Upstream-downstream benefit analysis of policy on water use by upstream tree plantations

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Abstract

This study focuses on the problem of water use by new upstream commercial tree plantations where fully-committed water entitlements are already held and traded among downstream sectors (urban water, wetlands and agricultural industries). High tree product prices strongly incentivise expansion of upstream plantation areas, particularly if there is no accounting for the predictable extra interception and use of water by trees. Planters could benefit greatly at the expense of downstream water users. Plotting this in a public-private benefit framework (PPBF) suggests a policy of "flexible negative incentives" to limit expansion of new trees, rather than 'across the board' banning of new plantations. We explore the 'flexible' option and the current 'no control' option for a case-study area, the Macquarie River catchment in central-west NSW, Australia, using three scenario sets:

(1) Policy setting — without or with the requirement for distributions of water use entitlements to be handled by extending the existing downstream market to new upstream plantations (the flexible negative incentive).
(2) Expected tree-product values — four exogenous levels ($40, $50, $60 or $70/m3), provide positive incentives for establishing trees.
(3) Water quality — FRESH or a hypothetical SALTY scenario where one of six up-stream watersheds seeps so much salt into the river that water for urban use is compromised when new plantations reduce fresh water yields from the other five.

We estimate quantitative consequences of all 16 combinations of the above scenarios, and show how an extended water market can deliver "flexible incentives" for efficient water distributions in which all new upstream and old downstream users either benefit by trading or remain unaffected.

Keywords: Water-catchment, Downstream-externality, Environmental-services, Policy, Interception, Murray-Darling Basin, Supply, Demand, Market, Urban-water, Irrigation, Wetlands, Biodiversity, Tree-plantations, Environmental-economic tradeoffs, Aggregation.
JEL Codes Q0, Q57, Q58

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1. Introduction

Water management in the Murray-Daring Basin is a topic of considerable interest among parties whose livelihoods depend on its water volumes and quality, and many who care about the biodiversity benefits of sustaining flows to wetland environments. Tree plantations are among the highest water users per hectare of any vegetative land cover. Perennial pastures use less water than trees and annual pastures and crops use the least (Zhang *et al*. 2001; Evans *et al.* 2004; Nordblom *et al.* 2006, 2010; Finlayson *et al.* 2010). The highest rainfall zones are typically in the upper watersheds, which serve to sustain stream flows to the lower plains where irrigated agriculture is most productive, and where water is needed for 'stock and domestic' use as well as to sustain riparian environmental assets, such as wetlands. Urban areas may also draw on river water directly or on groundwater, often recharged by surface water. The higher rainfall zones are also the best places for tree plantation productivity.

Wide expansion of new tree plantations in the upper watersheds may reduce the water supply on which downstream urban users, irrigation industries and threatened wetland environments depend. The popular myth that forests on the high ground attract more rain than without the forest cannot be sustained (Penman, 1963; Marcar *et al.*, 2010; Zhang *et al*., 2001) in the Murray-Darling Basin. It is rather the case that higher rainfall zones sustain forests and tree plantations, not the reverse. In the southeast corner of South Australia land owners wishing to establish tree plantations must first obtain permanent water entitlements from downstream water users (DW-GSA, 2000). A federal Carbon-Farming-Initiative proposes that land owners be required to purchase water entitlements to permit planting trees for carbon sequestration in areas having 600 mm annual rainfall or above (Minister for Climate Change and Energy Efficiency, 2011). This reflects a respect for property rights in water, and the need to maintain equity through compensation, where rainwater is intercepted and used by new plantations rather than flowing downstream to those who hold established entitlements to that water.

Nordblom *et al*. (2012a,b) provide economic analyses showing how the establishment of large new tree plantations in the upper watersheds can reduce volumes and change the quality of annual water yields. Jackson *et al.* (2005) and Schrobback *et al*. (2011) point out that carbon sequestration strategies typically favour standing biomass in tree plantations without considering the full environmental and economic consequences, which often include dramatic reductions in water yield. In early growth stages, carbon sequestration plantations may take as much water as production forest plantations, which are sustained in repeated rapid-growth and harvest cycles.

We consider what might be expected in a large NSW catchment (that of the Macquarie River in the Murray-Darling Basin) if new tree plantations in the higher rainfall watersheds were required to purchase permanent water entitlements (for the extra water they will use) from downstream entitlement holders. We account for how increased values (prices) of tree products affect the profitability of plantations and impact on downstream interests in stream volumes and water quality. We explore impacts that could be expected if one of the sub-catchments had such salty water yields that reductions in fresh flows from other sub-catchments would result in river salinity concentrations exceeding what urban water users can accept. We examine these issues quantitatively with simplified initial conditions, including those given in Figure 1. There we define six higher-rainfall watersheds [three with 600mm annual rainfalls, and one each with 700, 800 and 1,000 mm] where tree plantations could be established, and four downstream categories of water consumers [urban water and other high-security users, irrigation industries, ‘stock and domestic’ water users, and wetland environments] that would be affected by reduced river flows (Nordblom *et al.* 2009).

