these watersheds given the indicated stumpage value.

interests. In the present analysis, UHS (the urban and high security water sector) has a fixed entitlement of 27 GL and is not interested in buying or selling water entitlements. These settings are anchored to historical values of the downstream water market and comprise a simple and transparent scenario that can be used to consider physical and economic interactions with the upper catchment water sources. Historical water yields of the latter, and transmission losses, matched up with initial downstream uses in the catchment water balance (Nordblom *et al.* 2009).

As the downstream sectors are taken to hold all available entitlements, they are the only suppliers of water if upstream land owners want to establish tree plantations. Alternately, if widespread establishment of new tree plantations takes place in the absence of such a requirement, the downstream entitlement holders will suffer losses as their allocations of water are reduced. We take losses in stream flow (GL) to the IRR, S&D and WL sectors to be proportional to their initial shares of entitlements, such that their economic losses can be measured according to their marginal values (demand) for water (Figure 7a).

IRR and S&D can buy or sell water according to their marginal values (i.e., their demand relations). The aggregate supply curve for permanent water entitlements is constructed in Figure 7b as the horizontal sum of the marginal values of the downstream entitlement holders, IRR, S&D and WL, which interact with the upstream aggregate demand for water. The equilibrium price of water is discovered at the quantity where aggregate demand price is just equal to or greater than aggregate supply price; no new trades are expected at the margin where supply price exceeds demand price. This is how a market works. For fuller illustrations of simultaneous 'discoveries' by such a market, see Nordblom *et al.* (2011).



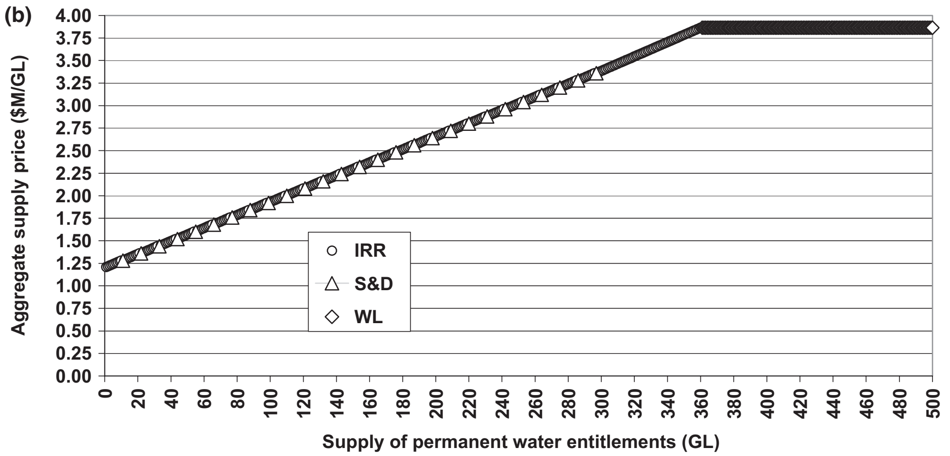


Figure 7 Assumed demand for changes in permanent entitlements to water (a) by downstream IRR, S&D and WL sectors initially holding entitlements to 333, 27 and 405 GL, respectively, with an equilibrium price of \$1.2 million/GL between IRR and S&D sectors; at this price (horizontal arrow) no trade (vertical arrow on zero) takes place between IRR and S&D. Holders of the wetland entitlements (WL) are assumed unwilling to sell any at prices below those for which the last GL of private entitlements are sold (\$3.8 million/GL), but willing to purchase 15 GL of additional entitlements at slightly more than the equilibrium price. The aggregate supply of water entitlements from downstream sectors IRR, S&D and WL (b) is constructed as the horizontal sum (of GL) that these entitlement holders would be willing to sell at different prices.

3.5. Distributions of water use and economic surpluses given supply and demand for water among sectors

We are now equipped to project the consequences of eight scenarios: four tree product prices, without or with a policy for tree plantations to purchase entitlements to the amounts of extra water the trees will consume (specific to rainfall zone and current land use). The intersections of aggregate demand curves (Figure 6) and the aggregate supply curve (Figure 7b) define the equilibrium supply and demand quantities (GL) and prices ($ million/GL) in a water market that connects upstream plantations with downstream industries and communities (Figure 8).

