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?

Tom Nordblom
Senior Research Scientist (Economics)
E H Graham Centre for Agricultural Innovation
(NSW Department of Primary Industries & Charles Sturt University), Wagga Wagga
Future Farm Industries CRC

John D. Finlayson
Formerly, NSW Department of Primary Industries, Orange
Presently, School of Agricultural and Resource Economics
University of Western Australia

Iain H. Hume
Soil Scientist
E H Graham Centre for Agricultural Innovation
(NSW Department of Primary Industries & Charles Sturt University), Wagga Wagga
Future Farm Industries CRC

Jason A. Kelly
Formerly, Salt Action Economist
NSW Department of Primary Industries, Tamworth

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Abstract
This study examines the use of water by existing downstream entitlement holders and their possible market interactions with upstream interests in new forestry plantations in the case of the Macquarie River Catchment, NSW. Demand for offset water to allow upstream plantation establishment is estimated as a function of tree product value and direct and opportunity costs in six sub-catchment areas with different rainfalls and locations with respect to urban and other high security water users (UHS). This upstream demand is aggregated with downstream demand for water. The aggregate supply of downstream water entitlements is posited in terms of marginal values to each of three sectors [stock & domestic (S&D), irrigation (IRR), and wetland (WL) areas] and their current entitlements. Assuming a fixed quantity of water entitlements, equilibrium quantities traded and the distributions of trade and associated surpluses are estimated given each of four stumpage values for tree products. This is done assuming four combinations of scenarios: with or without the policy that water entitlements must be obtained before establishing a tree plantation, and with or without one sub-catchment being very salty, the latter being a hypothetical case.

Assuming \$70/m^3 stumpage value for tree products, **without** the requirement to purchase offset water, total upstream surpluses due to extensive tree planting are projected to reach \$639M and \$688M in the FRESH and SALTY cases, respectively; downstream losses, not counting damages to the wetlands, are \$233M and \$236M (summing the IRR and S&D sectors) given uncompensated losses of 137 and 138 GL of water flow to them; further, uncompensated losses of 154 and 156 GL in annual river flow would be suffered by the wetlands. **With** the requirement to purchase water for establishing new tree plantations, upstream surpluses are projected to be \$192M and \$220M in the FRESH and SALTY cases, respectively, while downstream sums of IRR and S&D surpluses are \$138M and \$151M, given 90 and 97 GL of water traded upstream with no damages to the wetlands. Greater surpluses in the hypothetical SALTY cases are due to subsidies paid by UHS for tree planting to reduce water yields from the very salty sub-catchment, thereby lowering river salinity to acceptable levels for domestic use. Although sale of downstream water entitlements may just balance reductions in river flow due to new tree plantations, water delivery efficiency may be reduced and overhead costs increased for those not selling entitlements. Our analysis has not counted these costs.

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Senior Author's Contact:
Tom Nordblom, EH Graham Centre (NSW Dept of Primary Industries + Charles Sturt Uni), Wagga Wagga Agricultural Institute, Pine Gully Road, Wagga Wagga, NSW 2650 Australia
Telephone: (02) 6938 1627 Facsimile: (02) 6938 1809 tom.nordblom@industry.nsw.gov.au

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Table of Contents

List of Tables

List of Figures

Appendices

Acronyms and Abbreviations Used in This Report

CWCMA	Central West Catchment Management Authority, NSW
MMMC	Macquarie Marshes Management Committee
MMLC	Mid-Macquarie Landcare Group
MRFF	Macquarie River Food and Fibre
NSW DECC	New South Wales Department of Climate Change
NSW DPI	New South Wales Department of Primary Industries
SS	Scenario Set
Vic DPI	Victoria Department of Primary Industries

Weight, volume and concentration measures

1 L	1 litre = 1.057 US quart = 1 kg water at 4^oC
1 AF	(acre foot) volume of 66 ft x 660 ft x 1 ft = 43560 ft^3 = 1.234 ML
1 ML	Megalitre = volume of 10cm x 100m x 100m = 1000 m^3 = 10^6L
1 GL	Gigalitre = 810.68 acre feet
1 GL	1000 ML = volume of 100m x 100m x 100m = 10^6m^3 = 1 MCM
1 GL	roughly the volume of water required for one km^2 of cotton
1000 GL	volume of 1 km x 1 km x 1 km = 1 km^3 = 10^9m^3 = 1 BCM
1 ppm	concentration, one part per million = 1 mg/L = 1 milligram of total dissolved salts per litre
800 EC	World Health Organisation threshold of total dissolved salts for desirable drinking water quality
EC	electrical conductivity, widely used to express salinity concentration in water. One may convert 1µS/cm = 1 EC to mg/L (or ppm) with the factor of about 0.625; thus 800 = 800 EC = 500 ppm.
1M	one million = 10^6
$1m^3$	one cubic metre = 1000 litres
W,S	target combination of water-yield and salt-load from a catchment

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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.

Executive Summary

This study estimates the economic demand for water by new tree plantations in the 2.8 million hectare Macquarie Catchment in NSW. Trees displace current land uses in the upstream watershed and reduce river flow to downstream communities, agricultural industries and wetland areas. Economic gains are calculated for the upstream areas of new plantations as are economic losses for the downstream agricultural industries. We calculate economic surpluses for both upstream and downstream water users as a consequence of a policy requiring purchase of permanent water entitlements to permit establishing tree plantations.

- If tree products have stumpage values of $70/m^3, the model estimates 600,000 ha of new forest would be planted to earn a surplus of $639 million in net present value (NPV) but would transpire 483 GL more water annually, which would be unavailable for downstream users. The model apportions this loss of annual flow as 137 GL to agriculture, 154 GL to wetlands and 191 GL in riparian flow and evaporation. Estimated loss of agricultural NPV, due to lost water, is $233 million. A lower value of $40/m^3 for wood products limits forest expansion to 94,000 ha, earning a surplus of $53 million NPV and removing 106 GL of water from the river. Downstream agriculture's share of this loss would be in the order of 30 GL of water and $40 million in NPV.

- Modelling a policy requiring new upstream tree plantations to buy water entitlements from downstream entitlement holders showed no permanent trade of water upstream at a stumpage value of $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 support 78,000 ha of new forest upstream to earn a surplus $192 million in NPV, downstream agricultural sectors would gain $138 million in NPV from this sale of water; a total gain in NPV of $330 million.

- This study has, for the first time in NSW, quantitatively projected the impacts of a policy to require new upstream forest plantations to purchase the water they will use from downstream holders of water entitlements.

1. Introduction

The “environmental services” central to this study are the quantity and quality (volume and salt concentration) of water flowing from the upper parts of a catchment to rivers supplying water users in the lower catchment. This study integrates land use, water-yield, salt-load, and water use information in a bio-economic model to analyse the consequences of a policy that requires those establishing new forest plantations to first purchase water rights from those to whom river flows will be reduced. The study also considers the consequences of widespread expansion of tree plantations without such a policy to protect downstream urban and other high security water users, stock and domestic and irrigation water users, and wetland environmental assets.

Others (Adamson *et al*. 2007; Bell & Beare, 2000; Bell & Heaney, 2001; Bell, 2002; Bennett & Thomas, 1982; Characklis *et al*. 2005; Heaney *et al*. 2000, 2001a) have examined the costs of altering land use upstream and the downstream benefits and costs with respect to salinity and water yields. In their recent paper, “*Turning Water into Carbon: Carbon sequestration vs. water flow in the Murray-Darling Basin*”, Schrobback *et al.* (2009) called for more comprehensive research to describe how decreased water yields due to enlarged forested lands can be effectively accounted for under alternative water entitlement regimes. Our study specifically considers the prospects for establishing an extended water market to include new upstream tree plantations as water users.

Because water-yields and salt-loads from a watershed are positively correlated, reduced salt delivery to downstream users will be associated with reduced water flows to them, for a mix of benefits and costs. Against these must be compared the upstream benefits and costs of land-use changes. The above mentioned studies found mixed support for land use change, for example, calling for no action in Western Australia (Bennett & Thomas, 1982) or desalination engineering in Texas (Characklis *et al*. 2005).

Engineering solutions have been justified by the Murray-Darling Basin Commission and the Colorado River Basin Salinity Control Program where point sources of salinity have been identified. For example, pumping, multi-stage aquaculture and evaporation of salty groundwater to prevent its flow to the Murray River (MDBC, 2006; Kendall *et al*., 2004). Similarly, pumping and deep geological sequestration of salt brine below Paradox Valley prevents some 125,000 t of salt entering Colorado River each year (CRBSCP, 2007). The US$400M desalination plant at Yuma, Arizona, was built to ensure a salty tributary does not push the salinity of Colorado River flows to Mexico above the limits set by international treaty (USBR, 2007). By coincidence, that treaty guarantees Mexico will receive at least 1,850 GL of Colorado River water annually, with an upper limit on salt concentration. This is virtually the same volume (1,850 GL) and quality guarantees provided to South Australia by the MDBC (Kendall, 2005).

Historically, water shortages and water quality issues for cities have been solved by construction of aqueducts. Examples include the *Aqua Appia* in Rome (312 BC); the 550 km Kalgoorlie Aqueduct in Western Australia in 1903; the 360 km Los Angeles aqueduct from Owens River in 1913; and the 360 km South Australian pipeline from Morgan on the River Murray to Whyalla (1944). In this study we pose the hypothetical case of one of the tributaries below Burrendong Dam on the Macquarie River having very high salinity. In such a case, there is no technical reason the town of Dubbo in the Macquarie valley could not supply itself with fresh water via a shorter (85 km) pipeline directly from Burrendong Dam. The question would be one of economics, comparing the different options, including establishment of forests in the salty sub-catchment if there were a need; however there appears to be no salinity problem there now or in the foreseeable future that would justify such an option.

In Australia, there is growing interest in reforestation of lands cleared in the past century. Recovery of wildlife habitat and carbon sequestration, as well as job creation and growth in forestry products for domestic use and export may all be advanced by well-managed reforestation (Binning *et al*., 2002; Eco Resource Development, 2002; Garnaut, 2008; Gore & Melcher Media, 2006; Hall *et al*., 2004; Hawkins *et al*., 2007; iCAM, 2004; Lomborg, 2001, 2007; NRC, 2005; Punthakey *et al*., 2006; Robins & Marcar, 2007; van Dijk *et al*., 2004). Governments and private enterprise interests may combine to encourage tree plantations in the higher rainfall areas best suited to tree establishment and growth.

Little noted, however, is the fact that trees use far greater shares of the rainfall than other rainfed land uses such as annual pastures and cropping. That is, tree plantations may be expected to significantly reduce the yield of a watershed (Herron *et al*. 2003; Parsons *et al*. 2007; Zhang *et al.* 2001). This gives rise to a need to examine the upstream and downstream consequences of policies intended to encourage widespread reforestation. The downstream interests in watershed yields may include urban areas, stock and domestic water users, irrigation industries, and wetland environmental assets.

This paper aims to define the upstream and downstream elements of the balance of interests as a departure point for an anticipatory study exploring the possible consequences of encouraging large-scale reforestation. Examined also for the likely distributions of its consequences is the idea of an extended water market that could moderate the extent of reforestation and thereby mitigate the negative downstream impacts.

Severe water shortages in recent years highlight the need for policy development on water use/sharing in Australia (Challen, 2000). Zhang *et al*. (2003, 2007), Stirzaker *et al.* (2002), Evans *et al.* (2004), Gilfedder *et al.* (2009) and Wang *et al*. (2008) describe the biological and geophysical nexus of afforestation, water-yields and salt loads at catchment level, given that forest land-cover uses more water than any other land use. This provides a bio-physical foundation upon which we build a bio-economic model for considering the economic (efficiency), social (equity) and environmental service aspects linking upstream land uses, including new forestry plantations, and downstream uses of water.

Bennett & Thomas (1982) documented their large Western Australian study, which aimed to economically optimise land use change for water-yield and salt-load targets for several catchments in which expansion of forestry was an option. Adamson *et al*. (2007) have reported their state-contingent study of land use in the Murray Darling Basin, showing results for both sequential and global optimisation. In the latter, a simultaneous solution is found for land uses in all areas to maximise overall wealth from irrigation in the Basin and, as a by-product, ensure acceptable water quality for Adelaide near the bottom of the catchment. In the sequential case, land uses nearest the sources of water (upstream areas of the various sub-catchments) are optimised for highest local irrigation wealth; remaining water is optimised for highest wealth in the next areas downstream and so on to the lowest part of the Basin. A consequence of sequential optimisation is minimum stream flows to the lower catchment and salinity concentrations too high for either cropping or drinking. Adamson *et al.* (2007) did not consider upstream forestry plantations as potential water users in their sequential or global solutions. Schrobback *et al.* (2009) extended the model of Adamson *et al.* (2007) by including new forests as a carbon sequestration mechanism under a Carbon Pollution Reduction Scheme.

The present study explicitly considers upstream forestry plantations as large potential water users, as did Bennett & Thomas (1982). And, like Adamson *et al*. (2007) and Schrobback *et al*. (2009), we contrast sequential water rights (a) where upstream users have priority rights with no regard for downstream losses, with (b) where water rights are settled by a market ("globally") within a larger catchment. In the latter case we use the South Australian example where new forestry plantations in the south-east of that state are permitted only when water rights are purchased from current entitlement holders (Schonfeldt, 2005; DWLBC, 2005). In our case we focus on the Macquarie catchment, NSW.

This study aims to shed new light on several questions:

- Could policies and programs that encourage large-scale forestry expansion have the unintended effect of reducing the flows of important fresh water sources in Australia, the driest continent?
- Should this happen, would the most disadvantaged be general-security water entitlement holders (irrigators, stock & domestic users and vulnerable wet-land environmental assets)?
- Would urban and other high-security users receive saltier water supplies with high mitigation costs? And …
- Could a policy requiring purchase of existing water entitlements to permit establishment of forestry plantations help promote the most efficient allocations of this finite resource among competing users?

The 'Methods' section describes an example catchment and its upstream and downstream economic sectors, develops estimates of the marginal values of water use by tree plantations, assumes marginal values of water use by irrigators (IRR) and stock & domestic (S&D) water users, and develops a framework for estimating the distributions of water use and economic surpluses given supply and demand for water.