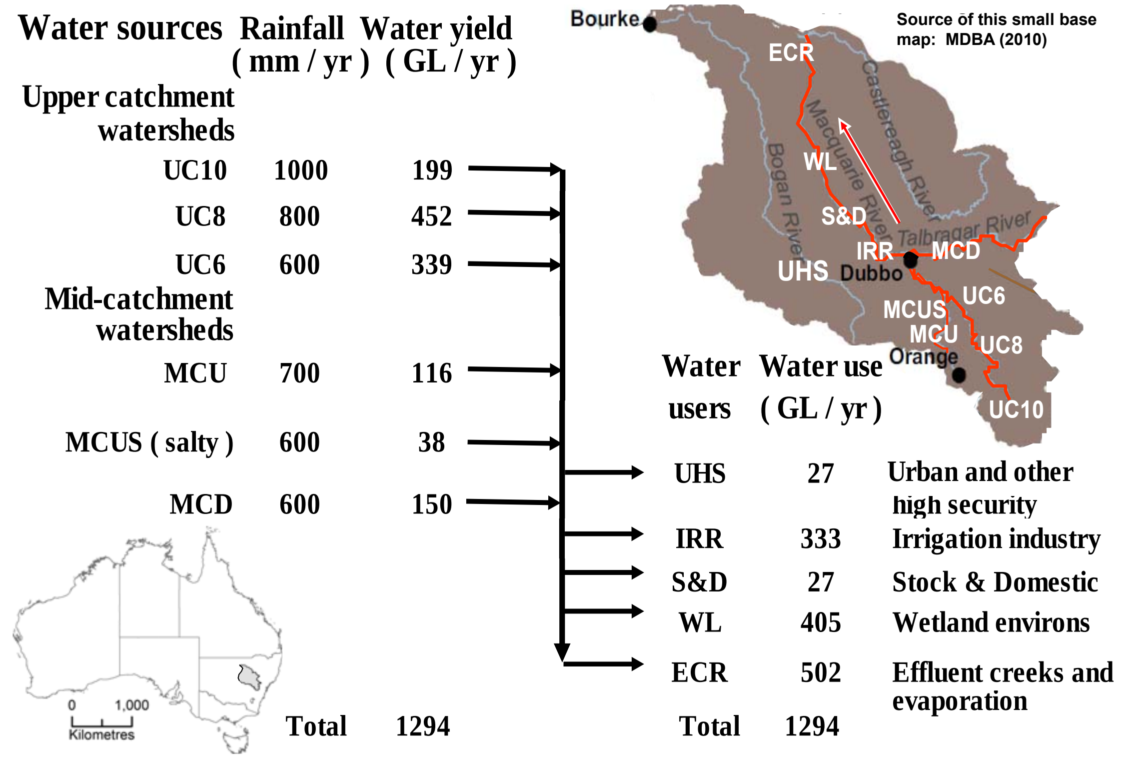

Figure 1. Schematic chart of upstream watershed sources and downstream water users in the Macquarie Catchment, NSW, Australia. Sources: Beale *et al.* (2000) water-yield averages for the 1975–1995 period, with totals delivered net of evaporation and transmission losses. Note, water yields of mid-catchment MCU and salty MCUS enter the river Upstream of UHS and influence the river salinity concentrations that urban water users face; MCD flows enter the river Downstream of UHS.

Results will depend on how changes in water volumes and water qualities are valued by each of the 10 water-use sectors mentioned above. How much will an extra quantity of water be worth to a particular sector, and what is the opportunity cost for that sector to forego access to a similar quantity of water? Marginal value curves for water were posited for each of the 10 sectors (Nordblom *et al.* 2009, 2011). We assume constant and continuing rainfalls at annual average levels for the respective parts of the catchment. Such a simplification allows complex impacts on water availabilities and qualities for downstream sectors due to changes in land use in the six watersheds to be demonstrated clearly.

The methods and data used to simulate this water economy and interactions among the various sectors are briefly described in section 2 of this paper. Many of the details that relate to this have been published elsewhere and easily accessible references are provided. Section 3 develops an upstream-downstream benefit analysis adapted from Pannell’s (2008, 2013) public-private benefit framework. We take on board Cary and Roberts’ (2011) and Convery’s (2013) admonitions to pay attention to economic pressures facing the different parties in any proposed plan. We evaluate the simultaneous impacts among the interacting sectors from the two policy settings, four tree product price levels, under the FRESH and SALTY scenarios. Discussion in Section 4 focuses on likely consequences from a change in policy toward requiring new plantations to obtain water entitlements to offset estimated reductions in stream volumes under the different combinations of price and salinity, with notes on limitations of the present analysis and on opportunities for improved analyses. Section 5 concludes.

2. Methods

The data used here are sourced from the results of Nordblom *et al*. (2009) which focused on land and water uses in the Macquarie River catchment of New South Wales, under 16 combinations of policy, price and salinity settings. Subsets of these settings are subjected to further analyses in the present paper. Schematic maps of our study area are given in Figure 1 (adapted from Nordblom *et al* (2012a). These are the initial conditions against which simulated changes are measured.

Nordblom *et al*. (2009, 2012b) use economic analysis to build upon this physical and biological foundation, to develop both catchment aggregate (Figure 2) and sub-sector by sub-sector disaggregated results (Figure 3).

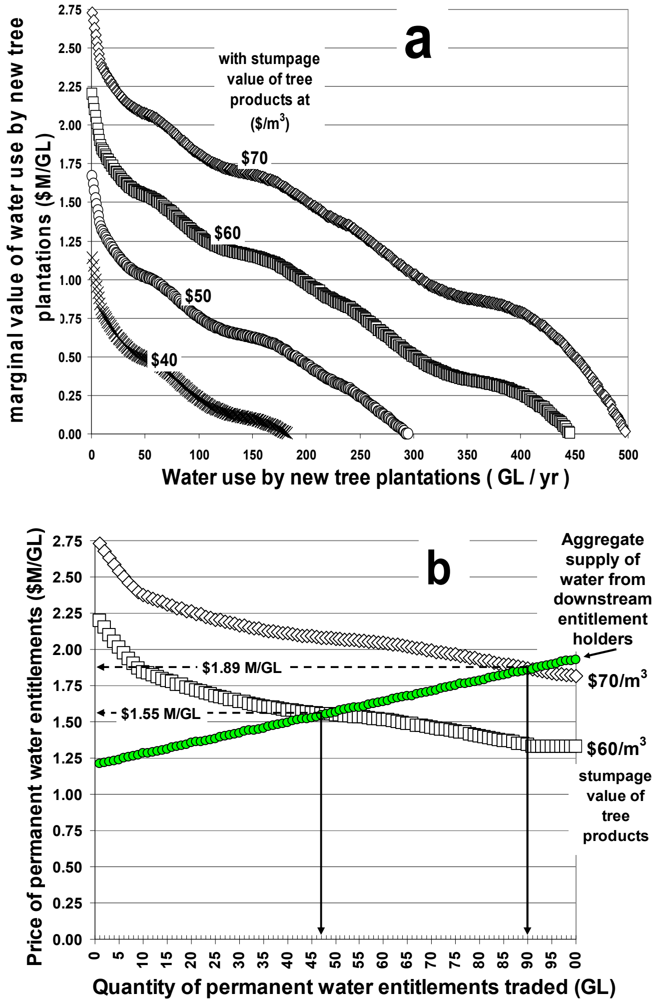

Figure 2. Given four exogenous stumpage values ($40, $50, $60 and $70/m^3) for tree products at harvest, the aggregate demands for water by all new plantations (**a**) are comprised of the horizontal sums of the demands by all six watershed (UC10, UC8, UC6, MCU, MCUS and MCD). Aggregating this upstream demand (given only the $60 and $70/m^3 stumpage values) with water demands of downstream water users (who already engage in their own water market), we estimate where total aggregate demand curves intersect (**b**) the aggregate supply curve of downstream water entitlement holders. These charts apply only to “FRESH, with policy” scenarios.