4. Results

4.1. Aggregate supply and demand

If there is no requirement to purchase water to plant trees, we assume upstream landowners can profitably expand plantations to the point where marginal returns from tree products are $0.2 million/GL (horizontal arrow in Figure 6). The use of 'unpriced water' would expand to the point that marginal benefit = zero. We have replaced zero with $0.2 million/GL to give a more conservative projection of cut-off points. Even so, large expansions in water use by vast areas of new plantations are projected. If tree products were valued at $40/m^3, for example, tree planting increases to the point that annual water-yields to the river system downstream of the new trees are reduced by some 106 GL. With tree product values at $50/m^3, water yield could be reduced by 258 GL; at $60/m^3 by 415 GL; and at $70/m^3 by 483 GL (Figure 6). The latter (largest) un-negotiated transfer of water to upstream from downstream use is associated with a $639 million increase in economic surpluses for the new upstream plantations. But it would be felt downstream as losses of $233 million in economic surplus by IRR and S&D, and losses of 345 GL in annual environmental flows.

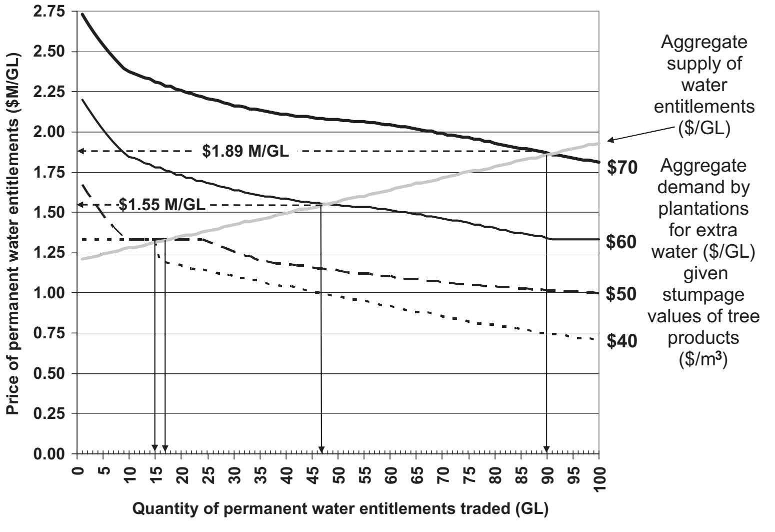


Figure 8 The aggregate supply curve of downstream water entitlement holders and four aggregate demand curves for extra water entitlements by upstream plantations determine equilibrium prices and quantities of permanent water entitlements traded given four tree product values.

Requiring new plantations to purchase water entitlements extends the downstream water market upstream. Given stumpage values of \$40 or \$50/m^3, only 15 or 17 GL of water would be traded at the \$1.33 million/GL price offered by the environmental agency for use by the WLs (Figure 8). At stumpage values of \$60 and \$70/m^3, 47 and 90 GL of water would be traded at prices of \$1.55 and \$1.89 million/GL, respectively, from the IRR and S&D sectors to those wishing to establish new upstream tree plantations. A \$70/m^3 stumpage value not only increased the present value of economic surpluses to upstream landowners establishing plantations by \$192 million but also increased the present value of economic surplus to downstream IRR and S&D sectors by \$138 million through sale of 90 GL of water entitlements. The aggregate gain from this market solution is therefore in the order of \$330 million, with no reductions in environmental flows (see Nordblom *et al.* 2009).

A brief summary of the above results provides a further perspective. In the case of \$70/m^3 stumpage values, requiring water entitlement purchases results in a net reduction in total surplus of \$76 million ((639 − 233) − (192 + 138)), but sustains 345 GL of annual environmental flows for a one-off social cost of seemingly only \$0.22/kL (= \$220/ML or \$0.22 million/GL). But this is much lower than the market value of the first units of that water to agriculture and forestry.