These distributions are estimated given four values for tree benefits, \$40 to \$70/m^3 of wood product, in four sets of scenarios defined as combinations of two policy-regulatory settings and two salinity settings; with and without the policy that new tree plantations require the prior purchase of water entitlements, and with and without the hypothetical case of a very salty sub-catchment existing upstream of the urban and other high security water use sector (UHS).

The 'Results' section summarises our quantitative estimates of the distributions of water use and economic surplus given supply and demand for water among the sectors. We generate estimates of upstream surpluses and the economic losses suffered by the downstream IRR and S&D sectors, as well as losses of flow to the wetlands, due to unilateral and uncompensated reductions of upstream water yields. We also generate estimates of the consequences of the policy requiring purchase of water rights to permit establishing new tree plantations, in terms of upstream and downstream economic surpluses and quantities of water traded.

The 'Discussion and conclusions' section draws out the practical meaning of our results and lists some caveats on their interpretation within and beyond the study catchment. The section summarises how our findings follow from general premises and the particular characteristics of the study catchment.

The present study provides the background analyses, the quantitative setup and analysis of supply and demand for water to anticipate the consequences of increased profitability of tree plantations with regard to the distribution of water and the impacts on economic surpluses and losses upstream and downstream … for FRESH and SALTY scenarios, with and without the policy and regulation that tree plantations are permitted only when water entitlements have been purchased to cover the extra water use.

2. Methods

This section describes a sequence of data assembly, analysis and intermediate results followed by higher-level assembly and analyses. It:

1. Describes an example catchment having upstream and downstream lands with different mixes of potentials due to differences in resource bases: rainfall, soils, infrastructure, etc;

2. Estimates of the gross marginal earning potentials of water use by tree plantations in the upstream sub-catchments, before costs;
3. Estimates marginal values of water for tree plantations, after counting direct and opportunity costs;
4. Assumes marginal values of water use by irrigators (IRR) and stock & domestic (S&D) water users starting with the price of permanent trades of water entitlements;
5. Develops a framework for estimating the distributions of water use and economic surplus given supply and demand for water among sectors of the catchment …
    - with four levels of plantation earning-power, from \$40 to \$70/m^3 tree product values across four rainfall zones, with differing productivities;
    - with and without a policy where permits to establish tree plantations require the purchase of water entitlements;
    - without and with very salty conditions in one of the sub-catchments ... which we call our FRESH and SALTY scenarios.

2.1 An example catchment having upstream and downstream lands with different mixes of potentials

The subject area for this study is the Macquarie Catchment in the Central West of New South Wales. The catchment is represented abstractly here as a series of blocks of land that yield water, salt and economic returns, depending on the physical resource base, including rainfall, and the uses the land is put to. The blocks reflect the resource sets that are available to the various economic interests. These are shown in the schematic map (Figure 1) as upper-catchment (UC10, UC8, UC6), and mid-catchment areas (MCU, MCUS and MCD), along with the downstream water consumers: urban and other high security users (UHS), and the general security water users, being irrigation interests (IRR), stock and domestic water users (S&D) and wetland areas (WL).

Water flows from the upper to the lower catchment and connects these blocks. Sub-catchment surface areas (km^2), average rainfall, water-yield and salt-loads are given in Table 1 along with roughly estimated current land use configurations. Due to evaporative and transmission losses between the five sub-catchments upstream of UHS, and the need for a consistent ‘metric’ for upstream - downstream water trade, we have reduced the 'apparent' upstream water yields from Table 1 to express 'deliverable' upstream water yields in Table 2.

Under current and foreseeable conditions the saltiest sub-catchment, MCUS, actually causes no water quality problems for downstream water users because of fresh dilution water from the other upstream sub-catchments. For the purpose of this study, one of the scenarios supposes the salinity of water flowing from MCUS to be 20 times greater in concentration than actual. We call this the 'SALTY' scenario. Such a high concentration of salt would be sufficient to cause water quality problems for UHS, particularly if there were reductions in the fresh dilution flows of water from the upper catchment due to widespread establishment of new tree plantations (Alexander & Heaney, 2003; Thomas & Cruikshanks-Boyd, 2001; Wilson & Laurie, 2002).

Under the 'SALTY' scenario and under current conditions, which we call the 'FRESH' scenario, any reductions in water flows from the upper and mid-catchment areas would negatively impact the downstream general security water, that is, the stock and domestic, irrigation and wetland environment water uses (Burton & Thurtell, 2005; CCC-CRC, 2007; Fazey *et al*., 2006; Finlayson, 2008; Hope, 2003; Humphries, 2000; Hajkowicz & Young, 2005). We assume the negative impact for these water users would be due to reduced water volumes, whereas the increases in salt concentrations reaching them under the SALTY scenario would cause no ill effects, remaining low enough for livestock and cropping.

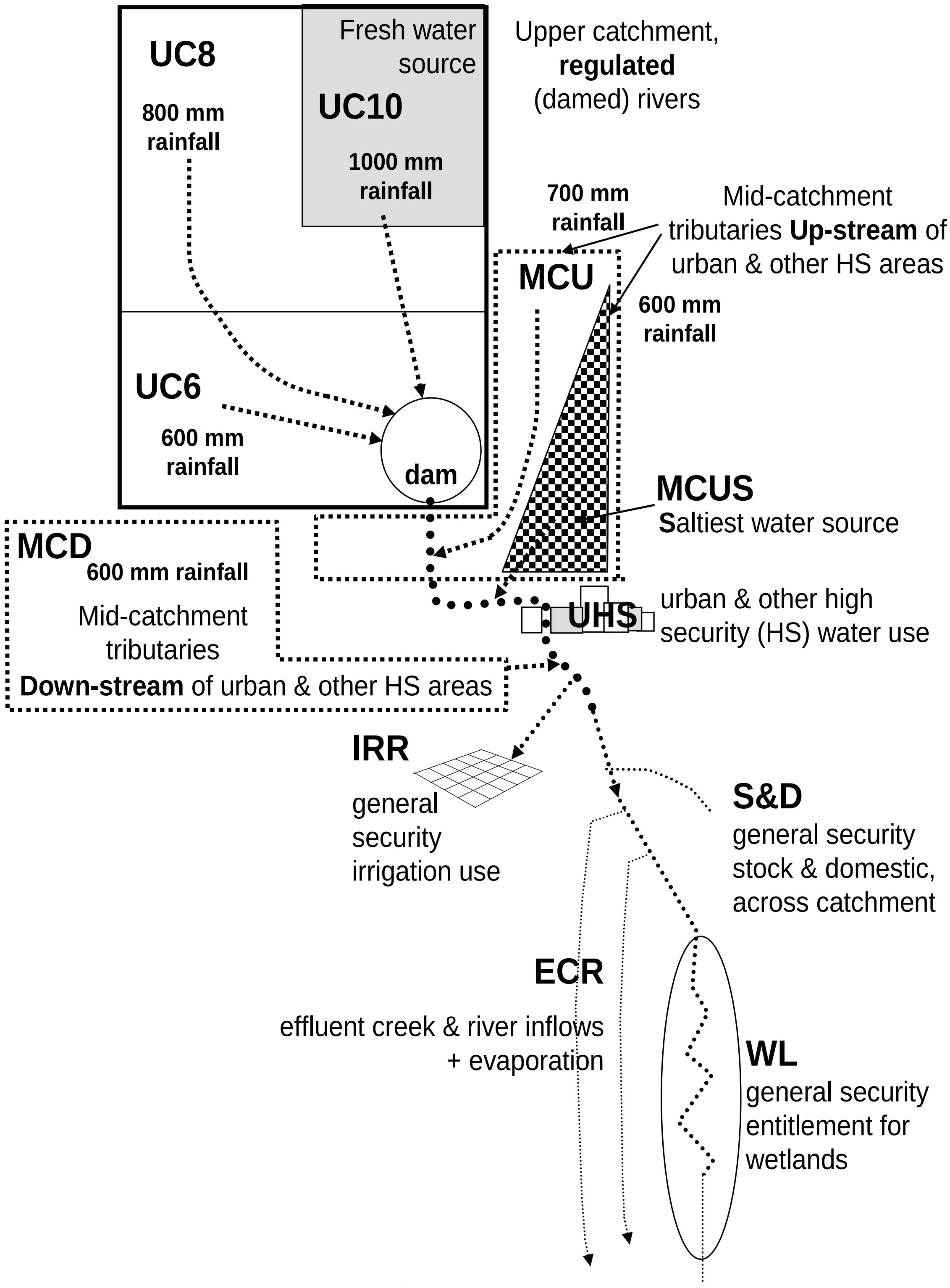

Figure 1. Schematic map of study area identifying key water sources by rainfall zone, salinity and location with respect to key classes of water users

Table 1. Initial conditions assumed for hydrology, salinity and land use in the cascade of water sources (+) and sinks (-) in example catchment[A]

Cascade sequence[A]	Catch-ment area (km^2)	Ave. rain-fall (mm)	W water-yield (use) (GL/yr)	S Salt-load (1000t/yr)	Salt conc-entra-tion (ppm)	Dryland cropping (%)	Cotton irrigation (%)	Irrigation (trees, other) (%)	Poor pasture (%)	Improved pasture (%)	Forest / woodland (%)	Forest plantation (%)
	current hydrologic parameters					current land use[B]						
Upper catchment												
+ UC10	2830	1000	264	32	121	30	-	-	30	15	20	5
+ UC8	5575	800	600	80	133	10	-	1	50	16	21	2
+ UC6	5575	600	450	68	151	10	-	2	50	16	21	1
Mid-Catchment **Up-stream** of urban, high-security water users:												
+ MCU	3100	700	154	38	247	35	-	1	38	10	15	1
+ MCUS	1900	600	51	27	529	25	-	-	40	9	25	1
Sum of above sources	18980	-	1519	245	161							
- evaporation losses	-	-	(60)	(0)	-	-	-	-	-	-	-	-
-Transmission losses	-	-	(315)	(51)	161	-	-	-	-	-	-	-
Sum, net of above losses	-	-	1144	194	170	-	-	-	-	-	-	-
- UHS (Urban & other high security users)	-	-	(27)	(5)	170	-	-	-	-	-	-	-
+ MCD Mid-Catchment, **Down-stream** of urban, high-security users	6500	600	150	46	307	20	-	2	40	18	18	2
General Security users												
- IRR irrigated areas	500	-	(333)	(62)	185	-	82	11	-	7	-	-
- S&D stock & domestic	-	-	(27)	(5)	185	-	-	-	-	-	-	-
- WL wetland areas	2000	-	(405)	(75)	185	-	-	-	-	-	-	-
- ECR effluent creek & river inflow + evaporation losses	-	-	(502)	(93)	185							

[A] See Figure 1 for schematic map of example catchment, and Appendix Tables 1, 2 and 3 for source references

[B] Visual estimates of the distributions of current land uses in the different sectors were made by the authors with 'Google Earth' satellite images and are only roughly indicative. The apparent similarities in proportions of land uses among the sub-catchment areas justified important simplifications in our quantitative analyses.

Table 2. Mass balance of Water[A] and Salt[B] deliverable downstream given current FRESH conditions, as in Table 1, and for the hypothetical 'SALTY' scenario, which assumes a very salty sub-catchment (MCUS)

			Delivered downstream with current conditions			**Hypothetical case (C) with Salt x 20 from MCUS**		
	Catchment area	Mean annual rainfall	W	S	concentr.	W	S	concentr.
	km^2	*mm*	*GL*	*1000t/yr*	*S t / GL* (ppm)	*GL*	*1000t/yr*	*S t / GL* (ppm)
Upper catchment tributaries								
+ UC10	2830	1000	199	25	127	199	25	127
+ UC8	5575	800	452	63	140	452	63	140
+ UC6	5575	600	339	54	159	339	54	159
Mid-Catchment tributaries upstream of urban, high-security water users								
+ MCU	3100	700	116	30	259	116	30	259
U Sum of tributaries upstream of UHS except for MUCS			**1106**	**173**	**157**	**1106**	**173**	**157**
+ MCUS (salty)	1900	600	**38**	**21**	**557**	**38**	**428**	**11132**
Sum upstream of UHS			**1144**	**194**	**170**	**1144**	**600**	**525**
- UHS (Urban & other high security user) consumption:								
			-27	-5	170	-27	-14	525
+ MCD Mid-Catchment tributaries, Down-stream of urban, high-security users:								
	6500	600	150	46	307	150	46	307
Sum, net of above (+, -)			**1267**	**235**	**186**	**1267**	**632**	**499**
General Security users downstream of UHS:								
- IRR irrigated areas	500	-	-333	-62	186	-333	-166	499
- S&D stock & domestic	-	-	-27	-5	186	-27	-13	499
- WL wetland areas	2000	-	-405	-75	186	-405	-202	499
- ECR effluent creek & river inflow & evaporation losses	-	-	-502	-93	186	-502	-250	499

[A] water yields of the upper and mid-catchment tributaries upstream of UHS were divided by a factor of 1.328 to account for transmission and evaporative loses

[B] salt loads from the upper and mid-catchment tributaries upstream of UHS were divided by a factor of 1.263 to account for transmission loses; evaporative loses of water, however, leave the salt in the river. See Appendix Table 1b for loss estimates

The different policy settings explored with this simplified construction of the catchment under 'current' FRESH conditions and hypothetical SALTY conditions are given in Table 3.