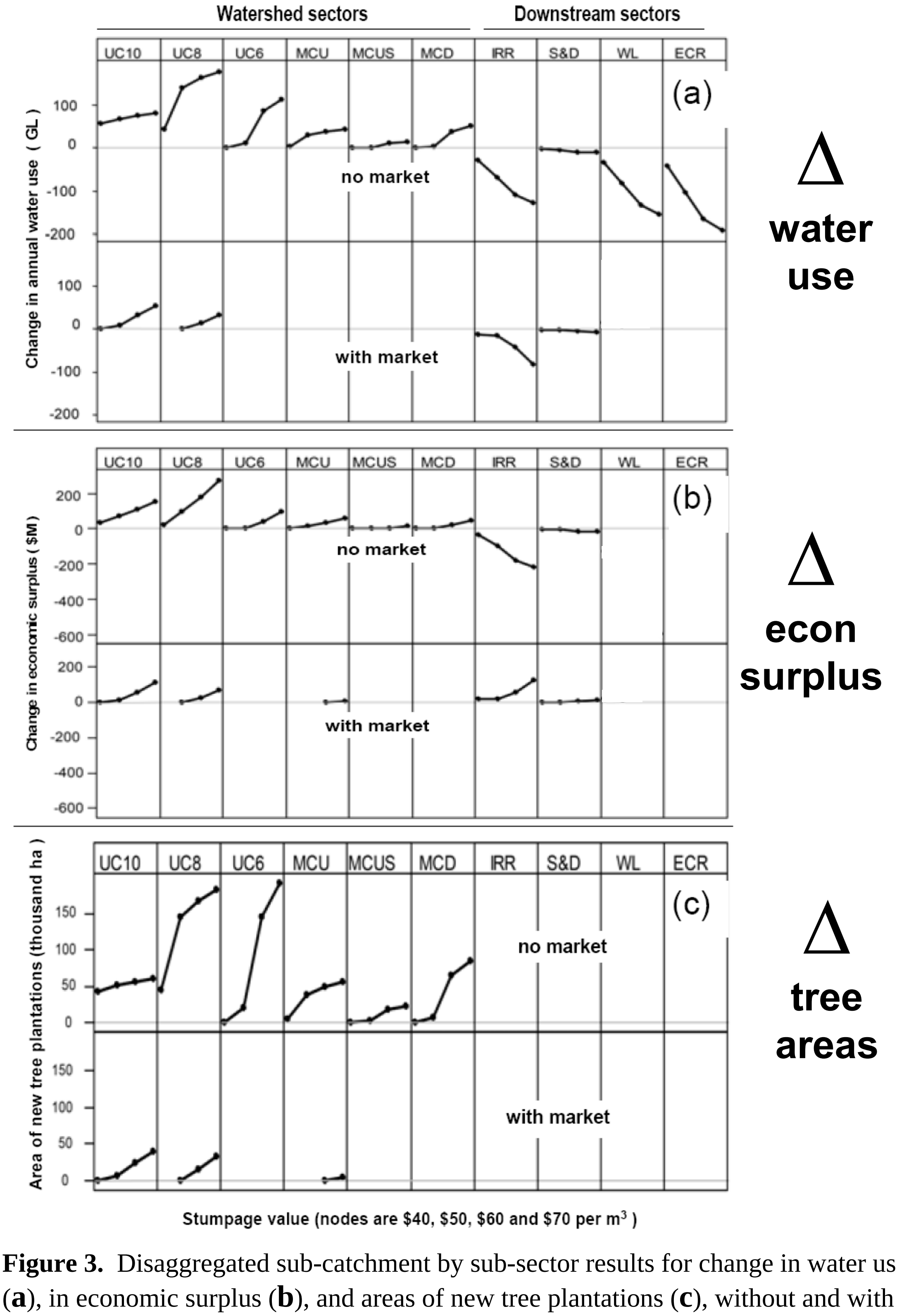

Figure 3. Disaggregated sub-catchment by sub-sector results for change in water use (**a**), in economic surplus (**b**), and areas of new tree plantations (**c**), without and with required water market participation by new tree plantations purchasing permanent entitlements from downstream water users, FRESH Scenario Sets 1 and 3 (Nordblom *et al.*, 2009, 2012b). The '**no market**' and '**with market**' values shown in these charts correspond to the "without and with policy" scenarios given FRESH conditions. See Figure 1 for identification of watershed and sub-sector names.

The aggregate analyses in Figure 2 define the prices and volumes of water traded to upstream tree plantations, given the \$60 and \$70/m^3 stumpage values. These market solutions indicate trade of 47 and 90 GL of water entitlements, respectively, to upstream watersheds (Nordblom *et al*. 2009, 2012a,b).

Changes in watershed water yields, downstream water use volumes, economic surpluses, and salt concentrations faced by the urban and high security consumers (UHS), were simulated with reference to yield and use data from Beale *et al*. (2000) based on records in the 1975-1995 period, as detailed in Nordblom *et al*. (2009).

Though all watershed sectors are expected to expand tree plantations if the extra water they use is free to them (that is, downstream losses uncompensated), only the highest rainfall watersheds (UC10 and UC8) are attracted to plant many new trees if they must obtain water entitlements. In the "with market" scenarios, however, all sectors either benefit from gains in economic surplus or suffer no losses (Figure 3).

Both catchment-wide aggregate and sub-catchment by sub-sector presentations of quantitative theoretical expectations and experimental observations of sector-by-sector results above reveal new insights. These include indications on which of the sub-sectors are likely to gain or lose water (and / or money) given particular combinations of price, salinity and policy. In the detailed results of Figure 3, watershed-by-watershed level comparisons are clear. Aggregated watershed sector values may be better suited for comparisons with the other sectors. Otherwise, the eye would need to sum across watersheds for each tree product value node (see legend at bottom of Figure 3). In the case of FRESH water volumes throughout the catchment, urban and other high security water entitlement holders (UHS) are taken to be unaffected. Information on the SALTY scenarios, where UHS is affected, is not provided in Figure 3.

Details comparing outcomes in both the FRESH and SALTY scenarios are shown in Nordblom *et al.* (2011), among the interacting sectors including the disaggregated watersheds. That study describes economic experiments to observe sub-sector by sub-sector responses under both FRESH and SALTY conditions but only under the "with market" policy setting (requiring purchase of water entitlements to plant trees), and only one price level (\$70/m^3) for tree products. The observed laboratory results for equilibrium water market prices generally converged on the theoretically-expected levels (\$1.89M/GL and \$1.92M/GL in FRESH and SALTY scenarios respectively). Exceptions that were found in the experiments involved lower than expected levels of trade, where sectors holding larger initial entitlements failed to sell as many units as expected by theory. This provided an example of the well known 'endowment effect' (Thaler, 1980; Kahneman, 2011). Until the present paper, results of salinity impacts on UHS have been available only in tabular formats in Nordblom *et al.* (2009).