4.2. Disaggregated results: changes in water use, changes in economic surplus and new tree plantation areas for each watershed and downstream sector

The above aggregate results mark the effects on upstream plantations and downstream water users. Disaggregation of the results at the intersection of aggregate marginal demand and supply values allowed the determination of each sector's gains and/or losses in water use (Figure 9), in economic surpluses (Figure 10), and new tree plantation areas in the different watersheds (Figure 11), under each of the four stumpage value scenarios.

If there were no requirement for new tree plantations to purchase water entitlements, the highest increases in water use for new tree plantations and highest gains in economic surplus (top panels in Figures 9 and 10, respectively) are seen in watershed UC8, the largest sub-catchment located in the moderate rainfall zone of the upper catchment.

Increasing stumpage values induced increases in tree planting and water use by new plantations, but at decreasing rates (Figures 11 and 9), whereas economic surpluses from this investment increased at increasing rates (Figure 10). This reflects the reality that only the most profitable plantation sites will be developed when stumpage values are low. As stumpage values rise the next most profitable sites also attract investment, whereas those initially profitable sites become even more profitable. The accompanying reductions in water flow to the downstream sectors are reflected in large reductions in their economic surpluses (Figures 9 and 10, top panels).

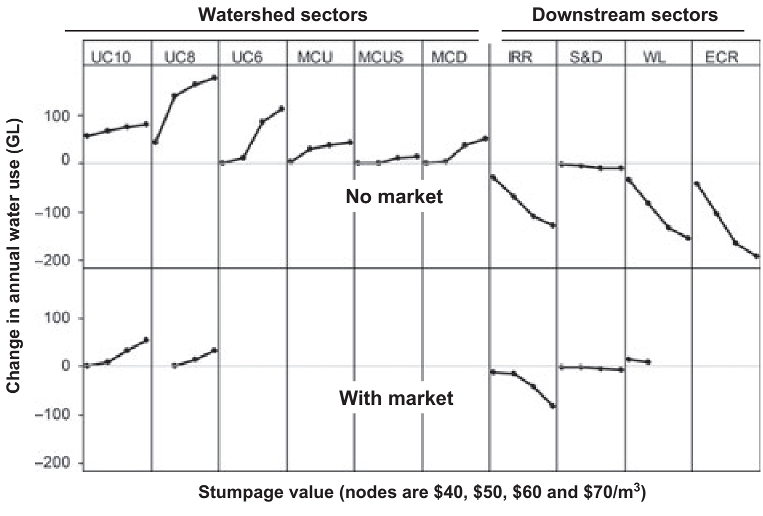


Figure 9 Changes in water use sector by sector, where there is no requirement for those establishing tree plantations to account for their water use (top panels), and where new tree plantations are only permitted after permanent water entitlements have been purchased from downstream entitlement holders (bottom panels). The four nodes shown for each sector are results given the four stumpage values for tree products: increasing from $40/m^3 (LH node) to $70/m^3 (RH node).

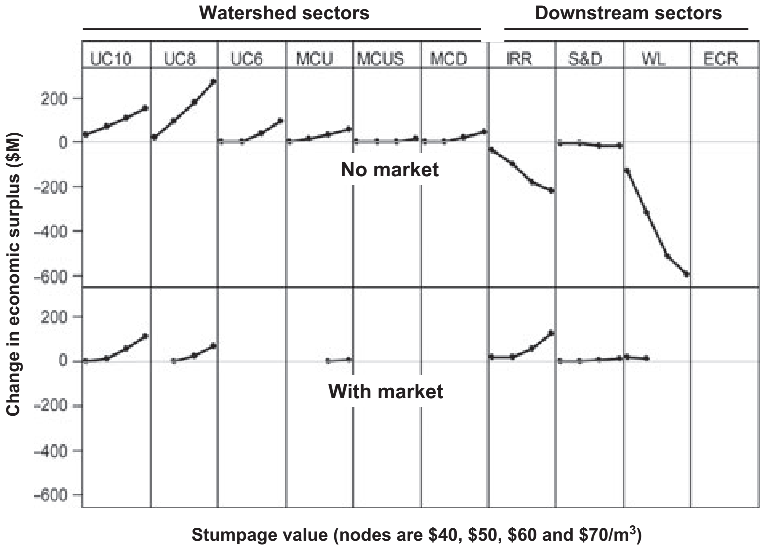


Figure 10 Changes in economic surpluses with conditions as described in Figure 9.