Table 3. Factorial design of this study, giving all combinations of four tree product values, with and without Policy E (requiring purchase of water entitlements to permit establishment of new plantations), and without and with (**C**) a very salty sub-catchment, MCUS

	scenario code (P,E,C)	given tree product values: **P**	Policy **E**	High salinity concentration **C**
Scenario Set 1	(70,0,0)	$70/m^3	0	0
FRESH	(60,0,0)	$60/m^3	0	0
	(50,0,0)	$50/m^3	0	0
	(40,0,0)	$40/m^3	0	0
Scenario Set 2	(70,0,1)	$70/m^3	0	1
SALTY	(60,0,1)	$60/m^3	0	1
	(50,0,1)	$50/m^3	0	1
	(40,0,1)	$40/m^3	0	1
Scenario Set 3	(70,1,0)[A]	$70/m^3	1	0
FRESH	(60,1,0)	$60/m^3	1	0
	(50,1,0)	$50/m^3	1	0
	(40,1,0)	$40/m^3	1	0
Scenario Set 4	(70,1,1)[A]	$70/m^3	1	1
SALTY	(60,1,1)	$60/m^3	1	1
	(50,1,1)	$50/m^3	1	1
	(40,1,1)	$40/m^3	1	1
Where:				
P = $40/m^3	indicates policy/market conditions not especially favouring tree plantations, stumpage value is $40/m^3 of wood product			
P = $50-$70/m^3	indicates policy/market conditions favouring tree plantations such that stumpage value is $50/m^3 to $70/m^3 of wood product			
E = 0	indicates no requirement to purchase water entitlements			
E = 1	indicates enforcement of policy that new tree plantations are permitted only when water entitlements have been purchased to compensate for predicted reductions in water yields			
C = 0	indicates no very salty tributary exists (this is the current case in the study area)			
C = 1	indicates existence of a very salty tributary upstream of the urban and other high security (UHS) water users (allowing UHS to contract to top-up the benefits of tree plantations for MCUS to reduce its salty water yields)			
A	indicates the two scenarios with $70/m^3 tree product values and having market solutions studied further with 'experimental economics' methods in Nordblom *et al*. (2009b)			

2.2 Estimates of the gross marginal earning potentials of water use by tree plantations in the upstream sub-catchments, before costs

The demand for water entitlements by upstream land owners is estimated for a range of 'stumpage values' for when new forest plantations are harvested ($\$/m^3$). Upstream land owners face both direct and opportunity costs when establishing tree plantations. These costs are subtracted from the benefits of plantations. We estimate these benefits and costs for each of six sub-catchments of different size, distributed over four rainfall zones. The purchase of water entitlements from downstream water users is added to the costs of establishing a plantation and the displacement of other land uses if this is required by regulation.

For the scenarios presented in this paper, the units of trade are permanent entitlements to one **GL** (one Gigalitre equals 1000 Megalitres or one million m^3) of annual flow of water. These translate to differing land areas under tree plantations depending on the mean annual rainfalls of the respective sub-catchments. We assume wood yields increase in direct proportion to water use and both are linear functions of mean annual rainfall over the range of 600 to 1000 mm (Table 4). Given these values, water-yield to the river is reduced one GL by 774 ha of new tree plantation in the 1000 mm rainfall zone. This compares to 1675 ha of new trees in the 600 mm zone.

Table 4. Parameters for wood production and water use by rainfall zone

Mean annual rainfall (mm)	MAI* in wood product (m^3/ha)	Water use ML/ha of new tree plantation**	Land / Water use ratio of plantation (ha/GL)
600	8.0	0.597	1675
700	10.5	0.784	1276
800	13.0	0.970	1031
900	15.5	1.157	864
1000	18.0	1.343	744

* MAI = mean annual increment as a linear function of mean annual rainfall in the study area

** values for 600-700mm areas approximated from South Australian Department of Water, Land and Biodiversity Conservation approval process for plantation forestry**:** **http://www.dwlbc.sa.gov.au/water/1overview/comercial_forestry/index.html**

The net present value (NPV) per hectare of tree plantation benefits is taken to be the MAI in a particular rainfall zone times the stumpage value per m^3 of tree product, times 30 years, discounted at 7%. The stumpage value is that received by the plantation owner after all harvest, transport and other charges are subtracted from the wood value at the mill. For illustration here (Figure 2), stumpage values of \$40 to \$70/m^3 are shown.

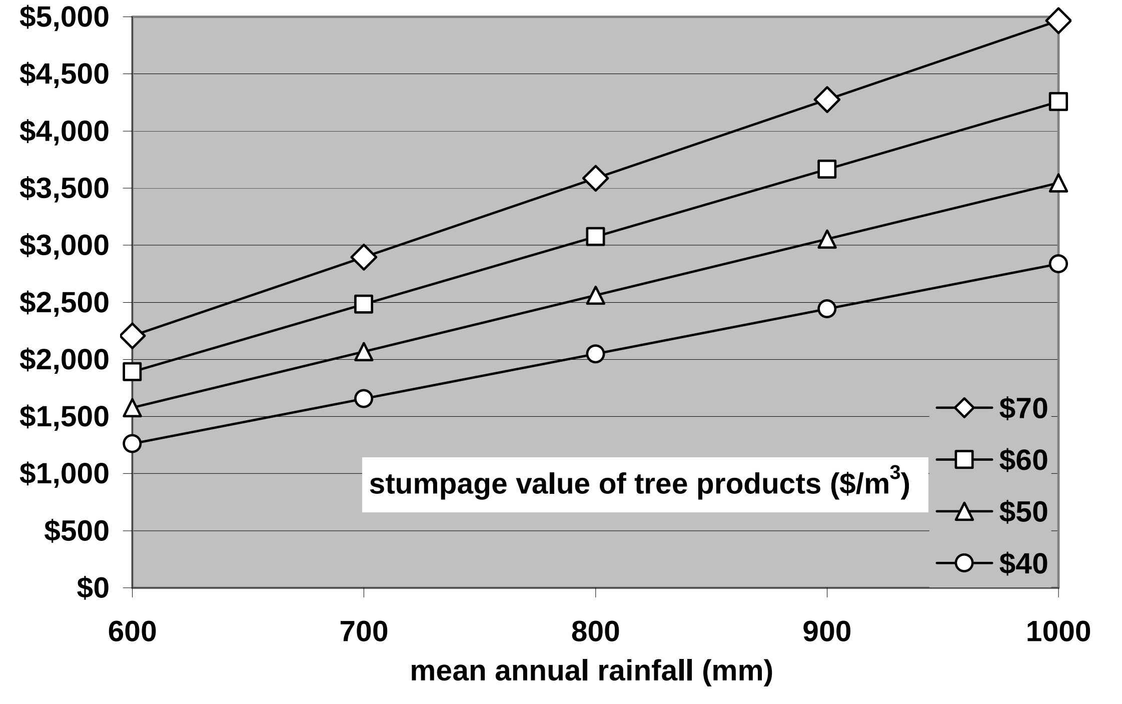

Figure 2. NPV of tree product income (\$/ha) by rainfall zone without establishment or opportunity costs or purchase costs of water entitlements

The NPV of tree plantation benefits per GL of water may be calculated for each rainfall zone by multiplying the above estimates of NPV of plantation benefits per hectare (\$/ha) by the land / water use ratio of tree plantations (ha/GL) for each rainfall zone (Table 1). Our assumptions on water use and productivity are balanced such that the NPV of new tree plantation benefits per GL of water used is constant across the ranges of water use and across rainfall zones. From the gross NPV of benefits for land owners per GL of water for tree products, must be subtracted the direct and opportunity cost of establishing tree plantations (\$M/GL of water use, see Figure 4 and Figure 5).

'Direct costs' include those of land preparation, rooted tree stock for planting, the planting operation itself, material and application costs of fertiliser, insecticide and weed control as necessary, and fencing; these costs may total \$1,200/ha.

'Opportunity costs' are the net income losses due to giving up the current use of the land on which the tree plantation is to be established. If it is poor grazing land the opportunity cost will be lower than for good grazing land and far lower than that of productive farm land; these costs need to be considered where a newly established tree plantation excludes other productive uses.

Derivation of Figure 4 began by summing the water-yields and salt-loads of clusters **a**, **b** and **c** in Figure 3 (identified as the 2nd, 3rd & 4th groundwater salinity classes in the Little River Catchment by Evans *et al.* 2004). Our linear programming analysis solved for least-cost land use changes to meet specified targets for changes in water and salt yields of the three classes of salt-source land (Figure 3). Our analysis assumed that all present forest areas will be retained while new forest plantations, even if not profitable in themselves, could be established to use water strategically for salinity mitigation. It is technically feasible to increase water-yields and salt loads by shifting land use away from perennial pastures and expanding annual pastures and cropping. However, our analysis focuses on the water-yield reducing effects of tree plantations.

2.3 Estimating marginal values of water for tree plantations, after counting direct and opportunity costs

Nordblom *et al.* (2006; 2007a,b; 2008a,b) explored the idea of minimising the direct and opportunity costs of reducing salt loads in streams through strategic changes in land use. A conclusion of that work, demonstrated again recently by Nordblom *et al.* (2009a, 2010), is that the least-cost pathway for reducing salt-load entering a stream from a catchment reaches an upper limit with new tree plantations replacing other land uses.

New analyses by the authors for Little River Catchment in the Macquarie Valley, NSW, have allowed us to plot such least-cost land use changes (Figure 3). The aggregated raw economic results (of clusters **a**, **b** and **c** in Figure 3) from our linear programming analyses for decreasing salt-loads and water-yields were smoothed by fitting a cubic function. The smoothed results were further adjusted to match in scale our catchment-wide water-yield and salt-load data for MCUS. They were adjusted further for evaporative and transmission losses to represent ‘deliverable’ water yields from MCUS (Figure 4).

The direct and opportunity costs of tree planting will depend on the land uses being displaced. Inspection of satellite images of upstream areas compared with Little

River, a well-studied sub-catchment (Evans *et al*. 2004; Finlayson *et al*., 2007, 2010; Hall *et al*., 2002; Murphy & Lawrie 1998; Nordblom *et al*. 2006) allowed estimates of various proportions of land uses in the other sub-catchments (Table 1). Lacking better estimates, these land use proportions appeared sufficiently similar to justify simply scaling up the plantation cost curve (Figure 4), 'stretching' it horizontally to match the relative ranges of water yield change in the other sub-catchments. The plantation cost curve, based on the lowest (600mm) rainfall zone, was adjusted downward for the higher rainfall zones, which need fewer hectares of plantation per GL of water used.

For example, we assume UC10 in the 1000mm rainfall zone requires only 744 ha of new plantation to reduce water-yield to one GL below the base level from that area, while in 600mm rainfall zones (such as UC6, MCUS and MCD) would need 1675 ha of new plantation to have the same effect (Table 4). The UC10 plantation cost curve, therefore, is reduced by a constant equal to the cost of the first GL unit from MCUS minus 744/1675 of that same cost. Thus the cost curves for the 800 and 700 mm zones (UC8 and MCU) are also adjusted downwards by constant amounts according to the areas of tree plantations needed in each to reduce water-yields by one GL relative to that of MCUS.

We assume the first GL of water used by new plantations in MCUS will have direct and opportunity costs on the order of $2M/GL while the highest-cost plantations will exceed $4.5M/GL in direct and opportunity costs. The latter cost figure is well above the highest NPV of plantation benefits we consider (Figure 2), so the cost curve will exceed or cut the benefit line in every case, providing a hard limit to the expansion of such water use. However, in some cases this limit is very high.

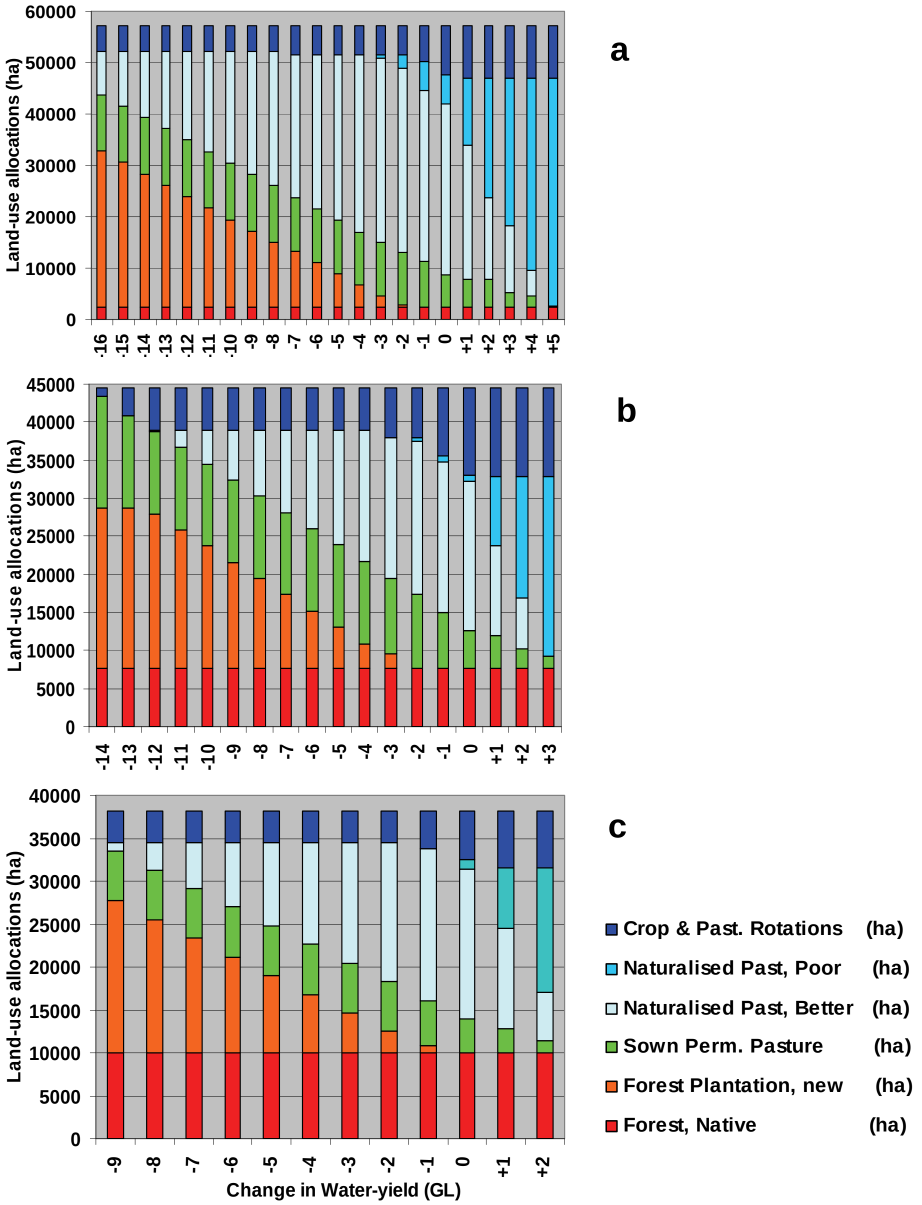

Figure 3. Least-cost land use changes to alter water-yields from three parts (**a, b, c**) of Little River. Present land use is shown at the zero-change point in each case.

