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An economic assessment of options for operating within plantation forestry water entitlements and tightening cap and trade policy

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Abstract
The Green Triangle (GT) region of southern Australia is one of only two jurisdictions globally to licence plantation forestry's groundwater use. In response to declines in groundwater resources caused by historical plantation expansion, reductions in forest water allocations (~50%) are likely for some parts of the region, presenting novel challenges for forest managers in maintaining revenues and timber flows. This article presents a mathematical programming model evaluation of water trade opportunities for plantation forest owners to adapt to reduced water entitlements and explores how tightening groundwater policy could affect forestry returns and land use mix for the region. Results suggest that even absent opportunity to sell water, relatively limited 11% reduction in return could be expected for a large (−50%) water entitlement and (−48%) land-use change out of forestry. Results suggest that opportunities for forestry companies to sell water entitlements may allow them to maintain or even increase combined returns from forestry and water sales. Whilst the results highlight the adaptive capacity of the plantation forestry sector to operate within reduced water entitlement, a significant sectoral and regional economy adjustment would be likely. The discussion focusses on the potential to realise optimisation model-identified adaptation opportunities accounting for real-world thin markets, transaction costs and market friction.

KEYWORDS
cap and trade, forestry, groundwater, water market, water trade

JEL CLASSIFICATION
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1 | INTRODUCTION

Demands on the world's limited freshwater supplies are increasing with the growing global population and increasing per capita consumption linked to rising living standards (Floerke et al., 2018; Wada et al., 2013). One result is that between 1.6 and 2.4 billion people currently live in water-scarce basins (Gosling & Arnell, 2016). Further water supply reductions expected in many regions will intensify profound trade-offs amongst the many demands for water such as irrigation, energy production, river transport, fish production, direct human consumption and the environment (Greve et al., 2018; Rosa et al., 2020). In many parts of the world, adverse consequences of surface water withdrawal became obvious more quickly than is the case for groundwater and bring rise to regulation of the resource sooner than is often the case for groundwater. Despite groundwater accounting for 50 per cent of drinking water and 43 per cent of irrigation water in many parts of the world (including many aquifers in the USA, China, France, Portugal and Australia), extractions from groundwater have traditionally been mostly unmonitored and unregulated (Aarnoudse et al., 2019; Brozović & Young, 2014; Rinaudo et al., 2012; Wheeler et al., 2016).

Over time, however, as the external costs of declining aquifers increase, there is increasing regulation of the resource, for example, in the US states of Colorado, Nebraska and Texas and some Spanish and Australian aquifers. Such regulation typically limits (caps) allowable groundwater pumping, requires metering of wells and enforcement actions for withdrawals above permissible levels (Brozović & Young, 2014; Closas et al., 2017; Lane-Miller et al., 2013; Schwabe et al., 2020). Water cap policies have grown into cap-and-trade policies that allow trade amongst extractors in some areas (e.g. in parts of the western United States, Spain and Australia) (Breviglieri et al., 2018; de Bonviller et al., 2020; Garrick et al., 2012).

A considerable water trade literature concludes that such a policy approach can reduce adverse economic impacts of water caps and improve economic returns to irrigation (Leonard et al., 2020; Schwabe et al., 2020; Zhou & Li, 2019). However, successfully realising the benefits achieved in the most successful water markets requires policy frameworks that provide requisite monitoring and enforcement, certainty in regulatory and trade policy for permit holders/traders, moderate transaction costs and reasonably large pools of potential traders (Breviglieri et al., 2018; Connor & Kaczan, 2013; Endo et al., 2018; Iftekhar et al., 2013, 2014; Wheeler et al., 2017).

Most water trade globally is for surface water. Groundwater cap-and-trade schemes are less developed in Australia (Lan et al., 2021a, 2021b) and globally (Brozović & Young, 2014). Furthermore, trade in capped water entitlements is most common amongst irrigators (Wheeler et al., 2017). Trade between irrigators and municipalities occurs to a lesser extent, especially in conditions of drought (Howitt & Hansen, 2005; Schwabe et al., 2020).

Recently, groundwater regulation has expanded to include forest plantation water impacts in regions where expanding forestry plantations have threatened security of water supply for municipal uses, irrigation and/or the environment (Bryan et al., 2015; Egginton et al., 2014). The risk of water supply arises because forested land use can lead to more interception of runoff, more evapotranspiration by vegetation and less groundwater recharge than cropping and grazing agricultural land uses that new plantations typically replace (Brown et al., 2007; Chu et al., 2010; Farley et al., 2005). South Africa was the first nation to regulate water interception from new plantation forests in the Fynbos ecoregion where large-scale reforestation was lowering stream flows and aquifer recharge (Chisholm, 2010). The regulation requires permits to establish new plantations that are only issued when the relevant State agency assessment indicates that streamflow impacts are acceptably small (Kruger et al., 2008).