Requiring the purchase of water entitlements from downstream sectors reduces the expansion of plantation areas relative to what would occur in the absence of such requirements. This is reflected in lower increases in water use and economic surpluses by upstream interests (bottom panels of Figures 9–11, respectively). The lower rainfall catchments (UC6, MCUS and

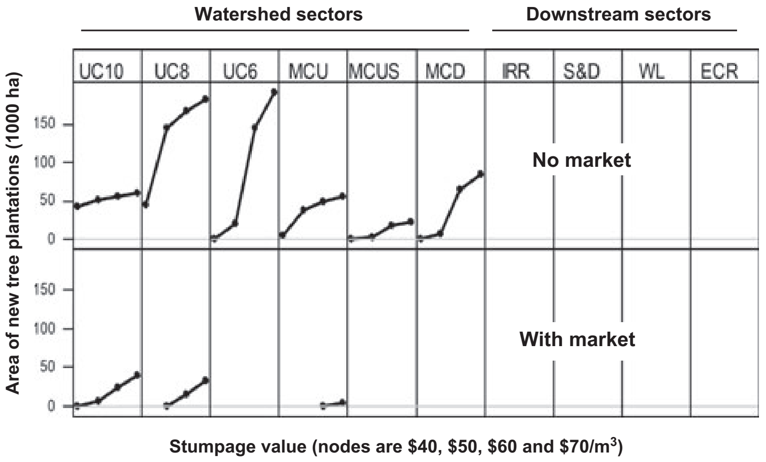


Figure 11 Changes in new tree plantation areas with conditions as described in Figure 9.

MCD) do not enter the market for water because they are unable to compete with the high rainfall areas (UC10 and UC8) where tree plantations are most profitable.

For the economic agents (land owners in all the watersheds and the IRR and S&D sectors) their 'bottom lines' are measured as changes in economic surpluses (Figure 10). With unrestricted expansion of tree plantations, WL and ECR suffer large declines in stream flow, the consequences of which may be non-linear as some reduction is possible before ecological functionality and resilience are compromised.

5. Discussion

5.1. 'Without market' scenarios

Where landowners are free to establish tree plantations without paying for the consequent water flow reductions, the areas of new trees planted will be limited only by tree product values minus the direct and opportunity costs of establishment. Plantations would expand to the maximum area that is profitable in each watershed, gaining the most in terms of their economic surpluses without regard to the reductions caused to stream flows. The downstream parties (IRR and S&D) would face large uncompensated economic loses, being disconnected from the gains enjoyed upstream. They and the environmental assets (WL and ECR) would likely face significantly reduced river flows.

We estimate the consequences for the 'without market' scenarios. Where tree products have stumpage values of $70/m^3$, we estimate some 600,000 ha of new tree plantations would be established to earn economic surpluses of $639 M, but stream flows would also be 483 GL/year less. Agriculture's share of this loss would be 137 GL/year of water flow and $233 million in economic surplus, whereas the WLs would lose 345 GL in annual flows. A lower stumpage value of \$40/m^3 for forest products limits tree expansion to 94,000 ha, earning an economic surplus of \$53 million and reducing river flow by 106 GL. Downstream agriculture would suffer reductions of 30 GL/year of water for a \$40 million loss in economic surplus, whereas annual environmental flows would fall by about 76 GL.

5.2. 'With market' scenarios

Requiring new plantations to purchase entitlements from the water market reduced both the size and extent of new plantations. With smaller areas of trees planted in fewer watersheds (Figure 11), much less water is used by trees (Figure 9), and downstream sectors profit by selling some water entitlements.