Subtracting the least-cost sequence of adding tree plantations to the landscape (Figure 4) from the benefits of plantations (horizontal lines) to landowners in this 600 mm rainfall area allows us to express the marginal values of water used by plantations; that is, their demand for water in \$M/GL. For this, the horizontal axis may be labelled "water use by plantations, GL/year" with the vertical axis being "marginal value of water to plantation owner, \$M/GL" (Figure 5).

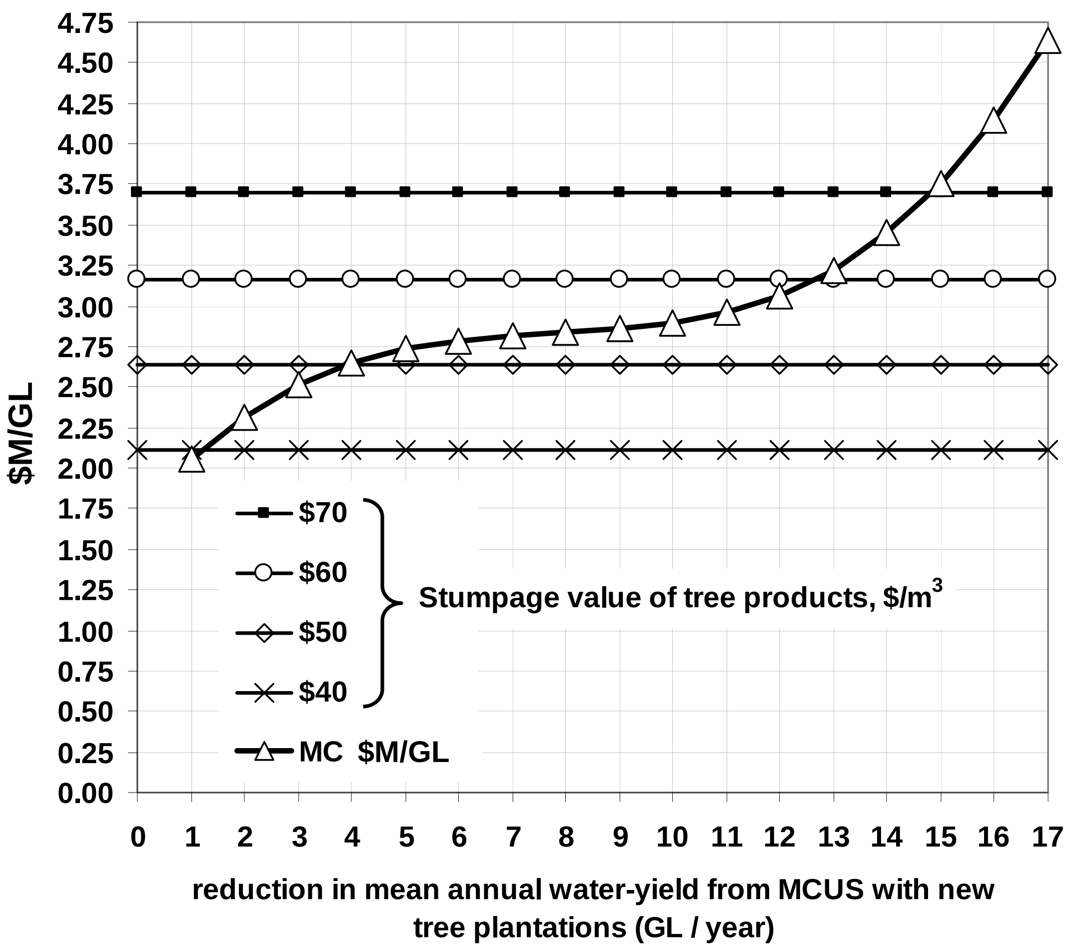

Figure 4. Marginal NPV of tree product income ($M/GL) given stumpage values, before opportunity and establishment costs or purchase costs of water entitlements. **MC** = marginal opportunity and establishment costs of tree plantations in MCUS ($M/GL). This is the marginal direct and opportunity costs of establishing and maintaining new tree plantations, estimated as a monotonic increasing cubic function of reduced mean water-yield ($M/GL), based on aggregated raw linear programming results for MCUS associated with land classes **a**, **b** and **c** in Figure 3. Initial increases in cost are due to displacement of lower to higher quality pastures; marginal costs increase little over the mid range as better quality pastures are displaced by trees; finally, marginal cost rise significantly as trees displace profitable arable cropping.

The MCUS sub-catchment, with its 600 mm annual rainfall, is among the places in the catchment where tree plantations will be least profitable in their own right. What makes it most interesting as a target for tree planting is in the hypothetical case that it is a very salty area in which downstream urban interests will pay to reduce its water-yield and high salt-load. In that case, as we shall see, the downstream subsidy to plant trees will appear to be added vertically to the marginal value curves (Figure 5) of land owners in MCUS, as illustrated in Figure 6.

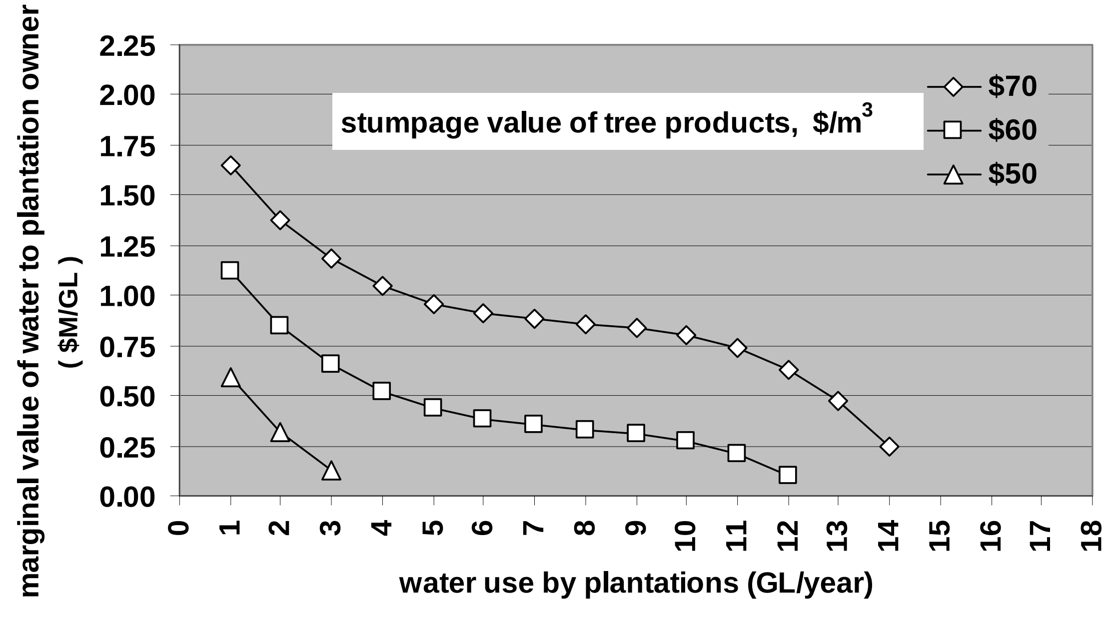

Figure 5. Upstream (MCUS) demand for new tree plantation water given different values of tree products, under Scenario Set 1, without special subsidisation from UHS

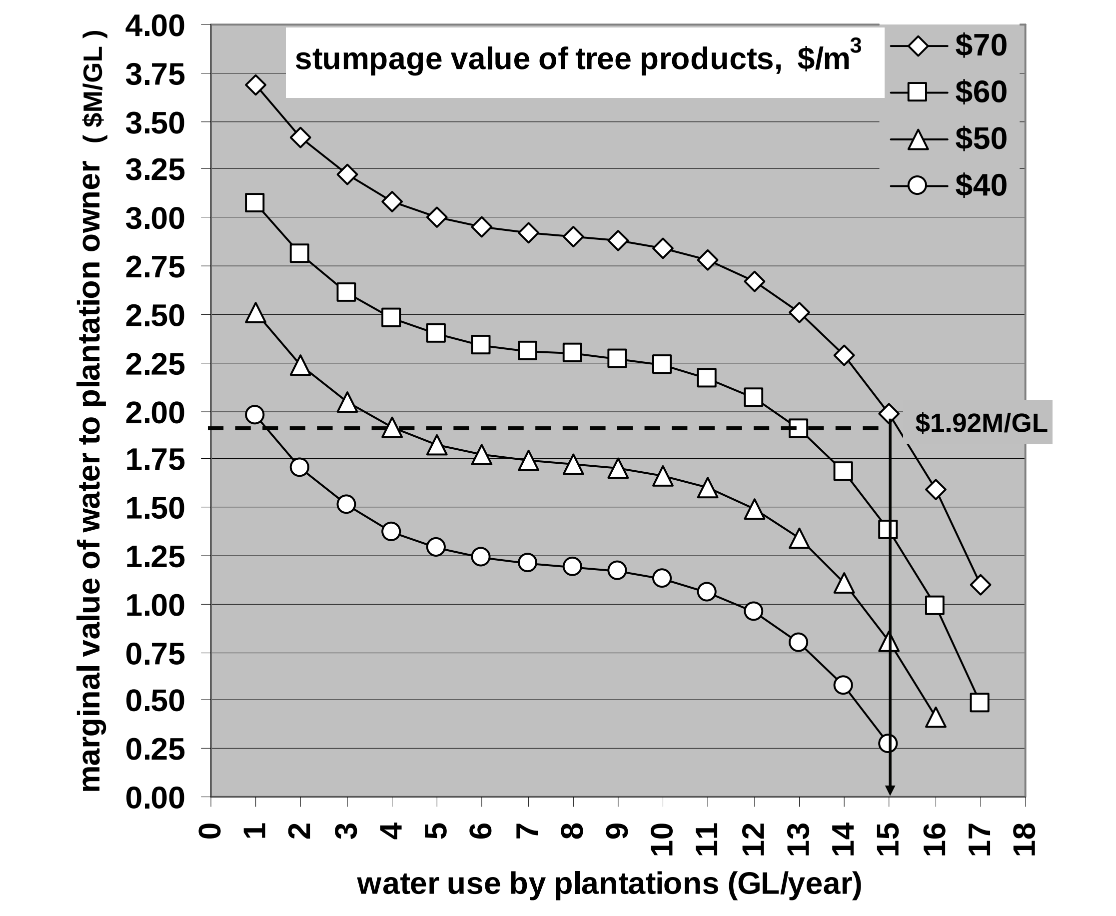

Figure 6. Upstream (MCUS) demand for offset water under Scenario Set 4 given the offer of 'top-ups' of $2M/GL from UHS to encourage tree plantations in very salty MCUS. **Note:** in Scenario Set 2 the 'top-ups' from UHS are higher than this, at $3M/GL, to compensate for large reductions in dilution flows due to large areas of tree plantations in the upper catchment

Of particular interest in this study are the lands of the upper catchment where tree plantations can be most profitable in their own right. The best example of this is UC10, an area with 1000 mm annual rainfall. By considering only tree product values and the direct and opportunity costs of new tree plantations in UC10 (Figure 7), we may illustrate the extreme limits of plantation expansion in the absence of Policy E.

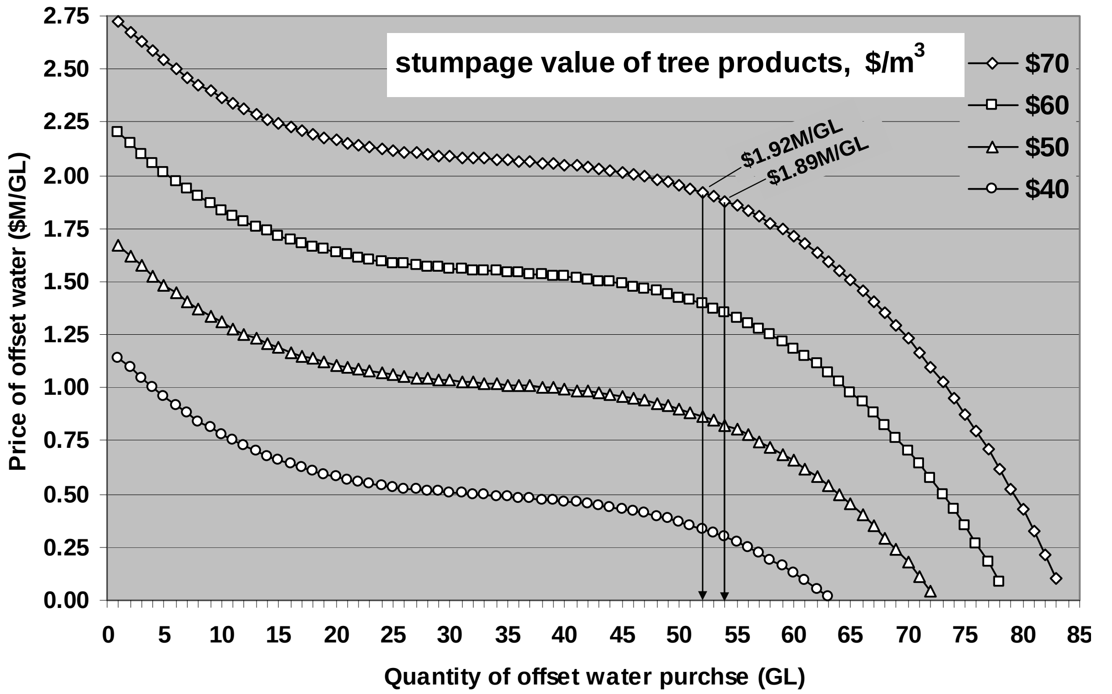

Figure 7. Upstream (UC10) demand for new tree plantation water used, given different values of tree products, as used in Scenario Sets 1 – 4.