The current study considers four main sectors: (1) Watersheds, comprised of six upstream sub-catchments capable of hosting profitable Private tree plantations (UC10, UC8, UC6, MCUS, MCU and MCD); with downstream Public sectors (2) UHS, urban and other high security users; (3) IRR+S&D, irrigation industry with rural 'stock and domestic' water users ; and (4) WL, wetland environmental assets. To examine how each of these four sectors could be affected under the four combinations of policy and salinity settings, a public – private benefit analysis is employed. Given particular scenarios of tree product value, salinity and policy, interactions among the various sectors are explored.

We use Pannell's (2008, 2013) public-private benefit framework (PPBF), to develop an analysis and plot the consequences of a policy change under different tree product prices and salinity conditions. A simple example of the basic logic of this form of presentation of policy choices is given in Figure 4. It is often hoped that new projects or policy ideas will produce benefits for all parties, or at least benefit most and harm none, but this is not always the case. Positive "win-win" benefits would locate such an "idea" in the north-east (**B**) quadrant of the PPBF chart in which positive Public net benefits (on the y-axis) are expected to accompany positive Private net benefits (on the x-axis). For detailed background please see Pannell (2008, 2013).

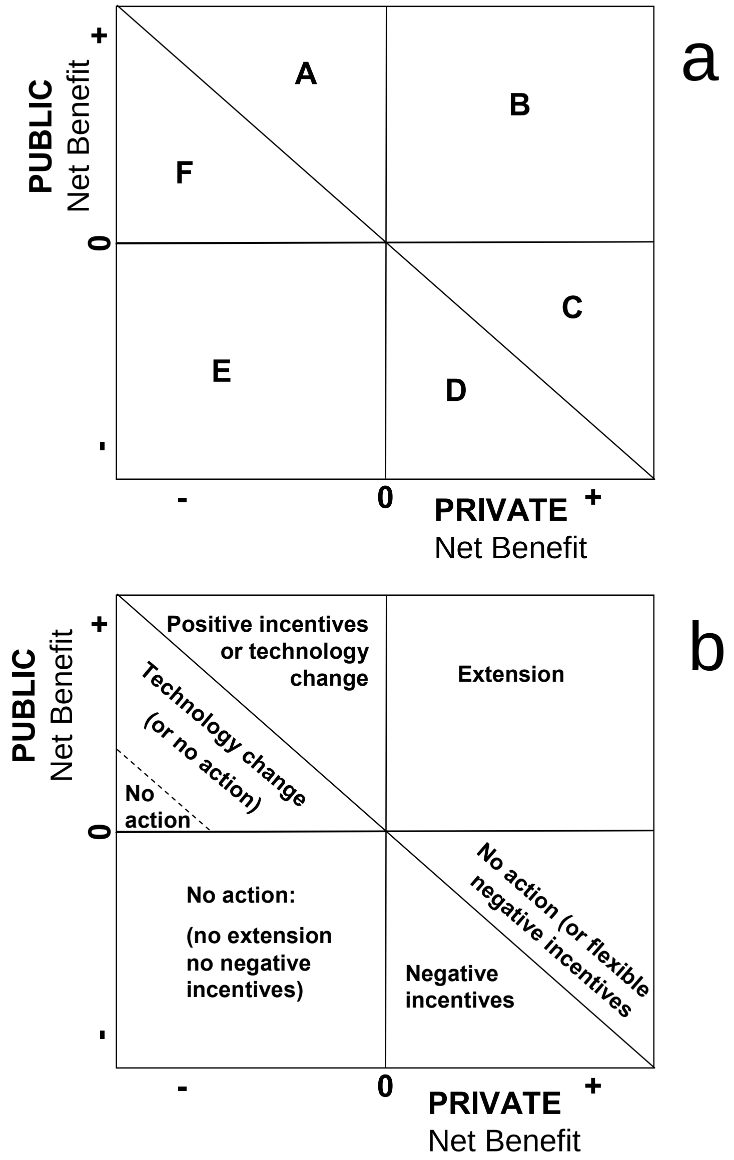

Figure 4. Elementary steps in Pannell's (2008, 2013) public-private benefit framework. The PRIVATE net benefits accruing to the private sector given choices it takes are plotted against the consequent changes PUBLIC net benefits. Ranges of combinations of Public and Private net benefits (A, B, C, D, E and F) are identified (**a**); these are associated with policies or programs (**b**) likely to bring about improved conditions with regard to balanced economic efficiency.

Our present analysis identifies new commercial tree plantations as the PRIVATE sector, which aggregates individual best levels of new plantings in the six watersheds given four tree product prices and no limits on water use. These four PRIVATE net benefit values are then plotted against the responses of aggregate PUBLIC net benefits (or losses) by the downstream sectors: UHS, IRR+S&D and WL (wetland) water deficits. To allow summing dollars and GL of water losses, we assign a range of money values to the latter. The IRR and S&D and wetland areas named in Figure 1, were the source of quantified sub-sector values combined to allow the aggregate analysis sketched in Figure 2. The disaggregated watershed and sector results could be determined from the calculations behind Figure 2. The aggregate results are simultaneous across the catchment for each tree product value, salinity and policy setting, as decisions taken in the upstream private tree-planting sector affect all others, particularly when salinity management for UHS is an issue. The disaggregated simultaneous sub-sector solutions could then be calculated, an essential intermediate step. Measured from initial conditions regarding watershed yields and downstream water uses (listed in Figure 1), estimated changes in water use, changes in economic surpluses and changes in areas of new tree planting could be calculated, as in the Figure 3 examples. That process is detailed in Nordblom *et al*. (2009). Our questions now are in regard to the conditions under which we might expect results that are "win-win-win-win" for Private upstream tree plantations and the Public sectors: UHS, IRR+S&D and wetlands.

Four key divisions in the present study are the combinations of "without or with" policy to require water entitlements for new tree plantations and the "FRESH or SALTY" scenarios. Results generated under each of these sets of conditions for the case of exogenous \$70/m^3 tree product values are listed in Table 1. The values given here for the FRESH Scenario Sets 1 and 3 correspond to those plotted at the \$70/m^3 nodes in Figure 3, "without and with" the market policy.

The extra costs to UHS (Table 1) are in the form of payments by them to subsidise tree planting in the SALTY sub-catchment (MCUS) to reduce that source of highly salty water yields. Indeed, in the SALTY scenarios we assume UHS offers a bonus of \$2M per GL of salty water yield reduction from MCUS, calculated to balance out reduced fresh dilution flows from the other sub-catchments. Such trees are likely not planted on salty ground in MCUS but on its higher grounds to minimise runoff and base-flow that otherwise mobilises the water reaching salty, waterlogged areas and seeping salt into the river system.