The water market between new upstream and current downstream uses was sensitive to the value of tree products. No permanent trade of water upstream was indicated if tree stumpage values were only \$40/m^3. However, if tree products were valued at \$70/m^3, the model estimates 90 GL of permanent water entitlements would be purchased to support 78,000 ha of new upstream plantations earning economic surpluses of some \$192 million, whereas downstream agricultural sectors would gain \$138 million in economic surplus from this sale of water while directing their remaining water only to the highest value uses. In this case the market would produce gains of \$330 million in economic surpluses, with no reductions in environmental water flows.

Regulations, taxation and subsidies can be used to balance and distribute water use, but they may lack efficiency and cut off valuable economic opportunities made possible by markets (Young and McColl 2009). Indeed, given the complexity of real-world landscapes, economics and weather, it is hard to see how regulation alone could allocate water efficiently among all its competing uses without including a market mechanism that allows adjustments year to year, and over time for larger changes; for example, technological breakthroughs or climate change (DECCW 2010).

5.3. Limitations

The present analysis develops a deterministic, static case study. No mention is made of how existing tree plantations would fit into water market scenarios. For example, when an existing 20 or 30 year old plantation is harvested, marketable water rights could be deemed to be 'created' if tree re-growth is prevented and land use reverted to permanent pasture such that stream flows increase. Are marketable water rights retained if the land is replanted with trees immediately following harvest? Or, must water rights be purchased to re-establish the plantation? On the other hand, would 'grandfathering' water rights to existing plantations enable continuous land and water use by trees where most profitable, but provide a release of land for grazing and of marketable water to the upstream/downstream market where no incentive or possibility to do so now exists?

The water model used here simply follows Zhang *et al.* (2001), assuming that water yields are a function of mean annual rainfall and land use. We have not accounted for variations in annual rainfall or other climate parameters over time. We have not accounted for different soils, different geological and topographic placements of tree plantations or sites with different slopes or aspect with respect to the sun. Neither have we accounted for different options in specific plant species (of trees, pastures, crops), nor how any of these are managed with regard to land preparation, pest control, planting, thinning, etc. (Van Dijk *et al.* 2004; Marcar *et al.* 2010; Webb and Kathuria 2012). However, for a simple 'range-finding' exercise, such as this, we considered that adding further layers of complexity would obscure the main results.

6. Conclusions

In this study, we described the application of a bio-economic model of the Macquarie Catchment to investigate the implications of alternative policy settings relating to the purchase of water rights by forestry plantation owners. For the first time in NSW, this study has provided quantitative projections of the economic, distributional and environmental benefits associated with requiring new upstream tree plantations to purchase water entitlements from downstream entitlement holders.

Where new tree plantations are not required to purchase water entitlements from downstream entitlement holders, several economic consequences are projected. If tree products have high values, expansion of tree plantations will be encouraged resulting in reduced stream flows to rural communities, irrigation industries and riparian environmental areas. High economic surpluses could be captured by new plantations, but this would be at the cost of large uncompensated losses subsequently faced by established local downstream economic and environmental interests.

Requiring new upstream tree plantations to buy water entitlements from downstream entitlement holders resulted in no permanent trade of water upstream given the lowest tree stumpage values in our analysis ($40/m^3). However, if tree products are valued at $70/m^3 the model estimates 90 GL of permanent water entitlements would be purchased to allow 78,000 ha of new plantations upstream. Net benefits to the new plantation owners ($192 million) would exceed the benefits to downstream agricultural sectors ($138 million) from this sale of water entitlements, for a combined gain in economic surpluses of $330 million, with no reductions in environmental water flows. Given $70/m^3 tree products, the net reduction of $76 million in economic surpluses in the catchment with the requirement for new plantations to purchase water entitlements, seemingly sustains 345 GL of annual environmental flows at a one-off social cost of only $0.22 million/GL (or $0.22/kL). But this is much lower than the market value of the first units of that water to agriculture and forestry.