In the absence of Policy E, UC10 tree plantations may be expanded profitably to the point where their marginal value equals zero. That is, consumption of up to 63 GL at $\$40/m^3$ tree stumpage value to land owners; 72 GL at $\$50/m^3$; 78 GL at $\$60/m^3$; and 83 GL at $\$70/m^3$. The latter represents a massive occupation of UC10 by tree plantations and a large reduction in water yield from the sub-catchment. Extra water consumption of 83 GL by new plantations in UC10 could be expected to reduce the water-yield of this sub-catchment by about 40%.

In the case of Policy E, the marginal cost (price) per unit of water purchased from water entitlement owners for use by the trees must also be considered. For the moment, we can illustrate the demand for water by MCUS and UC10 by supposing the market price is $1.92M/GL given a tree stumpage value of $\$70/ m^3$. The demand for water by MCUS will be 15 GL (Figure 6) and 52 GL by UC10 (Figure 7).

The price of water in such cases is determined in the competitive market given the marginal values of those wishing to purchase water and those of the downstream water entitlement holders. We now need to construct estimates of the marginal values of water for the downstream entitlement holders.

2.4 Marginal values of water use by irrigators and stock & domestic water users starting with recent prices of permanent water entitlement trades

We visualise the marginal values for water by IRR and S&D sectors as downward-sloping demand curves passing through the value of $1.2M/GL, a recent price for permanent trades, at the current entitlement levels of 333 and 27 GL, respectively (Table 2, Figure 8). This construction supposes that IRR and S&D would be willing to purchase more water at lower prices (e.g., 100 and 10 GL, respectively at $0.4M/GL) and to sell water at higher prices. It also supposes the WL sector, representing the government's environmental interests would offer to purchase up to 15 GL of water at a fixed price of $1.33M/GL (above recent prices of permanent trades), but not be willing to sell any of its entitlements for less than $3.86M/GL, just above the price at which IRR would be willing to sell its last unit of entitlement. This high reserve price by WL could be taken as that at which offsetting alternative wetland assets could be secured and developed. These scenarios also assume full 100% allocations of these entitlements with no year-to-year variations, and that all entitlements are held by these downstream interests and UHS which has a fixed entitlement of 27 GL. We also assume UHS is not interested in selling water or buying water for its own use. These assumptions, being somewhat arbitrary in marginal rates, are anchored to historical values of the downstream water market and comprise a simple and transparent scenario with which we may consider physical and economic interactions with the upper catchment water sources.

This construction, with downstream sectors holding all available entitlements puts these sectors in the position of the only potential suppliers of water entitlements in the case that Policy E is in force and upstream land owners are obliged to purchase water entitlements to permit the establishment of tree plantations. Alternatively, if widespread establishment of new tree plantations takes place in the absence of Policy E, the downstream entitlement holders will suffer losses as their allocations of water are reduced. We assume such losses (in GL) would be in proportion to their respective shares of the aggregate entitlements, just as general security percentage allocations are reduced by shortfalls today. And their economic losses would be valued by them according to their demand lines (Figure 8).

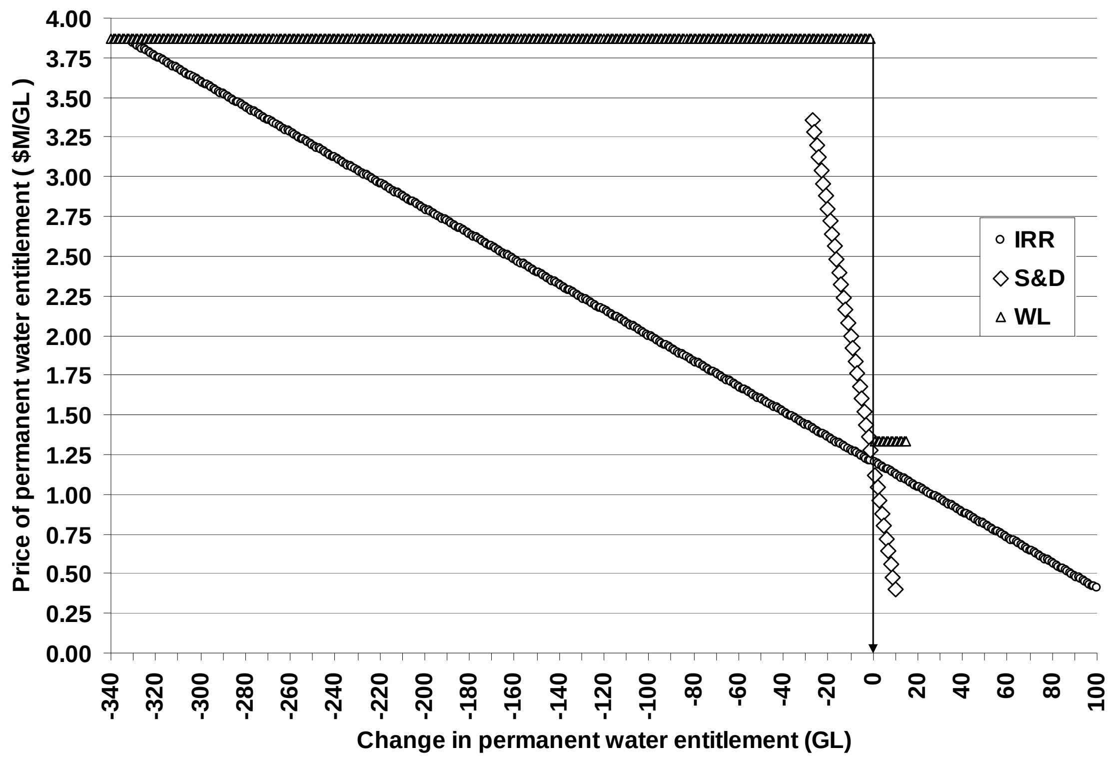

Figure 8. Assumed demand for changes in permanent entitlements to water by downstream IRR, S&D and WL sectors currently holding 333, 27 and 405 GL entitlements, respectively.

In the case that downstream entitlement holders are the only suppliers of water entitlements, we have assumed only IRR and S&D would be involved in selling water according to their marginal values (in their demand lines). That is, each would agree to sell only at prices greater than or equal to their marginal values, just as they would purchase water only at prices lower than or equal to their marginal values.

2.5 Framework for estimating the distributions of water use and economic surplus given supply and demand for water among sectors

The parts of the picture we have developed above allow us now to consider aggregate demand for water coming into equilibrium with aggregate supply in the cases of the 16 scenarios of tree product prices, presence or absence of Policy E, and with or without a very salty sub-catchment upstream of UHS (Table 3). Aggregate supply is expressed as the horizontal sum of the marginal costs IRR, S&D and WL would face if their access to water were reduced from their current levels (as in Figure 9).

Aggregate demand for water for new upstream tree plantations may be expressed as the horizontal sum of the individual sub-catchment demands (as in Figure 10 for the FRESH scenarios). The irregular 'wavy' character of these curves is due to the nature of their constituent sub-catchment curves (i.e., Figure 6 and Figure 7). Assembling the marginal value arrays of the constituent sectors in a column with a paired column identifying sector names, allows sorting the columns in descending order by marginal values, creating the 'horizontal sum' to represent the demand curve. A similarly constructed supply curve in ascending order is matched to find the equilibrium price. Then, up to that point, the demand and supply arrays are each sorted by source. The number of GL and the sum of marginal values from each source are the values listed as GL purchased (or sold), and economic surpluses (or losses) in Tables 5 – 8.

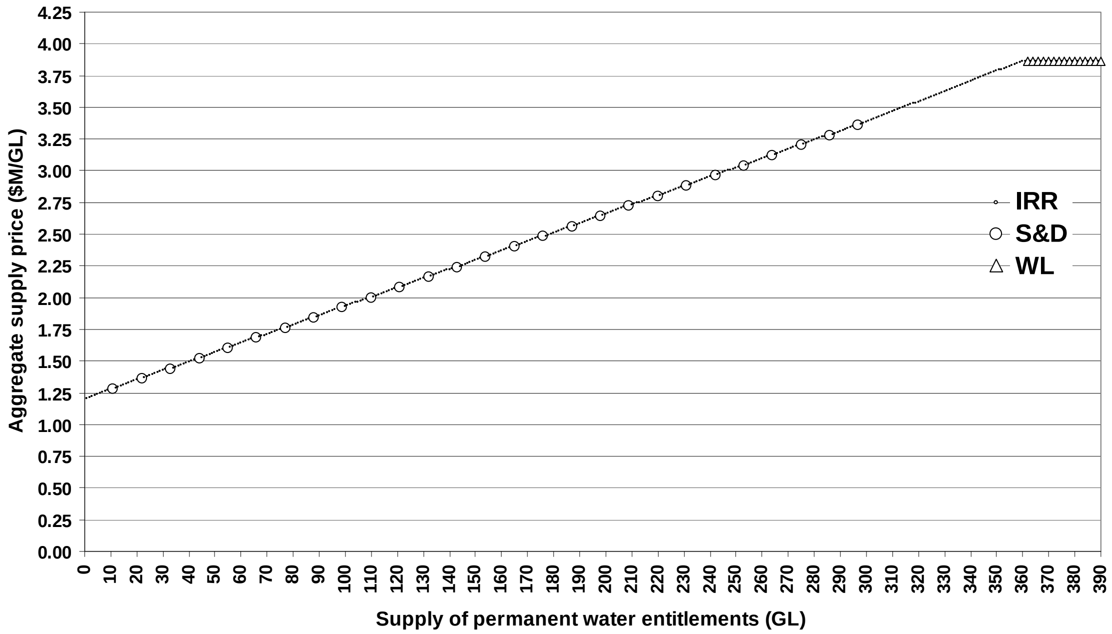

Figure 9. Aggregate supply of downstream water entitlements… of interest in the presence of Policy E where upstream landowners would need to purchase water entitlements to permit establishment of new tree plantations

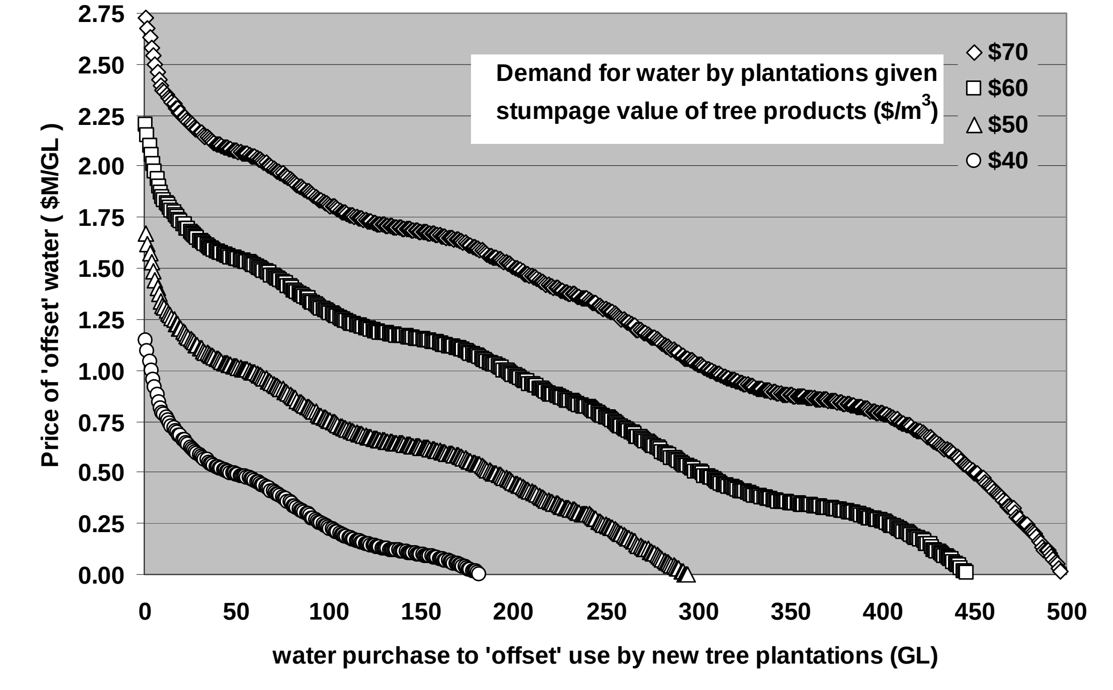

Figure 10. Aggregate demand by upstream areas (UC10, UC8, UC6, MCU, MCUS, and MCD) for downstream water entitlements in the FRESH Scenario Set 1 given different values of tree products

In Scenario Set 1, Policy E is not in force, the price upstream landowners pay for using water for new plantations is zero and they may profitably expand plantations to the point that their direct and opportunity costs of doing so are just covered by the value of their tree products. At $40/m^3$ they could reduce water-yields by over 150 GL; at $50/m^3$ by nearly 300 GL; at $60/m^3$ nearly 450 GL; and at $70/m^3$ nearly 500 GL (Figure 10). These are extreme estimates assuming tree planting by upstream landowners would expand to the point where their private gains just break even with those of their current land uses, oblivious to the large reductions in water-yield passed to the downstream consumers. Such reductions would obviously cause large economic losses to those downstream sectors. These losses are assumed to be distributed among the downstream sectors according to their shares of water-use and valued by them according to their marginal values (Figure 8). Estimates of the upstream gains and downstream losses, where there is no Policy E in force, are given in the ‘Results’ section below.

Where Policy E is in force and the water market is extended upstream, downstream demand for additional water beyond the current entitlements (Figure 8) is added to upstream demand to arrive at aggregate demand for water (Figure 11). Notice the demand for 15 GL at $1.33M/GL by WL appears as a horizontal step in each of the aggregate demand curves.