Table 1. Quantitative results of Upstream-Downstream Benefit Analysis driven by tree-product values of $\$70/m^3$ given combinations of two policy settings and two water quality assumptions for the MCUS sub-catchment (actual and 20 x more salty).

	Scenario Set	**1**	**2**	**3**	**4**
Strategic Conditions	**Policy** requiring new upstream tree-plantations to purchase permanent water entitlements?	**No**	**No**	**Yes** extended water market	**Yes** extended water market
	Water Quality from sub-catchment MCUS. The hypothetical SALTY case requires UHS to subsidise trees in MCUS	**FRESH** (actual) 557 ppm	**SALTY** (hyp.) 11,132 ppm	**FRESH**	**SALTY**
	PRIVATE NET BENEFITS With new upstream tree plantations (PV$ of change from present*****)	$639M	$688M	$192M	$220M
	PUBLIC BENEFITS (+ and -)				
	To **UHS** (Urban & High Security) (PV$ of change from present*****)	No loss	-$34M	No loss	-$30M
	To **IRR+S&D** (Irrigation and Stock & Domestic water users) (PV$ of change from present*****)	-$234M	-$236M	$138M	$151M
	To **Wetlands** (change from present, GL/year*****)	-154GL/year	-156GL/year	No loss	No loss
	Loss if valued at $0.5M/GL	-$77M	-$78M	No loss	No loss
	Loss if valued at $1.0M/GL	-$154M	-$156M	No loss	No loss
	Loss if valued at $1.5M/GL	-$231M	-$234M	No loss	No loss

***** PV$ = discounted present value (7%). Dollar values are ‘one-off total’; GL amounts are yearly flows
Source: compiled from $\mathbf{\$70/m^3}$ tree product results in Tables 5, 6, 7 and 8 of Nordblom *et al.* (2009)

3. Results

A Public-Private benefit analysis, as sketched in Figure 4, is plotted in Figure 5 with the results of Scenario Set 1 in Table 1 for the $\$70/m^3$ tree product value. Also plotted are results for the $40, $50 and $60 values derived from Nordblom *et al.* (2009).

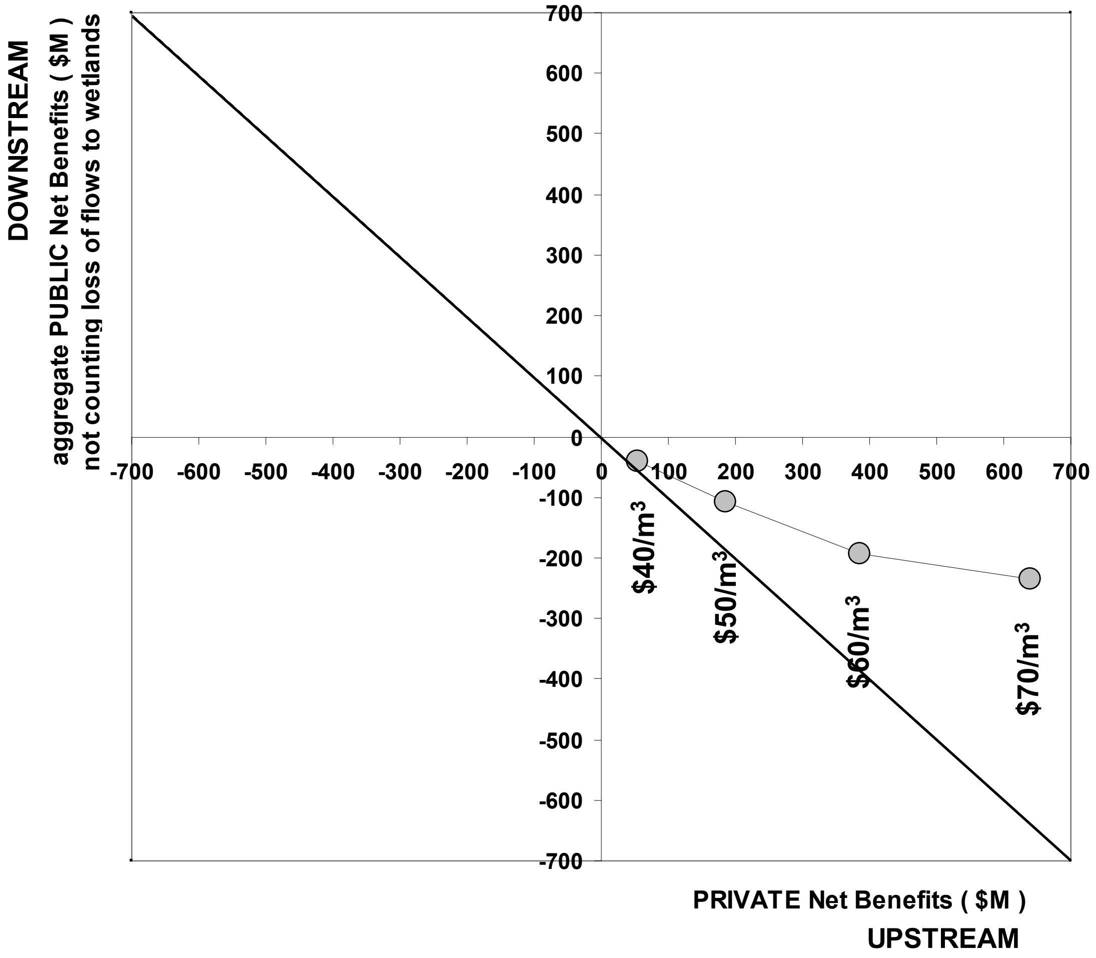

Figure 5. Effects of tree product values, \$40 to \$70/m^3. This example of Public – Private benefit analysis assumes no loss value for water flow reductions to wetlands. It also assumes relatively FRESH flows from all watersheds.

The Public-Private benefit analysis in Figure 5 aggregates public sectors (UHS, IRR+S&D and WL). The text and captions let the reader know this figure does not value any losses of water flow to the Wetlands. That is, by valuing only losses to economic sectors, it understates possible environmental water losses which may also be of concern to the Public. Figure 6, provides examples for a range of dollar values assigned to these Wetland water losses. It also contrasts FRESH and SALTY Scenario Sets 1 and 2, which depict results when water is taken by upstream private tree plantations without compensation to downstream water users.

The vision offered in Figure 6 is rather gloomy for the prospects of finding anything like a “win-win-win-win” solution. Because of the consistently negative Public outcomes juxtaposed with highly positive Private results for plantation investors, it is not immediately apparent that an efficient, equitable and environmentally friendly solution could be found.