The above results may not be easily generalised to other catchments with significantly different resource mixes and scales in their water economies. For example, a catchment which drains directly to the ocean presents very different opportunities than a catchment supplying water to urban areas, irrigation industries and/or important fresh-water WLs in the dry interior regions. Large new plantations in the ocean-flow catchment may raise little cause for concern. However, large new plantations in the water-source areas of inland catchments will need some means of reaching economically efficient, socially equitable, flexible and environmentally sustainable settlements with the local downstream water interests. Such settlements may be within reach given balances of policy and regulation that allow the market to work.

References

Ajani, J. (2010). *Climate Change Policy Distortions in the Wood and Food Market*. Paper, 54th Annual Conference, Australian Agricultural and Resource Economics Society, 10–12 Feb 2010, Adelaide, Australia. Available from URL: http://purl.umn.edu/58877 [accessed 27 Feb 2012].

COAG. (2004). Intergovernmental agreement on a National Water Initiative, between the Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory. Available from URL: http://www.coag.gov.au/coag_meeting_outcomes/2004-06-25/docs/iga_national_water_initiative.rtf [accessed 27 Feb 2012].

Crossman, N.D., Summers, D.M. and Bryan, B.A. (2010). Opportunities and threats for South Australia's Agricultural Landscapes from Reforestation under a Carbon Market. CSIRO Client Report. Final Report—March 2010. CSIRO Sustainable Ecosystems. Available from URL: http://www.csiro.au/files/files/pviu.pdf [accessed 27 Feb 2012].

DECCW (Department of Environment, Climate Change and Water NSW) (2010). *NSW Climate Impact Profile, The impacts of climate change on the Biophysical environment of New South Wales*. DECCW, Sydney, NSW, 168 pp. ISBN 978 1 74232 259 9 Available from URL: http://www.environment.nsw.gov.au/resources/climatechange/10171climateimpactprof.pdf [accessed 27 Feb 2012].

DW-GSA (Department for Water, Government of South Australia) (2010). *Approval Process for Plantation Forestry under the Natural Resources Management Act 2004*. Government of South Australia, Department for Water. Available from URL: http://www.waterforgood.sa.gov.au/wp-content/uploads/2010/06/Plantation%20commercial%20forestry/ForestryFS Updatejune08.pdf [accessed 27 Feb 2012].

Evans, W.R., Gilfedder, M. and Austin, J. (2004). Application of the biophysical capacity to change (BC2C) model to the Little River (NSW). CSIRO Land & Water Technical Report No. 16/04. March 2004. Available from URL: http://www.clw.csiro.au/publications/technical2004/tr16-04.pdf [accessed 27 Feb 2012].

Finlayson, J.D., Bathgate, A., Nordblom, T., Theiveyanathan, T., Farquharson, B., Crosbie, R., Mitchell, D. and Hoque, Z. (2010). Balancing land use to manage river volume and salinity: economic and hydrological consequences for the Little River catchment in Central West, New South Wales, Australia. *Agricultural Systems*, 103, 161–170.

Galiana, I. and Green, C. (2010). Technology-led climate policy, Chapter 7, in Lomborg, B. (ed.), *Smart Solutions to Climate Change, Comparing Costs and Benefits*. Cambridge University Press, Cambridge, pp. 292–339. ISBN 978-0521-13856-7.

Gerrand, A., Keenan, R.J., Kanowski, P. and Stanton, R. (2003). Australian forest plantations: an overview of industry, environmental and community issues and benefits. *Australian Forestry* 66(1), 1–8.

Gilfedder, M., Walker, G.R., Dawes, W.R. and Stenson, M.P. (2009). Prioritisation approach for estimating the biophysical impacts of land-use change on stream flow and salt export at a catchment scale. *Environmental Modelling & Software* 24, 262–269.

Grieve, A., Wood, S. and Cowie, A. (2008). *Carbon Trading and Catchment Management Authorities: Realising the Revenue Potential of Environmental Plantings under the New South Wales Carbon Market*. Rural Industries Research and Development Corporation (RIRDC) Publication No 08/136, RIRDC Project No CGA-2A. ISBN 1 74151 725 7, ISSN 1440-6845. August 2008. Available from URL: https://rirdc.infoservices.com.au/downloads/08-136.pdf [accessed 27 Feb 2012].