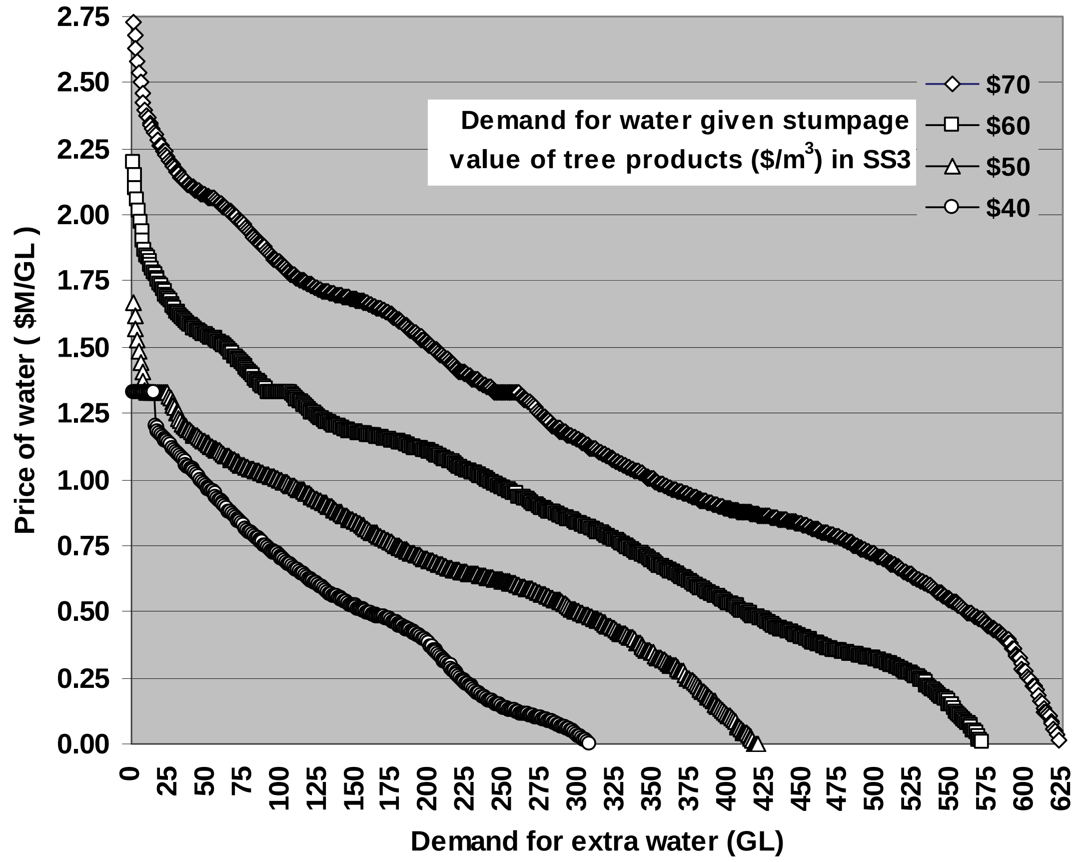

Figure 11. Aggregate upstream and downstream demand for extra water in FRESH Scenario Set 3

3. Results

Here we see the interactions between supply and demand in terms of quantities of water traded (or used and lost) among the different sectors, and distributions of gains and losses of economic surplus among sectors under our four Scenario Sets (Table 3).

3.1 Upstream gains and downstream losses from new forest expansion without policy and regulation for compensation to those receiving lower water flows

Results for the first two Scenario Sets are presented in Tables 5 and 6, for the FRESH and SALTY cases respectively. Both assume there is no requirement for new upstream tree plantations to purchase water entitlements (no Policy E), so the only limits to tree planting are the values expected at harvest and the land owners' own direct and opportunity costs. The differences between these cases occur because of the damages to water quality expected to be received by UHS due both to the high salinity of the sub-catchment MCUS and to the reduction in fresh water dilution flows from the other upstream sub-catchments. In this case we assume UHS will pay $3M/GL for water yield reductions from a very salty MCUS through planting trees there (see Appendix Tables 4 and 5 for calculations). From the viewpoint of MCUS this is a substantial ‘top-up’ of their demand curves (Figure 5 and 6).

Tables 5 and 6 are each divided into estimates of gains to the upstream sub-catchments and losses to the downstream sectors, in terms of changes in water used and changes in economic surpluses. Because in these scenarios there is no market to balance the economic surpluses and compensate losses in these changes, the upstream sectors are the big winners and the downstream consumers are the big losers. Higher values for tree products magnify these disparities substantially.

In our text about upstream new plantation demand for ‘free’ water (Figure 10) the mentioned quantities (GL) of water that would be used were the maximum that may be taken with the smallest net benefit to upstream land owners. Somewhat smaller quantities would be used by new plantations if these land owners set a minimum margin of net gain not at zero but at $0.2M/GL. This was the cut-off level for the totals reported in Tables 5 and 6, where there is no market constraint on water use.

Table 5. Economic results of Scenario Set 1, with fresh water flows from all sub-catchments and no Policy E (that is, no requirement for those establishing new tree plantations to purchase downstream water entitlements)

a. Gains to water-source catchment areas from expanding tree plantations, assuming no payments are required for extra water use

Sector	Water yield reduction (GL/yr) with tree product values ($/m^3) $70	$60	$50	$40	Gains in surpluses ($M)[B] with tree product values ($/m^3) $70	$60	$50	$40
UC10	82	76	69	57	151	108	69	32
UC8	178	163	140	45	274	181	96	19
UC6	114	87	12		99	40	4	
MCU	44	39	30	4	57	34	13	1
MCUS	14	11	2		13	5	1	
MCD	51	39	5		44	18	2	
Totals	**483**	**415**	**258**	**106**	**639**	**386**	**185**	**53**

b. Losses faced by downstream water users due to unilateral reductions in upstream water yields, assuming water losses are distributed in proportion to current water use

Sector	Current flows[A] GL	Current flows[A] share	Lost water availability (GL/yr) given tree product values ($/m^3) $70	$60	$50	$40	Imposed **losses** of surplus ($M)[C] with uncompensated reductions in water flow given tree product values ($/m^3) $70	$60	$50	$40
- IRR irrigated areas	**333**	**26%**	127	109	68	28	217	179	100	37
- S&D stock & domestic	**27**	**2%**	10	9	5	2	16	14	7	3
- WL wetland areas	**405**	**32%**	154	133	82	34	595	514	317	131
- ECR[D]	**502**	**40%**	191	164	102	42	0	0	0	0
Totals	**1267**	**100%**	**483**	**415**	**258**	**106**	**829**	**707**	**424**	**171**

[A] values from Table 2

[B] cumulative sum of marginal benefits for increments in water use by upstream sectors for new tree plantations

[C] cumulative sum of marginal costs for decrements in water availability for IRR, S&D and WL

[D] **ECR** = effluent creek & river inflow & evaporation losses. Changes in water flow to ECR are not assigned economic values here

Note: There is no impact on **UHS** which has high security entitlements, "fresh" water and is assumed always to receive its full amount of 27 GL

Table 6. Economic results of Scenario Set 2, with very salty sub-catchment MCUS, and no Policy E, UHS toping-up MCUS benefits of tree plantations for salinity relief

a. Gains to water-source catchment areas from expanding tree plantations assuming no payments are required for their extra water use

	with tree product values (\$/m^3)				with tree product values (\$/m^3)			
Sector	**\$70**	**\$60**	**\$50**	**\$40**	**\$70**	**\$60**	**\$50**	**\$40**
	Water yield reduction (**GL/yr**)				Gains in surpluses (**\$M**)[B]			
UC10	82	76	69	57	151	108	69	32
UC8	178	163	140	45	274	181	96	19
UC6	115	87	12		100	40	4	
MCU	44	39	29	4	57	34	13	1
MCUS	17	17	17	16	62	50	36	22
MCD	51	39	5		44	18	2	
Totals	**487**	**421**	**272**	**122**	**688**	**431**	**219**	**76**

b. Losses faced by downstream water users due to uncompensated reductions in upstream water yields, assuming water losses are distributed in proportion to current water use

	Current flows[A]		given tree product values (\$/m^3)				given tree product values (\$/m^3)			
Sector	**GL**	% share	**\$70**	**\$60**	**\$50**	**\$40**	**\$70**	**\$60**	**\$50**	**\$40**
			Reduced water availability (**GL/yr**)				Imposed **losses** of surplus (**\$M**)[C]			
- IRR irrigated areas	**333**	**26%**	128	111	71	32	220	183	106	43
- S&D stock & domestic	**27**	**2%**	10	9	6	3	16	14	9	4
- WL wetland areas	**405**	**32%**	156	135	87	39	603	522	336	151
- ECR[D]	**502**	**40%**	193	167	108	48	0	0	0	0
Totals	**1267**	**100%**	**487**	**421**	**272**	**122**	**839**	**719**	**451**	**197**

[A] values from Table 2

[B] cumulative sum of marginal benefits for increments in water use by upstream sectors for new tree plantations

[C] cumulative sum of marginal costs for decrements in water availability for IRR, S&D and WL

[D] **ECR** = effluent creek & river inflow & evaporation losses. Changes in water Flow to ECR are not assigned economic values here

Note: Differs from Scenario 1 (Table 5) as UHS 'tops up' benefits of MCUS for reducing water-yields and salt concentration given reduced fresh dilution flows from the upper catchment

The effects of increases in earning power of new forest plantations ($40 to $70/m^3) are quite dramatic in the absence of regulatory or market limitations on expansion (Tables 5 & 6). Large amounts of water are used, and large economic surpluses captured, by the upstream sectors. In these scenarios we project equally large reductions in water flow to the downstream sectors. Assuming these losses would be shared among the downstream sectors in proportion to their current entitlements, large economic declines are projected for the IRR and S&D sectors, while environmental declines can be expected in the WL and ECR sectors. We have put a price on the WL losses, unsure whether this would be sufficient to replace the environmental functionality with replacement and/or renovations elsewhere. We have not priced the ECR losses, which presumably include some contributions to the Darling River.

3.2 Upstream and downstream surpluses from new forest expansion with policy and regulation enabling water trade from downstream to upstream

With an extended water market, results indicate establishment of smaller areas of forest and compensation for lost water; so all sectors benefit (Tables 7 & 8). We assume water trading is only from the IRR and S&D sectors, while current entitlements continue to be fulfilled to the WL and ECR sectors. With Policy E, water use by new tree plantations in the upstream sectors is much lower than the free water scenarios (Tables 5 and 6). Further, under Policy E, new plantations are limited to those parts of the catchment where they are most profitable in their own rights. In Scenario Set 4 (Table 8) MCUS is offered subsidies of $2M/GL by UHS to plant trees for reduced salt-water yields. The calculated subsidy offer from UHS is lower than in Scenario Set 2 ($3M/GL) because the areas of new plantations and their water use are substantially smaller than in the 'free water' case. That is, most of the former fresh dilution flows continue in the case where a market price has to be paid for water used by new tree plantations.

The idea that new tree plantations should be prevented by regulation is discounted by our results. If our assumptions are approximately correct, the benefits of trading 90 GL of water from downstream uses to upstream plantations are on the order of $138M and $192M to those sectors, respectively, in the FRESH case with the highest value tree products (Table 7). In the SALTY case (Table 8) the downstream and upstream surpluses are expected to be higher at $151M and $220M, respectively, as seven

Table 7. Economic results of Scenario Set 3, with fresh water from all sub-catchments and Policy E in force (water use by new tree plantations must be covered by purchase of existing downstream water entitlements)

a. Water entitlements sold by downstream sectors

	given tree product values ($/m³):				given tree product values ($/m³):			
	$70	**$60**	**$50**	**$40**	**$70**	**$60**	**$50**	**$40**
Sector	Amount of water supplied (**GL**)				Gains in surpluses (**$M**)			
IRR	82	43	16	14	126	59	20	18
S&D	8	4	1	1	13	6	1	1
Totals	**90**	**47**	**17**	**15**	**138**	**65**	**22**	**19**
Equilibrium water price ($M/GL):					**1.89**	**1.55**	**1.33**	**1.33**

b. Water demand from sectors purchasing water

	given tree product values ($/m³)				given tree product values ($/m³):			
	$70	**$60**	**$50**	**$40**	**$70**	**$60**	**$50**	**$40**
Sector	Amount of water purchased (**GL/yr**)				Gains in surpluses (**$M**)			
UC10	54	32	9		117	56	13	
UC8	33	15			69	26		
MCU	3				6			
WL			8	15			11	20
Totals	**90**	**47**	**17**	**15**	**192**	**82**	**24**	**20**
Equilibrium water price ($M/GL):					**1.89**	**1.55**	**1.33**	**1.33**

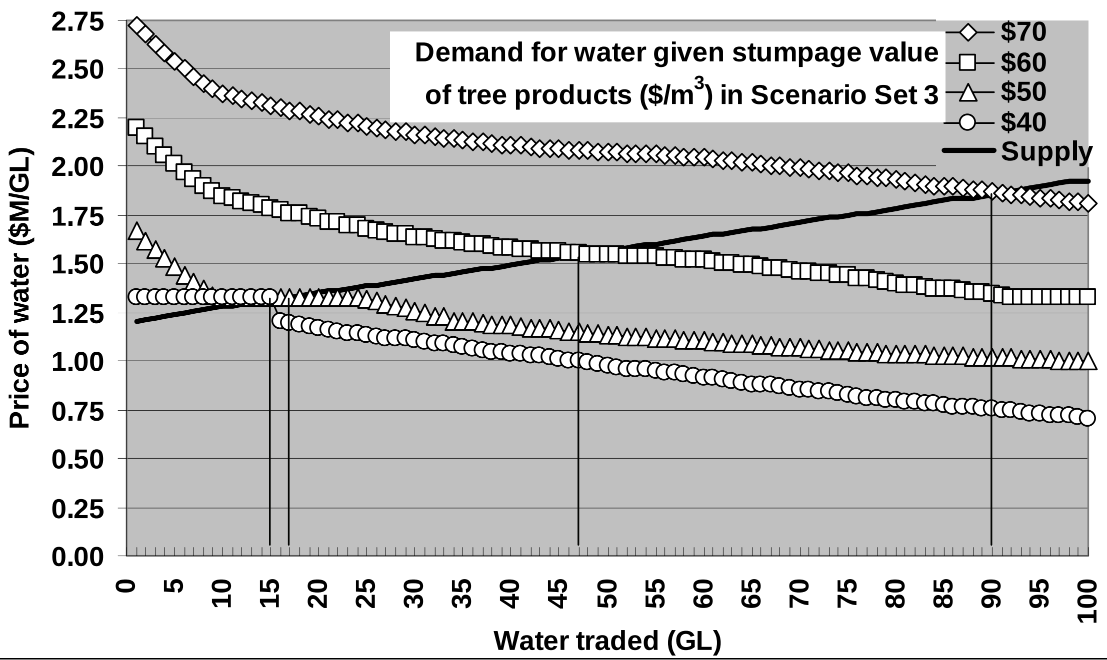

Figure 12. Aggregate upstream and downstream demand for extra water intersecting with aggregate downstream supply of water from the IRR and S&D sectors in the FRESH Scenario Set 3