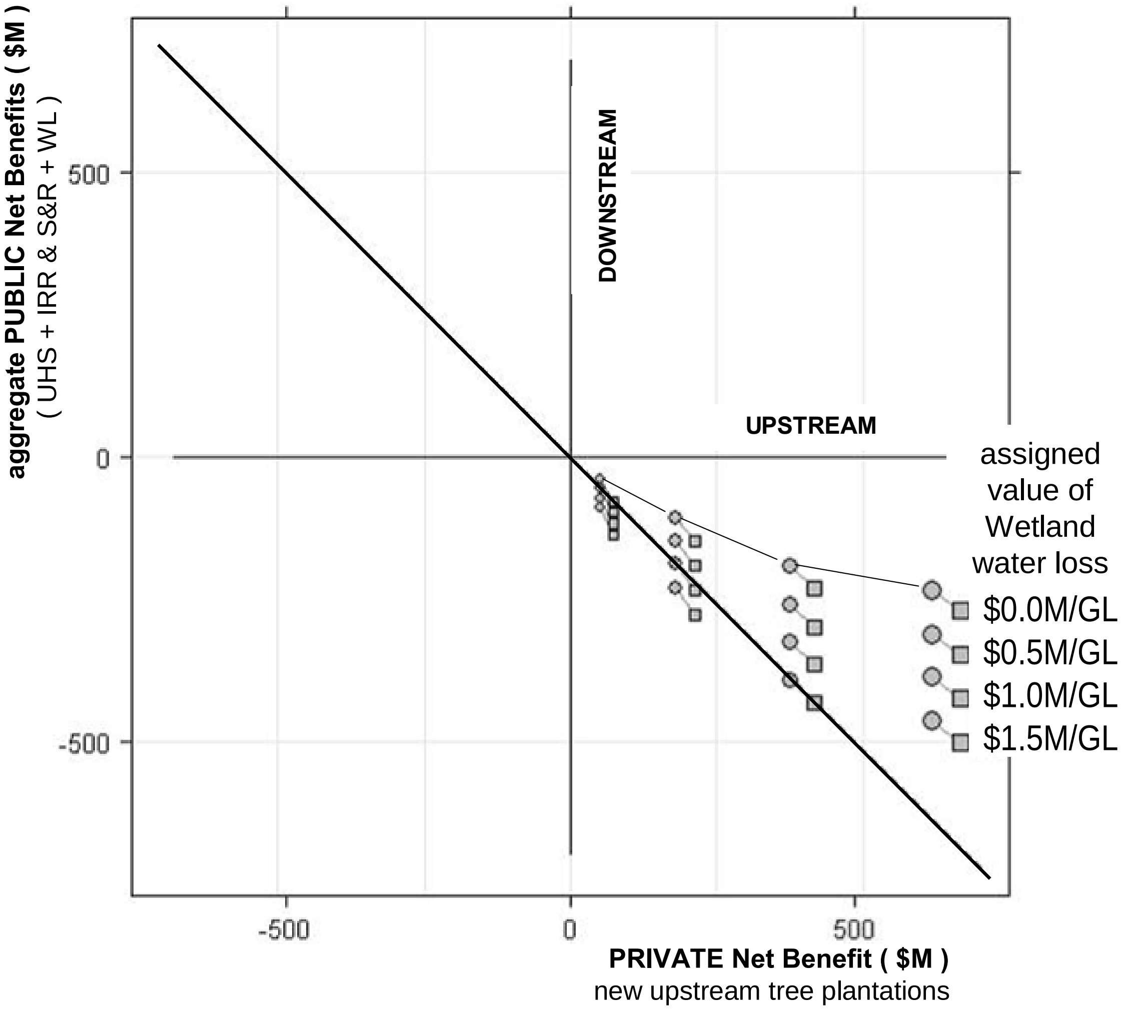

Figure 6. Results of Scenario Sets 1 and 2 (FRESH ● and SALTY ■) at four tree product values ($40 - $70/m^3) indicated by symbol size, and four assigned values for Wetland water losses (between $0 and $1.5M/GL). Note, the top string of FRESH aggregate Public - Private values here is the same as plotted in Figure 5.

Here (Figure 6) Private net benefits to new upstream plantations are plotted against aggregate Public net benefits (UHS, IRR+S&D, WL). The negative impacts of the SALTY scenarios for the Public are due to the need for UHS to subsidise tree planting for river salinity mitigation, while Private impacts for the tree plantations are positive.

Large increases in tree product values greatly magnify the Private incentives to plant trees, which induce reductions in Public benefits of comparable scales. Finally in Figure 6, the effect of changing the Public's valuations of permanent losses of water flows to Wetlands are shown. In these scenarios, assigning higher values per GL of reduced water flow to wetlands impacts only on the Public sense of lost Net Benefits; Private net benefits to new upstream plantations are unaffected. Notice that assigning a value of $1.5M/GL to the loss for flow to wetlands more than doubles the apparent aggregate Public Net losses, which could drive the public judgement from "No action (or flexible negative incentives)" toward simply "Negative incentives" for plantations; that is from area C to area D in Figure 4 (after Pannell, 2008, 2013). When aggregated, the Public Net Benefits not only reveal nothing about the relative changes among downstream sectors, but suggest incorrectly that all will benefit equally in the FRESH compared to the SALTY scenario.

When the Public net benefits are disaggregated (as in Figure 7, panels 1 and 2) it becomes clear that UHS is the sector bearing the greatest burden in the SALTY scenario, without or with the policy; but bears no burden in the FRESH scenarios. The increasing burdens of reduced Public benefits arising with increased tree product values are instead carried by the other sectors (IRR+S&D and WL).

Most striking however are the differences induced by the 'With Market' policy setting compared with "No Market'. The latter allows large amounts of water to be used for tree plantations, benefiting only the businesses associated with that sector, while imposing losses of comparable magnitude on the downstream interests (Figures 5, 6 and 7 panels 1 and 2). The 'With Market" scenario delivers something closer to a "win-win-win-win" for all four of our aggregate sectors: upstream tree plantations, UHS, IRR+S&D and the wetlands (Figure 7 panels 3 and 4). Each is better off, or no worse off than at present. There will be gains from trade, where downstream water entitlements, presently in low value uses, are sold to permit upstream tree plantations in locations wherever they can be most profitable as judged by those investing in them.

In Scenario Sets 1 and 2 outcomes for downstream IRR+S&D and WL sectors are strongly negative, that is fitting in sector C of Figure 4, which calls for flexibly negative incentives for upstream plantations. Such disincentives are present with the policy requiring new plantations to obtain water entitlements from downstream entitlement holders for the extra water to be taken from the river yields.

Scenario Sets 3 and 4 reflect the new balance in water use made possible by the policy. Less water would be taken by smaller areas of tree plantations, which are limited to those that are profitable even when paying for the extra water they take. With compensation to IRR+S&D by the market for water entitlements traded to upstream plantations, the results of the policy have shifted to sector B of Figure 4, indicating a 'win-win' outcome.