The Lower Limestone Coast Prescribed Wells Area (LLC PWA), in the south-east of South Australia, is another one of the very few areas globally where plantation forestry requires water licences. The sudden growth in plantation forestry areas (approximately 35,000 ha by 2002

(Harvey, 2009)), particularly hardwood plantations (mainly *E. globulus*) used for pulp production, led to concerns amongst irrigation water licence holders. They were concerned that expanded forest estates were introducing significant additional demand on regional groundwater water resources that were unaccounted for in existing agricultural irrigation water regulation. This had potential to lower groundwater tables in a way that would threaten the security of irrigation water entitlements and groundwater-dependent wetland ecosystems (Prosser, 2009).

Observed declines in aquifer levels in some parts of the region led to the setting of volumetric allocations for irrigation water withdrawals and for entitlements for plantation forests at 'deemed' rates per hectare equal to estimated rates of water interception and extraction. Total levels of entitlement across all forest stands are differentiated across 61 Water Management Areas or WMAs (Figure 1). Due to continued declines in ground water levels in some parts of the LLC PWA, more stringent limits will become binding on the harvesting of current standing estate in some WMAs, and this is likely to result in reductions in forested areas and timber output from the region. However, the forest sector's water entitlements are tradeable, for example to irrigated lucerne, broadacre cropping, viticulture and horticulture industries in the region that also require water entitlements (ABS, 2020). Conceptually, the ability to trade water could reduce the adjustment costs for the forest industry given that reducing forested area can in-prnciple generate income from the sale of water permits that can at least partially offset lost revenues from forest products.

This article explores how the opportunity for water trade built into LLC forest water policy can facilitate flexibility and adaptation that reduces the cost of water entitlement curtailments for the forest sector. The specific questions addressed in this paper are: (1) what is the impact of the reduction in water extraction rights on business profit and land use mix?; (2) what is the benefit to the forestry industry from participating in a water market?; (3) what market price of water would compensate for the loss of profit from water allocation reductions; and (4) how sensitive are optimal business profit and land use mix to the key assumptions related to crop and water price assumptions?

A mathematical programming model is an appropriate way to evaluate the possibilities, given that the market for water trade between forestry and irrigation is prospective, and no water has been traded from forest to irrigation entitlement to date. Whilst evaluations of benefits from surface water and groundwater trade amongst irrigators are common, including many evaluations using mathematical programming (e.g. Gao et al., 2013; Ghosh et al., 2014;

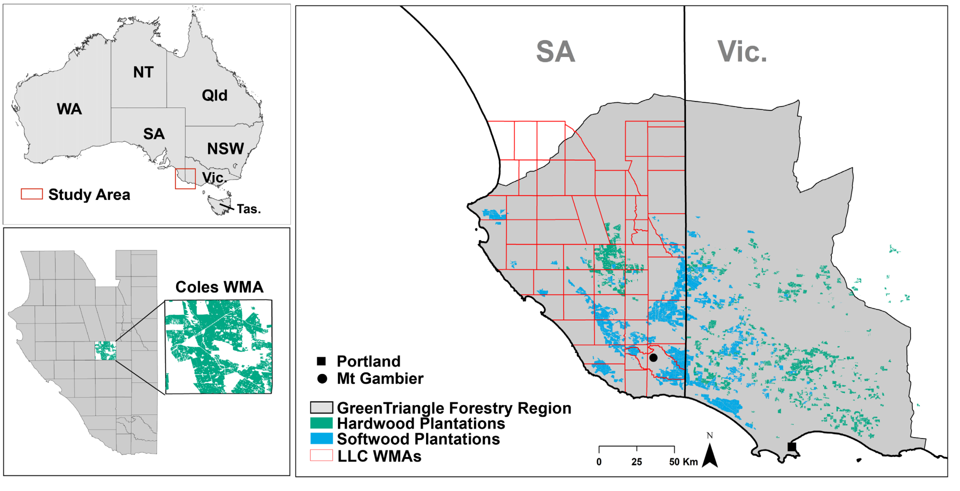

FIGURE 1 Lower Limestone Coast study area. [Colour figure can be viewed at wileyonlinelibrary.com]

Kahil et al., 2015; Ma et al., 2020), the focus of these is mostly the cropping and horticulture sectors. We are not aware of any other study that evaluates forest business profit impacts of reducing water entitlement levels or how the potential to participate in water markets can reduce this cost.

The remainder of the article is organised as follows. The next section describes the case study area. Section 3 describes the mathematical programming model developed to represent the economics of forest production and adaptation to reduced water entitlement levels, scenarios evaluated and how sensitivities to key uncertainties are evaluated. Results presentation in Section 4 describes how profit and forest plantation area in the region would likely evolve with and without possibilities to trade water and with a range of assumptions about key uncertainties. The article closes with a discussion of prospects and challenges for water trade policy to reduce forest sector costs of water entitlement curtailments.