Table 8. Economic results of Scenario Set 4, with very salty MCUS, Policy E and UHS 'topping up' MCUS benefits from tree plantations for salinity mitigation

a. Water entitlements sold by downstream sectors

	given tree product values ($/m^3):				given tree product values ($/m^3):			
Sector	**$70**	**$60**	**$50**	**$40**	**$70**	**$60**	**$50**	**$40**
	Amount of water supplied (**GL**)				Gains in surpluses (**$M**)			
IRR	89	48	19	16	139	67	24	20
S&D	8	4	1	1	12	6	1	1
Totals	**97**	**52**	**20**	**17**	**151**	**73**	**26**	**22**
Equilibrium water price ($M/GL):					**1.92**	**1.59**	**1.37**	**1.33**

b. Water demand sectors purchasing water

	given tree product values ($/m^3):				given tree product values ($/m^3):			
	$70	**$60**	**$50**	**$40**	**$70**	**$60**	**$50**	**$40**
Sector	Amount of water purchased (**GL**)				Gains in surpluses (**$M**)			
UC10	52	25	8		114	45	12	
UC8	28	13			59	22		
MCU	2				4			
MCUS	15	14	12	4	43	33	22	7
WL				13				17
Totals	**97**	**52**	**20**	**17**	**220**	**100**	**34**	**24**
Equilibrium water price ($M/GL):					**1.92**	**1.59**	**1.37**	**1.33**

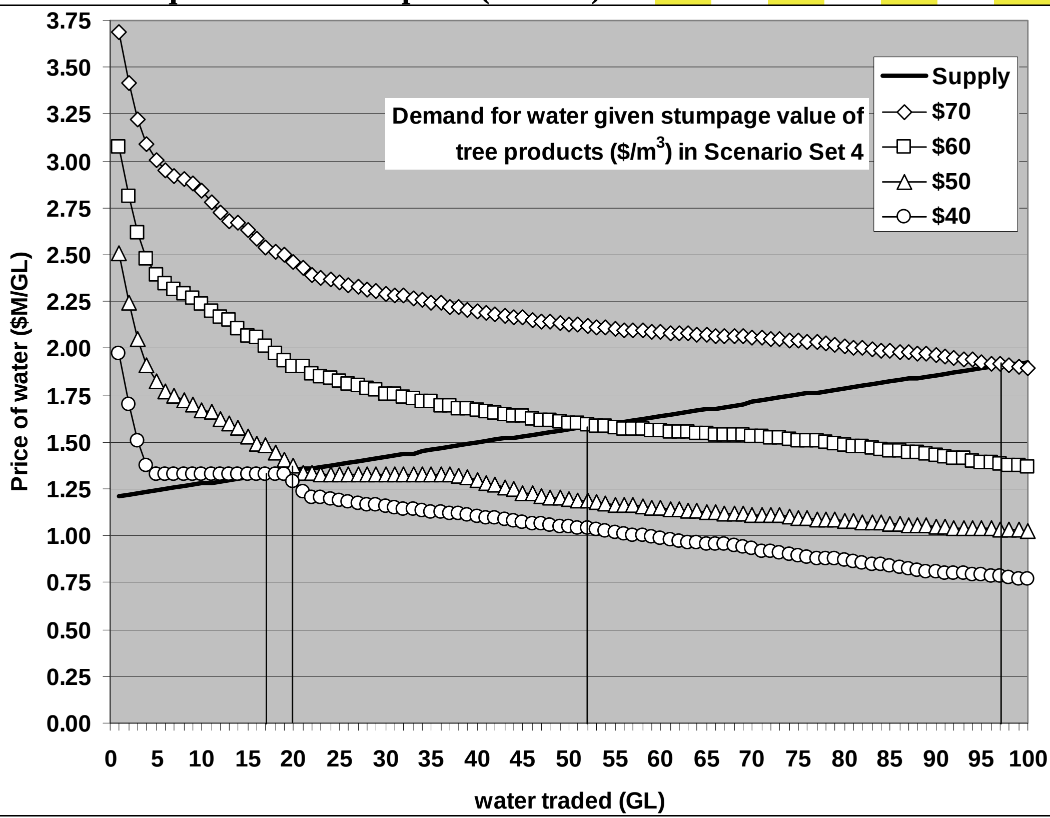

Figure 13. Aggregate upstream and downstream demand for extra water intersecting with aggregate downstream supply of water from the IRR and S&D sectors when UHS tops up benefits to MCUS for reducing water yield in SALTY Scenario Set 4

further GL of water are traded. These seven, plus eight GL drawn away from tree planting elsewhere, make up the subsidised 15 GL purchased by MCUS in contrast to zero in the FRESH case where UHS has no need to deal with salinity. Between the FRESH and SALTY cases the price of water increases from $1.89M to $1.92M/GL.

4. Discussion and conclusions

In the ‘free water’ FRESH and SALTY cases of Scenario Sets 1 and 2 (Tables 5 & 6), total upstream surpluses due to tree planting are $639M and $688M, respectively. These are contrasted with downstream losses on the order of $829M and $839M, respectively. Counting downstream losses to the aggregate of the IRR and S&D sectors, these add up to $233M and $236M in the FRESH and SALTY cases, respectively, given uncompensated losses of 137 and 138 GL of water flow to them; further, uncompensated losses of 154 and 156 GL in annual river flow would be suffered by the wetlands.. How do these scenarios of ‘free water’ for tree plantations compare with Scenario Sets 3 and 4 (Tables 7 & 8) in which new tree plantations must enter the market for the water they use?

With the requirement to purchase water for establishing new tree plantations, upstream surpluses are projected to be $192M and $220M in the FRESH and SALTY cases, respectively, while downstream sums of IRR and S&D surpluses are $138M and $151M, given 90 and 97 GL of water traded upstream (Tables 7 & 8). In these scenarios, trading and water use changes are assumed only among the downstream (IRR and S&D) sectors and the six upstream sub-catchments, such that flows to the wetlands are preserved. Greater surpluses in the hypothetical SALTY cases are due to subsidies paid by UHS for tree planting to reduce water yields from the very salty sub-catchment, thereby lowering river salinity to acceptable levels for domestic use.

Do the large potential upstream surpluses in the ‘free water’ Scenario Sets 1 & 2 outweigh the smaller downstream economic losses? Surely, from the viewpoint of the downstream sectors, the answer is “no”.

Can we make the case that the ‘extended market’ Scenario Sets 3 & 4 (Tables 7 & 8) produces more efficient, equitable and environmentally friendly results than the ‘free water’ Scenario Sets 1 & 2 (Tables 5 & 6)?

- Yes, if ‘efficient’ means water going to various uses in which its marginal values are equal… such that no high value uses are starved for water while it is ‘employed’ in lower value uses.
- Yes, if ‘equitable’ means no sector’s access to water is appropriated by another without compensation, but water is traded at mutually agreeable prices or not at all.
- Yes, if ‘environmentally friendly’ means water entitlements for riparian habitats and wetlands are protected and honoured. Where adjustments to these entitlements are judged necessary, the state may enter the market to do so.

Our assumptions regarding land uses, the direct and opportunity costs of planting large areas of trees in the different areas and the downstream demands for water may all be challenged, though there is little doubt the directions of change presented are correct.

The consequences of higher marginal values for water by the downstream IRR and S&D sectors are clear… their aggregate water supply line would simply cut the aggregate demand curves at higher prices and result in lower quantities traded than in the cases of Scenario Sets 3 & 4 (Tables 7 & 8). In the ‘free water’ Scenario Sets 1 & 2 (Tables 5 & 6), higher marginal values of water by the IRR and S&D sectors would simply mean greater losses to them.

The changes in water yields are presented as if they are instantaneous with the establishment of tree plantations, whereas we do expect water-yields to gradually decline to a lower steady state over a number of years. We have dealt with such time issues by using NPVs and permanent water trade prices, both capturing the long-run.

We have made GL of water the metric of trade because it is a common denominator already for downstream water trade and readily translated into particular surface areas of forest, as a function of annual rainfall.

We have developed a static model based on long-run rainfall figures, without concern for historical year-to-year variations and droughts, or climate change. With respect to the latter challenge, however, this study should give pause to the popular notion that the obvious ‘right’ response is for us to plant lots of forest, here on the driest continent.

We have noted two simplifying assumptions in our methods: (1) that mean annual rainfalls, which range from 1000mm to 300mm in different parts of the catchment, hold constant over time with no year-to-year variation and (2) that land use changes are reflected quickly in changed catchment water-yield and salt-load. This means all our point estimates of water-yield and salt-load changes are uncertain, within unspecified probabilistic clouds and smeared across time. On one hand, this may suggest it is a folly to ‘fine tune’ land use in a catchment to achieve small changes in salt-loads and water-yields. On the other hand, the negative impact on water-yields due to large increases in forest areas appears potentially large and relatively certain.

The two sources of variance in water-yields noted above raise challenges for the accounting and trading of up-stream and downstream water rights. For example, if downstream interests wish to alter the environmental services flowing from a catchment by inducing certain land use changes there, the outcomes are necessarily uncertain. Another example is the attribution of culpability for reduced catchment water yields to new tree plantations; this is a classic case of externality damages but heavily obscured by year-to-year variations in rainfall, non-uniform hydrologic response times, as well as uncertainties in “climate change” (Nordblom *et al*. 2009a, 2010).

While mainly about water, this study incorporates concerns for river salinity and a way those in an Urban area (UHS) most troubled by it (in a hypothetical case) could deal with the problem presented by a sub-catchment seeping lots of salt into their otherwise fresh water source. They could ‘top up’ the benefits land owners may have from planting trees, thereby reducing water-yields from that particular area. An alternative option for UHS in the hypothetical SALTY scenario could be to construct a water pipeline directly to the most reliable fresh water source.

We have presented abstract upstream and downstream sectors, which are in reality each constituted by many individual decision makers, as if they are single decision makers each acting ‘rationally’ only for their individual best advantage.

The present model constructs simple economic profiles of each sector then given several tree-product values calculates the equilibrium results expected when these sectors interact. There are several clear conclusions that may be framed as answers to the questions posed at the start of this paper:

- Could policies and programs that encourage large-scale forestry expansion have the unintended effect of drying up important fresh water sources in Australia, the driest continent? Clearly, yes.
- Should this happen, would the most disadvantaged be general-security water entitlement holders (irrigators, stock & domestic users and vulnerable wet-land environmental assets)? Clearly, yes.
- And would urban and other high-security users receive saltier water supplies with high mitigation costs? Only in the case where a very salty sub-catchment is located up-stream of these users who would suffer from reduced fresh dilution flows and increased river salinity. Such a case has been posed hypothetically in this study to demonstrate this effect.
- Could a policy requiring purchase of existing water entitlements to permit establishment of forestry plantations help promote the most efficient allocations of this finite resource among competing users? Such a system has been implemented in southeast South Australia. Our study shows how extending the water market from current downstream water users (urban, stock & domestic and irrigators) to interests wishing to establish new forest plantations in the upper catchment could result in a balance that is more efficient, equitable and environmentally friendly than the case where new forests are not required to obtain water entitlements.

Does it matter that we have assumed all water entitlements are initially only in the hands of downstream sectors? Probably, but in the direction of less water trade than predicted in this supply and demand analysis. Nordblom *et al.* (2009b) treat this question explicitly. Coase (1960) posited that property rights will be sorted out optimally with trade, regardless of the distribution of initial endowments, except where there are high transaction costs.

Effective policy and regulation minimising transaction costs could facilitate trade of water rights to new upstream forest plantations. Young & McColl (2009) have reasoned that if entitlement and allocation regimes are set up in ways that have hydrological integrity, the system "can autonomously adjust to climatic shifts, changes in prices and changes in technology without compromising environmental objectives".

Does it matter that we have assumed (in SS3 and SS4, the market scenarios) general security water entitlements are the same as high security water entitlements, expressing rights to exact volumes of water to the entitlement holder each year and tradable as such? There is no doubt that general security water entitlements, which receive only allocated shares of their denominated volumes according to the rainfall and storage levels that differ from year to year (as in SS1 and SS2) will present results varying from those shown.

However, trade in entitlements for fixed volumes or probabilistic volumes of water can be reconciled with a premium on certainty (or discounts for uncertainty). Adamson *et al*. (2007) have provided an example of how to do this, but did not include new forest plantations in the market for water. The present study provides missing details that would allow a fuller analysis.

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Appendices

Appendix Table 1. Mean annual inflow sources to the Macquarie River at "Baroona", below Dubbo, and distribution to the environment and consumptive uses

a. Contributions of inflow sources to the mean average flow in the Macquarie River at "Baroona"

	%	**ML**
Windameer Dam inflows	4	60,000
Cudgegong Tributaries, guaged inflows	6	90,000
Cudgegong Tributaries, unguaged inflows	2	30,000
Burendong Dam inflows	58	870,000
Macquarie Tributaries, guaged inflows [A]	18	**270,000**
Macquarie Tributaries, unguaged inflows	12	180,000
	100	**1,500,000**

b. Mean annual distribution of Macquarie water source inflow to the environment and consumptive uses

	%	**ML**
Windameer Dam net evaporation	1	15,000
Burrendong Dam net evaporation	3	45,000
Cudgegong River transmission losses	1	15,000
Macquarie River transmission losses	20	300,000
Cudgegong Valley extractive use	1	15,000
Macquarie Valley extractive use	25	375,000
Macquarie Marsh inflows	27	405,000
Effluent Creek inflows	22	330,000
	100	**1,500,000**

Source: MCRMC (2002), particularly, text and Figures 1 and 2, and Part A, Page 9

[A] The main unregulated (but gauged) tributaries include the Bell, Little and Talbragar Rivers and Coolbaggie Creek, “which provide an annual runoff of about 250 000 ML". Kingsford & Auld (2005, p 198)

Appendix Table 2. Summary of mean annual extractive water uses

	Cudgegong[A]	**Macquarie**	**Totals**
High Security & Town Water Supply	3,470	23,069	26,539
Stock & Domestic (deduced for Cudg.)	4,085	22,424	26,509
Irrigation	7,445	325,909	333,354
Totals	15,000	371,402	386,402
proportion of totals from Table 1.b [B]	1.000	0.990	0.991
totals from Table 1.b [B] (this report)	15,000	375,000	**390,000**

Source: MCRMC (2002), from Table 1, page 10, and Fig 3, page 11, in Part A of that report. Note: the same Fig 3 refers to "Supplementary Water" as being among the "uses", presumably irrigation from unregulated tributary flows

[A] The Cudgegong Valley flows, minus these extractions, join the upper Macquarie River behind Burrendong Dam.