Jackson, R.B., Jobbágy, E.G., Avissar, R., Roy, S.B., Barrett, D.J., Cook, C.W., Farley, K.A., le Maitre, D.C., McCarl, B.A. and Murray, B.C. (2005). Trading water for carbon with biological carbon sequestration. *Science* 310, 1944–1947.

Johnson, I. and Coburn, R. (2010). *Trees for Carbon Sequestration*. Primefact 981. Primefacts for profitable, adaptive and sustainable primary industries. NSW Department of Industry and Investment. ISSN 1832-6668. Available from URL: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/317559/Trees-for-carbon-sequestration.pdf [accessed 27 Feb 2012].

Lawson, K., Burns, K., Low, K., Heyhoe, E. and Ahammad, H. (2008). *Analysing the economic potential of forestry for carbon sequestration under alternative carbon price paths*. Australian Bureau of Agricultural and Resource Economics, Canberra, Australia. Available from URL: http://www.treasury.gov.au/lowpollutionfuture/consultants_report/downloads/Economic_Potential_of_Forestry.pdf [accessed 27 Feb 2012].

Marcar, N., Theiveyanathan, T., Roxburgh, S., Gilfedder, M., Littleboy, M., Christy, B., Barlow, K., Almeida, A., Crawford, D. and Benyon, R. (2010). Methodology to assess site-specific impacts of plantations on catchment water yields. CSIRO: Water for a Healthy Country National Research Flagship. Available from URL: http://www.clw.csiro.au/publications/waterforahealthycountry/2010/wfhc-plantations-site-impacts.pdf [accessed 27 Feb 2012].

MDBA (Murray-Darling Basin Authority) (2010). *Guide to the Proposed Basin Plan: Overview*. Murray-Darling Basin Authority, Canberra. ISBN (online) 978-1-921557-73-6 Available from URL: http://download.mdba.gov.au/Guide_to_the_Basin_Plan_Volume_1_web.pdf [accessed 27 Feb 2012].

Nordblom, T., Hume, I., Bathgate, A. and Reynolds, M. (2006). Mathematical optimisation of drainage and economic land-use for target water and salt yields. *Australian Journal of Agricultural and Resource Economics* 50(3), 381–402.

Nordblom, T.L., Finlayson, J.D., Hume, I.H. and Kelly, J.A. (2009). Supply and demand for water use by new forest plantations: a market to balance increasing upstream water use with downstream community, industry and environmental use? Economic Research Report No 43, NSW Department of Primary Industries, Wagga Wagga. CRC for Future Farm Industries. Available from URL: http://www.dpi.nsw.gov.au/research/areas/biosecurity/economics-research/reports/43 [accessed 27 Feb 2012].

Nordblom, T.L., Christy, B., Finlayson, J., Roberts, A. and Kelly, J. (2010). Least-cost land-use changes for targeted salt-load and water-yield impacts in south-eastern Australia. *Agricultural Water Management* 97(6), 811–823.

Nordblom, T.L., Reeson, A., Finlayson, J., Hume, I., Whitten, S. and Kelly, J. (2011). Price discovery and distributions of water rights linking upstream tree plantations to downstream water markets: experimental results. *Water Policy* 13, 810–827.

Nuberg, I., George, B. and Reid, R. (eds.) (2009). *Agroforestry for Natural Resource Management*. CSIRO Publishing, Collingwood, VIC.

Oliver, I., Ede, A., Hawes, W. and Grieve, A. (2005). The NSW Environmental Services Scheme: results for the biodiversity benefits index, lessons learned, and the way forward. *Ecological Management & Restoration* 6(3), 197–205.

Pannell, D.J. and Roberts, A.M. (2010). Australia's National Action Plan for Salinity and Water Quality: a retrospective assessment. *Australian Journal of Agricultural and Resource Economics* 54(4), 437–456.

Parsons, M., Frakes, I. and Gerrand, A. (2007). *Plantations and Water Use. Science for Decision Makers*. Department of Agriculture, Fisheries and Forestry. Bureau of Rural Sciences. Available from URL: http://www.plantations2020.com.au/assets/acrobat/Aug2007_plantationsandwateruse.pdf [accessed 27 Feb 2012].