Notice that UHS suffers some loss under either policy setting when river conditions are SALTY. The level of Wetland water losses in Scenario Sets 1 and 2 would change in proportion to any increase in the value assigned to them, allowing for this matter of public concern to justify strong negative incentives to any new plantation investments. In Scenario Sets 3 and 4, the assumption has been that water flows to the Wetlands will be maintained at the present level, by allowing water entitlement trading only between downstream UHS and IRR+S&D sectors and upstream watershed sectors.

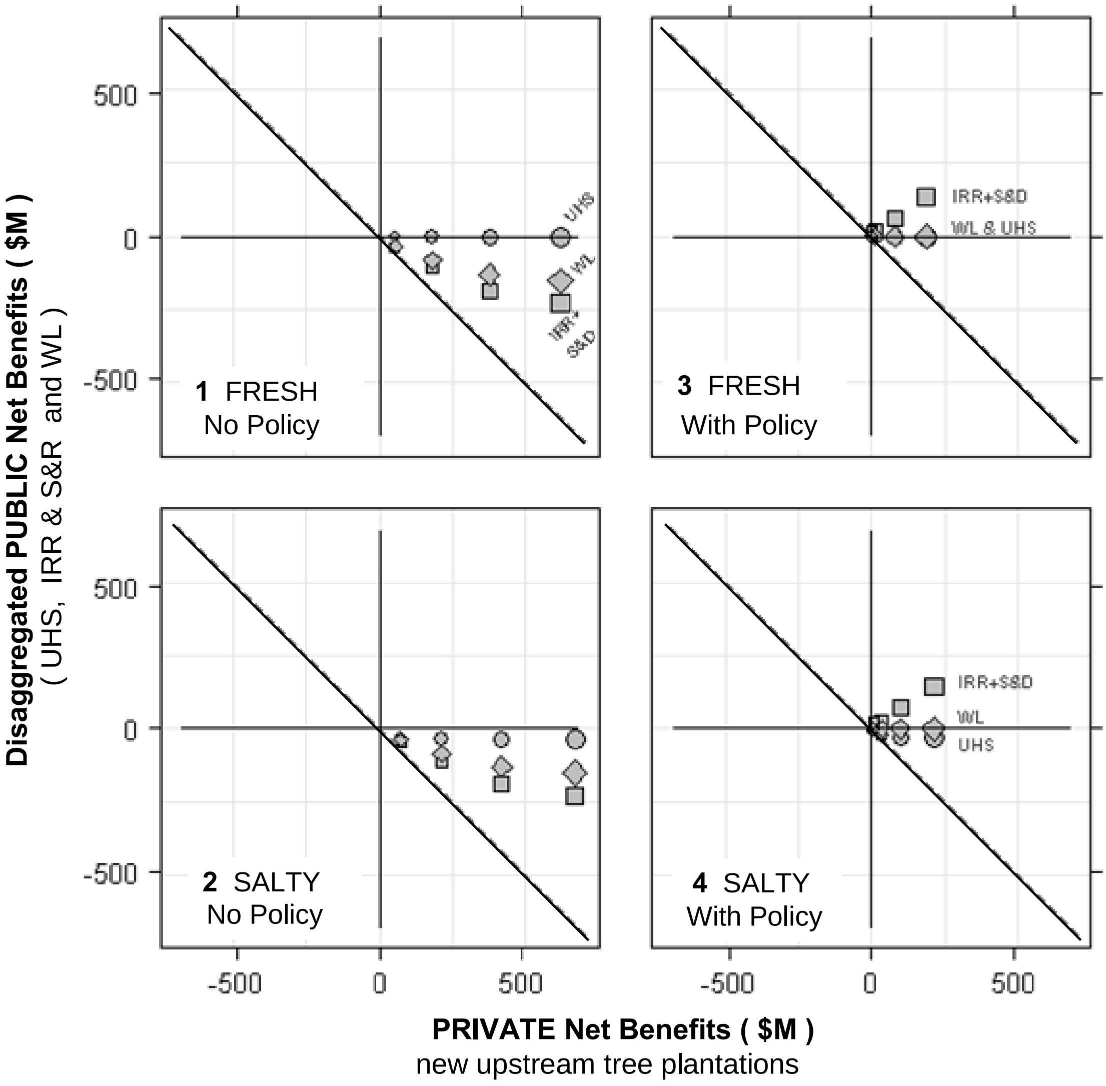

Figure 7. Public - Private benefit analysis under four Scenario Sets combining the two policy settings, the FRESH and SALTY settings and four tree-product values ($40 - $70/m^3) indicated by size of symbols. Public Net Benefits are disaggregated and distinguished as UHS ●, IRR+S&D ■, and WL ◆ with assignment of $1.0M/GL to any reduction in flows to Wetlands.

4. Discussion

In all scenarios, differences in equilibrium water distributions and economic impacts among the sectors are magnified strongly by increasing values of tree products.

Scenario Set 1 (FRESH catchment No water entitlements needed by plantations)
In this case, expansion of new plantation areas is limited only to the point at which marginal benefits to the planters exceed their direct and opportunity costs of taking land out of current uses to establish trees. They need not be concerned that expansion of tree plantations reduces stream flows to downstream parties, impacting negatively on the IRR+S&D sector and the wetlands. Because river flows are FRESH and UHS has high-security water entitlements, this sector is not directly impacted by expansion of upstream plantations. For the purpose of this non-market scenario we assume reductions in water flows to IRR+S&D and the wetlands are proportional to their

current shares of water use, as is roughly the practice for allocations to general security water entitlements.

Scenario Set 2 (SALTY watershed MCUS, No water entitlements needed by new plantations)
As in Scenario Set 1, expansion of upstream tree plantations is expected to be limited only by planters' assessments of their own benefits and costs. However, negative impacts on downstream parties are increased due to extra costs imposed on UHS. MCUS, the hypothetically very SALTY watershed upstream of UHS becomes an increasing threat to water quality when there are large reductions in FRESH dilution flows from upstream areas due to new tree plantations. The effect of this further salinity-mitigation tree planting in MCUS for the benefit of UHS is to reduce river flows more than those of Scenario Set 1.

Scenario Set 3 (FRESH catchment; Water entitlements required by new plantations)
Here, water supplies of UHS are guaranteed as in Scenario Set 1 and entitlements for the wetlands are also assumed to be protected. Any new permanent water yield reductions by upstream plantations must be offset by entitlements purchased from the downstream IRR+S&D sectors. Though this is far less profitable to planters than when water is free to them for the taking (Scenario Sets 1 and 2), it will still be quite profitable for the most productive plantation areas (high rainfall UC10 and UC8) to establish trees that will cover not only their direct and opportunity costs, but also the cost of purchasing permanent water entitlements for the extra water they are calculated to use.