[B] **"Note**. By limiting long-term extractions to an estimated **391,900** megalitres per year this Plan ensures that approximately 73% of the long-term average annual flow in this water source (estimated to be 1,448,000 megalitres per year) will be preserved and will contribute to the maintenance of basic ecosystem health**"** (DIPNR, 2004 p.5)

Appendix Table 3. Upper & Mid-Macquarie catchment details, after Beale *et al.* (2000)

	Catchment area [A] *km²*	Ave. water-yield[A] *mm/yr*	**W** water-yield [A] GL/yr	***S*** salt-load [A] *1000t/yr*	Salt concentration *ppm*
UC10 [B] High Rainfall zone of Upper Macquarie Catchment:					
Fish River at Tarana	570	160	91.2	5.1	56
Campbells River u/s Ben Chifley Dam	950	89	84.6	12.4	147
"Residual" area R1	1310	67	87.8	14.2	162
Totals:	**2830**		**263.5**	**31.7**	**120**
Macquarie River, Narromine	26160	48.9	1279.2	234.0	183
minus the upper catchment (ending just down-stream of Burrendong Dam)	13980	75	1048.5	147.8	141
= Mid-Macquarie (by difference)	**12180**		**230.7**[C]	**86.2**	**374**
Mid-Macquarie "details"					
Upstream of Dubbo MCU [B]					
Bell River at Neurea	1620	67	108.5	30.4	280
"residual" area R7	1806	25[D]	45.2	7.8	173
MCUS [B] (saltiest sub-catchments)					
Buckinbah Ck at Yeoval	694	30	20.8	12.6	605
"residual" areas R5/R6	1226	25[D]	30.7	14.2	463
MCD [B] Downstream, below Dubbo:					
Talbragar R. at Elong Elong	3050	27	82.4	15.5	188
Coolbaggie Ck at Rawsonville	626	29	18.2	6.5	358
"residual" areas R8/R9	2894	17.7	51.2	24.3	474
Sum of Mid-Macquarie "details"	**11916**		**356.9**	**111.3**	**312**
Mid-Macquarie "**detail**" as proportion of Mid-Macquarie "**by difference**"	0.98		1.5	1.3	0.8

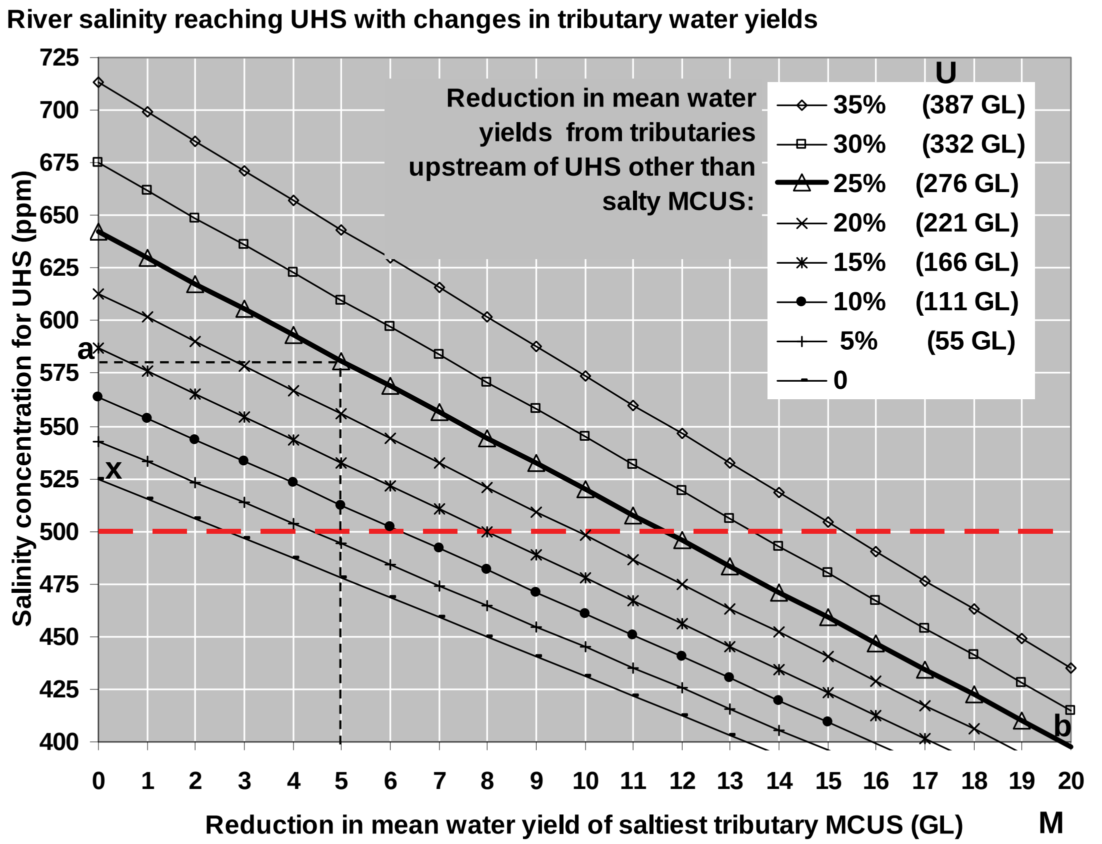
[A] Drawn from Figs 5.9 and IX, and Tables 5.7 and 5.8 in Beale *et al*. (2000), based on 1975–95 conditions

[B] See Fig 1 for contexts of acronyms in describing sectors of the example catchment

[C] This estimate of mean total water yield from the gauged, but unregulated Mid-Macquarie catchment (comprised of the Bell, Little and Talbragar Rivers and Coolbaggie Creek) is close to the 250 GL/yr value cited by Kingsford & Auld (2005, p 198) and close to the 270 GL/yr assumed by MCRMC (2002) for inflows from the same tributaries.

[D] these 25 mm/yr water yield values replace blanks in Beale *et al*. 2000 Table 5.7

Appendix Table 4. Changed salinity with reduced dilution flows to urban area
Urban and high security water consumers can anticipate approximate increases in river salinity (in parts per million, ppm) given estimates of reductions in dilution flows from the fresh upstream sub-catchments (**U**) and the reductions in salinity (ppm) possible with reduced water-yields from a very salty MCUS (**M**).



Appendix Table 5. Urban calculation of subsidies for new forests in salty area

Initial expected **reductions** **in**		**GL**
Upstream water yield	**U** =	**430**
MCUS water yield	**M** =	**0**
UHS may expect salinity ppm:		**742**

New increments =	M_M **20**	Increments above **M**	Expected **UHS ppm**	Change in UHS ppm	Damage reduction (**$m/GL**) at $200,000 per ppm
1	20	M+1	**727**	14.89	$2.98
2	19	M+2	**712**	14.89	$2.98
3	18	M+3	**698**	14.89	$2.98
4	17	M+4	**683**	14.89	$2.98
5	16	M+5	**668**	14.89	$2.98
6	15	M+6	**653**	14.89	$2.98
7	14	M+7	**638**	14.89	$2.98
8	13	M+8	**623**	14.89	$2.98
9	12	M+9	**608**	14.89	$2.98
10	11	M+10	**593**	14.89	$2.98
11	10	M+11	**578**	14.89	$2.98
12	9	M+12	**564**	14.89	$2.98
13	8	M+13	**549**	14.89	$2.98
14	7	M+14	**534**	14.89	$2.98
15	6	M+15	**519**	14.89	$2.98
16	5	M+16	**504**	14.89	$2.98
17	4	M+17	**489**	14.89	$2.98

Note: The arrow points to the calculated salinity concentration given a reduction in diluting water flows of 430 GL (**U**) from the fresh sub-catchments upstream of UHS and no reduction in MCUS water-yields (**M**).

The first step in expressing this information as a single equation was to describe the ppm intercept values of the figure in Appendix Table 4 for M=0 and the values at M=20, to cover the range of possible water yield reductions from MCUS. Quadratic functions were fitted in each case.

The second step was linear interpolation between the two functions to give an estimate of UHS ppm for any combination of **U** and **M** values within the range of interest. This can be expressed simply as:

$$\text{UHS ppm} = (a_0 + b_0U + c_0U^2) - M((a_0 + b_0U + c_0U^2) - (a_{20} + b_{20}U + c_{20}U^2))/20$$

where:

for M = 0, $a_0 = 525.65$, $b_0 = 0.28128$, $c_0 = 0.00051731$
for M = 20, $a_{20} = 336.32$, $b_{20} = 0.14291$, $c_{20} = 0.00026837$

Reductions in river salinity (ppm) at UHS were estimated for one-GL steps reducing water yields (M) by MCUS. The damage reductions anticipated by UHS for each GL of M are based also on UHS estimation of the NPV of their salinity damages of $200,000/ppm.

Appendix Table 6. CAVEATS (warnings and what research remains to be done, or done better)

"The aim of science is to seek the simplest explanations of complex facts. We are apt to fall into the error of thinking that the facts are simple because simplicity is the goal of our quest. The guiding motto in the life of every natural philosopher should be, **Seek simplicity and distrust it**." Alfred North Whitehead (1919)

1. This study presents static, deterministic models rather than stochastic (probabilistic) analyses. Possessing the virtue of simplicity, they do not account for year to year variations in prices or rainfall, or sustained drought periods.

2. The study takes the simplifying assumption that all downstream water entitlements, high and general security, are the same and fully deliverable, expressing rights to exact volumes of water to the entitlement holder each year and tradable as such. Where there has been over-allocation of water entitlements or shortfalls in rain, however, general security allocations will only be some fraction of the face value of the entitlements. These fractions have been reduced to zero or near zero in drought periods. Reconciliation of these issues is a subject worthy of further study.

3. To permit the planting of a new forest area that will use 1 GL of extra water in a normal year, for example, the purchase of a permanent general security entitlement to one GL, which may be expected to deliver only, say, 1/2 GL of water in a normal year, will result in losses to those not selling entitlements. If there were an 'exchange rate' that would equate some number of general security entitlements to one high security entitlement, a rule permitting new forest plantations could be made to reflect this. That is, the extra water new forests consume beyond the previous land uses may be considered to be the equivalent of high security water consumption.

4. Although sale of downstream water entitlements may just balance reductions in river flow due to new tree plantations, water delivery efficiency may be reduced and overhead costs increased for those not selling entitlements. Our analysis has not counted these costs, which are worthy of further study.

5. There is no doubt that general security water entitlements, which receive only allocated shares of their denominated volumes according to the rainfall and storage levels that differ from year to year, will present results varying from those shown. Probabilistic volumes of water may be reconciled using 'state contingent' analysis. The present study provides many of the details that would allow such analysis.

6. The study takes the simplifying assumption that 'off allocation' flows from unregulated rivers (such as the Bell, Talbragar and Little River) are subject to marketable entitlements, though in reality they are not. Indeed, irrigators may be allowed to pump river water for a 24 hour period following short-notice announcements from the water authority. Also, tactical releases of stored water on the backs of the occasional 'floods' from the unregulated rivers may be staged by the water authority for the purpose of meeting environmental aims, such as sustaining the Macquarie Marshes.

7. Though the Macquarie River is technically classed as non-terminal, the study ignores any spill-over of water contributing to the larger Murray-Darling Basin. In recent years little water has exited the catchment due to lack of rain and floods; the latter have largely been minimised by dams and water use by irrigators. The study simply assumes long-run average flows of 1975–95 as its base line and does not account for the recent drought period.

8. The study assumes trading is only for permanent, not temporary, water entitlements though the latter are more common in practice. Such trades are compatible among participants in the current market. However, the question arises of whether new forest plantations might be permitted with purchases of temporary water entitlements when the life of a plantation may run to 30 years. There is a corollary question of re-sale of water entitlements obtained for a forest plantation when the forest is harvested and the land returned to use as pasture.

9. For the sake of simplicity, the study poses an arbitrary high price for any water entitlements lost by the Wetlands in the cases where new forest plantations do not require water entitlements. Ignored was recent work by Morrison *et al.* (1999), Bennett (2002) and others on the estimation of monetary values for environmental benefits and costs. Combining the insights and quantitative measures from that research would add depth to the present line of study.

10. We have ignored the fact that it is not simply the annual volume of water, but the timing of water delivery that affects the wetland environments. For example, pulses of water mimicking floods may be preferred to a continuous seep summing to the same volume over time. This study has not quantified the environmental impacts of changed flows to the Marshes. This remains a serious challenge generally, not just in this case (NRC 2005), a challenge requiring the combined skills of ecologists and resource economists.

11. We have developed the means to define menus of minimum-cost land use change to deliver different options of water yield and salt loads from a catchment. Can we develop a similar menu of options for a wetland's response to receiving water in different amounts at different timings? What is the range of options for sustaining a wetland's biodiversity and its functions, from full and guaranteed to irrecoverable collapse? Some may regard such questions as immoral, in favour of returning to full pre-European settlement conditions at any cost, but these questions must be faced to help assure the future of the most treasured environmental assets.

This long list of caveats covers only some of the great complexities found in the environment and management of a catchment.

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