Plantations for Australia: The 2020 Vision. Available from URL: http://www.plantations2020.com.au/index.html [accessed 27 Feb 2012].

Schrobback, P., Adamson, D. and Quiggin, J. (2011). Turning Water into Carbon: carbon sequestration and water flow in the Murray-Darling Basin. *Environmental Resource Economics* 49, 23–45.

SKM (Sinclair Knight Merz, CSIRO and the Bureau of Rural Sciences) (2010). *Surface and/or Groundwater Interception Activities: Initial Estimates Waterlines Report*. National Water Commission, Canberra. Waterlines Report Series No 30, June 2010. Available from URL: http://www.nwc.gov.au/__data/assets/pdf_file/0006/10968/Surface_and_or_groundwater_interception_activities_23June.pdf [accessed 27 Feb 2012].

Sohngen, B. (2010). Forestry carbon sequestration, Chapter 3, in Lomborg, B. (ed.), *Smart Solutions to Climate Change, Comparing Costs and Benefits*. Cambridge University Press, Cambridge, pp. 114–132, ISBN 978-0521-13856-7.

Stirzaker, R., Vertessy, R. and Sarre, A. (eds.) (2002). *Trees, Water and Salt: An Australian Guide to Using Trees for Healthy Catchments and Productive Farms*. Joint Venture Agroforestry Program, RIRDC publication number: 01/086. Available from URL: https://rirdc.infoservices.com.au/downloads/01-086.pdf [accessed 27 Feb 2012].

Van Dijk, A.I.J.M., Austin, J., Theiveyanathan, T., Benyon, R. and Hairsine, P.B. (2004). Representing plantation scenarios in hydrological modelling: requirements and limitations in representing commercial environmental forestry scenarios in stream flow and salinity modelling. CSIRO Land and Water. Commercial Environmental Forestry report CLW/02. Available from URL: http://www.clw.csiro.au/publications/consultancy/2004/Representing_Plantation_Scenarios_in_Hydrological_Modelling.pdf [accessed 27 Feb 2012].

Vertessy, R.A., Zhang, L. and Dawes, W.R. (2003). Plantations, river flows and river salinity. *Australian Forestry* 66 (1), 55–61.

Water Act 2007 (2007). *Act No. 137 of 2007 as Amended. Prepared on 5 March 2010 Taking into Account Amendments up to Act No. 8 of 2010*. Office of Legislative Drafting and Publishing, Attorney-General's Department, Canberra. Available from URL: http://www.austlii.edu.au/au/legis/cth/num_act/wa200783.txt [accessed 27 Feb 2012].

Webb, A.A. and Kathuria, A. (2012). Response of streamflow to afforestation and thinning at Red Hill, Murray Darling Basin, Australia. *Journal of Hydrology* 412–413, 133–140. doi:10.1016/j.jhydrol.2011.05.033.

Wood, S., Cowie, A. and Grieve, A. (2008). *Carbon Trading and Catchment Management Authorities: Predicting above-Ground Carbon Storage of Plantations*. Rural Industries Research and Development Corporation (RIRDC) Publication No 08/191, RIRDC Project No CGA-2A. ISBN 1 74151 780 X, ISSN 1440-6845. December 2008. Available from URL: https://rirdc.infoservices.com.au/downloads/08-191.pdf [accessed 27 Feb 2012].

World Bank (2010). *World Development Report 2010, Development and Climate Change*. The International Bank for Reconstruction and Development/The World Bank. Washington, DC. DOI:10.1596/978-08213-7987-5.

Young, M.D. and McColl, J.C. (2009). Double trouble: the importance of accounting for and defining water entitlements consistent with hydrological realities. *Australian Journal of Agricultural and Resource Economics* 53, 19–35. doi: 10.1111/j.1467-8489.2007.00422.x

Zhang, L., Dawes, W.R. and Walker, G.R. (2001). Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research* 37(3), 701–708.