Scenario Set 4 (SALTY watershed MCUS; Water entitlements required by new plantations)
Here, as in Scenario Set 2, to ensure adequate water quality, UHS faces even greater costs of subsidising tree planting and the purchase of permanent water entitlements for the SALTY sub-catchment. The SALTY MCUS is assumed to receive 600 mm annual rainfall and, as such, offers doubtful profitability for tree plantations in their own right. However, where trees can serve an important salinity-mitigation role if subsidised by parties dependant on river water for human consumption, this becomes a viable option. Trees would be planted profitably in the SALTY watershed to the point where their direct and opportunity costs are met, plus the cost of permanent water entitlements appropriate to the extra water taken by tree plantations in this rainfall area given help from UHS in meeting these costs.

Further detail is found in Figure 3 in relation to FRESH Scenario Sets 1 and 3, where the 'no market' case of free-for-all water is contrasted to the 'with market' case of negotiated purchase of water entitlements from IRR+S&D for new upstream tree plantations. The detail in Figure 3 is for all disaggregated sectors, indicating the distributions of water use, changes in economic surplus, and areas of new tree plantations under each of the tree product values in the FRESH catchment case.

Limitations to the analysis To keep this work tractable we made a number of abstractions from reality**:**

- **Long-run average rainfalls** We took estimates of long-run annual average water yields for the six watersheds, along with estimates of their land areas and rainfall values, ignoring the very large year-to-year variations in rainfalls. For example, in the Macquarie catchment the standard deviations of annual water yields from many sub-catchments exceed their annual averages (Nordblom *et al*., 2012c). Hydrology is simplified in our analysis where surface and base flows of water yield, minus that taken by new plantations in the watersheds, and minus allowances for evaporation and other transmission losses, is the remaining water yield carried by the Macquarie River to the various water-consuming sectors, Further evaporation and losses to effluent creeks occur in the catchment (see Figure 1). With our assumption that rainfall is the same every year we could ignore the vital water storage functions of the Oberon, Windamere and Burrendong dams.

- **Simplified watershed structure** We defined a limited number of watershed areas (six), each being an aggregation of heterogeneous land forms, rainfalls, and smaller sub-catchments; treating each of the six as if it is a simple unit offering a different prospect for water yields and tree plantations. Plantation growing potentials (in m^3/ha/year) were taken to be as discussed in Nordblom *et al*. (2009); functions of average annual rainfall. We assumed the proportions of different soil types and land uses are similar in each watershed to those in the 600 mm rainfall MCUS in regard to areas of remnant or other forest, poor pasture, improved sown pastures, and annual crop rotations areas. These are behind the pattern of opportunity costs for taking land out of present uses into new tree plantations; low for giving up poor pasture and highest for lands suited to crop rotations. In turn these conditions affect the estimated marginal value curves for water consumption by new plantations (Nordblom *et al*., 2006, 2009).

- **Simplified downstream water economy** Similarly, downstream sectors were defined in big chunks, as if UHS, IRR+S&D and wetlands each has a simple identity and a simple demand curve (marginal value). Each of these sectors in reality, of course, represents diverse elements and potentials. Initial water use by each was estimated from the report of Beale *et al*. (2000) and other sources documented in Nordblom *et al*. (2009). Like the real-life variations in water yields from the watersheds, water available to the downstream sectors varies through droughts and floods. None of this is accounted for in the present analysis.

- **Exogenous prices for tree products, and endogenous catchment-wide water balance** We assumed four externally set prices for tree products, though in reality these would shift with international and domestic supply and demand. We assumed simple costless application of a policy to extend the downstream water market to new upstream tree plantations, which heretofore had no institutional connection with a water market. In practice such an institution would be challenging to administer. Among the questions to be answered would be the appropriate exchange rates between passive continuous water take by tree plantations and the actively-adjusted and controlled water take by irrigation with pumps or gates (Nordblom *et al*., 2012c)

- **Costs of reductions in permanent water flows to wetlands** We assigned fixed values (from \$0 to \$1.5M/GL) for losses of water diverted from flowing to the Wetlands in order to have a monetary loss value which could be added

> to those faced by the other downstream sectors. Only marginally connected to the water market, managers of the wetlands have sometimes purchased temporary water entitlements in drought periods. That practice may wane with the environmental allowances for water under a Murray Darling Basin Plan. We assumed that under the policy new tree plantations must first obtain permanent water entitlements from the downstream commercial water consumers (IRR+S&D), a certain amount of water for the wetlands is quarantined from other uses. Where there is no such limitation on water taken by new tree plantations, we assume the subsequent shortfalls in water availability are experienced by all downstream sectors except UHS.

5. Conclusions

It is clear that the “No policy” scenarios 1 and 2 will be strongly favoured by land owners in the higher-rainfall watersheds who can consider establishing profitable tree plantations with no concern for downstream consequences. Downstream interests stand to be damaged, however. The imbalances appear to be correctable with the policy that new upstream tree plantations are permitted only after purchasing water entitlements from downstream parties holding them, as in scenarios 3 and 4, which also preserve water entitlements for the wetlands. It is obvious that such a means of compensation for voluntary surrender of water entitlements would be preferred by downstream interests compared to scenarios in which their water supplies further, slowly disappear.

An important lesson from our upstream-downstream analysis is that the level of aggregation most useful for presenting consequences under differing policies, prices and physical conditions is that which highlights the likely simultaneous effects on the most important constituencies. Greater aggregations (as Figure 2), or aggregation of sectors that directly compete for a vital resource, as do irrigation industries and large private tree plantations can mask the differential effects. Conversely, disaggregation (as Figure 3), though an essential step in calculations, should not be allowed to distract attention from the key constituencies who are affected by a policy change. By comparison, the Public-Private Benefit Framework can provide a perspective with clearer policy relevance.

The framework indicates ‘flexible negative incentives’ for plantations taking water when downstream sectors already hold entitlements. We show this flexibility extends as far as allowing UHS to subsidise new tree plantations in the SALTY MCUS watershed only for river salinity mitigation while paying for the extra water taken from other downstream water users. Flexibility is also present with the policy that new plantations may be established wherever they are deemed profitable by land owners individually in each watershed while paying for the water they take from the system at prices agreeable to downstream entitlement holders. This is how each exogenous tree product price defines a market equilibrium solution for all economic players. No regulatory quota is needed to set the areas of new plantations in advance for each watershed because the water market will solve the question most efficiently. Regulatory constraints, such as to quarantine some share of water for environmental purposes, can be added to limit trading to the remaining quantities.

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