2 | LOWER LIMESTONE COAST STUDY AREA

The study area is the LLC PWA in South Australia (Figure 1), an area covering approximately 1.45 million hectares in the south-east of the state (DEW, 2019a). The area is a highly productive agricultural region, with outputs valued at approximately AU$1.25 billion in 2018/2019 (ABS, 2020). The Limestone Coast also comprises part of the *Green Triangle* (GT) forest region. The GT is one of Australia's major plantation forestry regions and has extensive plantation hardwood and softwood resources totalling more than 200,000 hectares. In 2015–2019, the GT region accounted for 28 per cent of total national available plantation hardwood pulp log supply and 18 per cent of total national softwood sawlog (ABARES, 2018).

The LLC contains significant high-quality underground water resources in the form of two distinct underground water systems: the upper unconfined Tertiary Limestone Aquifer (known generally as the unconfined aquifer) and the lower Tertiary Confined Sand Aquifer (SENRMB, 2019). Declines in confined and unconfined aquifer levels had been observed in the LLC for some time with declines being attributed to a combination of reduced rainfall, increased groundwater extraction and interception of recharge to the aquifers (DEW, 2019a).

The LLC PWA is divided into 61 WMAs (Figure 1) in which volumetric allocations are set and groundwater resource condition is monitored.[1] Many WMAs in the LLC PWA are deemed to be at low risk of overallocation. However, several WMAs, including Coles, the WMA evaluated in this study, are seen to be at high risk of overexploitation and are marked for significant further reductions (50 per cent of current allocation) in volumetric allocation. Coles is of particular interest because it currently contains a large area of hardwood plantations, approximately 11,200 hectares (ABARES, 2018).

3 | LOWER LIMESTONE COAST WATER ALLOCATION PLAN

The lower Limestone Coast has experienced considerable hydrological changes due to drainage, clearance of native vegetation, irrigated agriculture and over a century of commercial forestry operations (Brookes et al., 2017). Commercial forestry plantations affect regional hydrology in several ways, through direct interception of rainfall, uptake of groundwater and increased losses by evapotranspiration (Benyon et al., 2007; Brookes et al., 2017). Due to widespread declines in ground water levels, all commercial plantation forestries in LLC PWA have been required to hold

[1]The LLC PWA is South Australian state legislation and does not apply to the Victorian Green Triangle.

water allocations under the LLC WAP since 2014. The LLC WAP provides entitlements for commercial forestry attached to a forest water licence which are required for activities including:

- Existing commercial forests;
- Commercial forests clear-felled no more than 3 years prior to the adoption of the WAP;
- Unplanted land where a valid development authorisation exists for a change of land use to commercial forest (DEW, 2019a).[2]

The water entitlements allocated to commercial forestry activities account for both recharge interception and direct groundwater extraction. All commercial forestries in the LLC PWA are deemed to intercept recharge; however, direct groundwater extraction is only applied where a plantation is planted above an aquifer with a depth of 6 m or shallower (DEW, 2019a; Figure S2). Additionally, hardwood and softwood species are deemed to intercept recharge and extract groundwater at different rates (see Supplementary Material).

A key feature of the LLC WAP is the ability to reduce water allocations in instances where the objectives of the plan are not being met (DEW, 2019a). A risk assessment undertaken in 2012 found significant changes in the depth to groundwater in several WMAs, including Coles, Short, Frances, Hynam East, and Zones 3A and 5A[3] (DEW, 2019b; Simmons et al., 2019). All six of these management areas had reduction in water allocations in 2016, with additional cuts planned for subsequent years. The WMA of Coles is targeted for the largest potential reduction in water allocations and is seen by regulators as being significantly overallocated. For example, the Target Management Limit (TML) for Coles is 25,228 ML/year; however, the WMA has outstanding allocations of approximately 51,161 ML/year (DEW, 2019b), necessitating reductions of up to 50 per cent in the most extreme case.

Regulated reductions in forest water entitlements would not take effect immediately, necessitating the sudden clearing of land, but would be applied after the harvest of existing stands. This would involve the staged reduction in forest extent that meets regulated allocation reductions in a way that minimise economic losses. However, an alternative to regulated reductions in water allocations also exists. Under the South Australian Natural Resource Management Act, 2004, the Act of parliament that administers the LLC WAP, the Minister responsible may approve alternative water use reduction strategies for forest water licensees such as changing species grown or silvicultural practices that demonstrably reduce water use. This provides forestry companies with flexibility in how they achieve forest water allocation reductions and/or demonstrate reduced impact of forestry activities on ground water resources. In order to avoid regulated allocation reductions, a forestry company could demonstrate diminished impact on the water resource by voluntarily committing to reducing forest extent and converting the land to nonwater extractive land uses, such as dry land agriculture. This enables the sale and transfer of the water asset to another currenlty under allocated WMA before allocations are terminated by regulators.

4 | MODEL DESCRIPTION

A mathematical programming model was developed to represent profit maximising responses to changes in water entitlements from a hardwood plantation forest estate consisting of multiple forest stands. Mathematical optimisation is a standard method that is regularly used in agricultural and environmental decision problems. While a CBA would allow us to estimate the net benefit of predefined scenarios, the benefit of mathematical

[2]Forest water allocations were automatically granted to existing plantations at the introduction of the LLC WAP.

[3]Full mapping of declines in water tables observed in the 2012 risk assessment can be found in DEW (2019b).

optimisation is that the optimal solutions across many scenarios and different targets can be found. The model involves staged decisions including: (1) when to harvest each of the currently planted stands, (2) whether to replace that harvested stand with another stand of timber or convert the land to pasture given water entitlement constraints for the estate water use as a whole and (3) whether to sell water entitlements necessitating further reductions in forest replanted.

The objective function is a maximisation of returns from four decision variables: (1) the area of existing forest stands harvested, $ab_{t,h,q,g}$ by initial stand age t, site quality q, deemed water use g harvested in year h. This is multiplied by revenue from the harvest of a stand with initial age class t at harvest period h on site quality q, and by return per hectare for this activity, $NPV_{t,h,q}$ in Equation 1; (2) area of harvested stands replanted to forest, $rab_{h,q,g}$, again multiplied by the present value of the future revenue expected from initiating this land use in year and continuing in perpetuity ($RLEV_{h,q}$, in Equation 1); (3) ag_h area of harvest forest converted to agricultural pasture, again multiplied by the net present value (NPV) of future revenue that this activity would be expected to create in perpetuity, $RPVag_h$; and (4) any revenues from sales of water entitlement, which is defined as volume sold ws_h.This is multiplied by price of water, WP discounted for h years in Equation 1. This could represent water sold within or out of the water plan area.

$$Maximise\ z = \sum_{t \in T} \sum_{h \in H} \sum_{q \in Q} \sum_{g \in G} ab_{t,h,q,g} \bullet NPV_{t,h,q} + rab_{h,q,g} \bullet RLEV_{h,q} + ag_h \bullet RPVag_h \sum_{h \in H} ws_h \bullet WP/(1+i)^h \quad (1)$$

The optimisation is subject to several area constraints. This includes constraints limiting areas harvested in all possible harvest years, h to be less than or equal to areas in existing stands of each quality, deemed water use level and stand planting date $AB_{t,q,g}$ (Equation 2). Further area constraint requires that the sum of harvested areas replanted to forest or converted to agriculture to be less than or equal to harvested forest area (Equation 3) and that all area decision variables take only positive values (Equation 4).

$$\sum_{h \in H} ab_{t,h,q,g} \leq AB_{t,q,g} \quad (2)$$

$$\sum_{h \in H} \sum_{q \in Q} \sum_{g \in G} rab_{h,q,g} + \sum_{h \in H} \sum_{q \in Q} ag_{hq} \leq \sum_{t \in T} \sum_{h \in H} \sum_{q \in Q} \sum_{g \in G} ab_{t,h,q,g} \quad (3)$$

$$ab_{t,h,q,g} \geq 0; rab_{h,q,g} \geq 0; ag_{hq} \geq 0; \quad (4)$$

A water entitlement constraint restricts the sum of water use of replanted forest, $\sum rab_{h,q,g} \bullet WU_g$ to be less than or equal to the total water use entitlement for the WMA, WA (Equation 5). Note that no entitlement is required for conversion of the stand to dryland agriculture, and this is the main possibility to reduce water use to stay within this constraint.

$$\sum_{g \in G} \left(\left(\sum_{q \in Q} \sum_{h \in H} rab_{h,q,g} \right) \bullet WU_g \right) \leq WA \quad (5)$$

In scenarios that allow water sales, a water sales constraint restricts the sum of water allocated to new forest stands, $\sum rab_{h,q,g} \bullet WU_g$ and any volume sold on water market, $\sum ws_h$ to be less than or equal to total entitlement for the estate, WA (Equation 6).

$$\sum_{g \in G} \left(\left(\sum_{q \in Q} \sum_{h \in H} rab_{h,q,g} \right) \bullet WU_g \right) - \sum_{h \in H} ws_h \leq WA \quad (6)$$

A notable feature of both constraints Equation 5 and Equation 6 is that consistent with the regional water policy, reductions in forest water entitlements are only required after harvesting of existing plantations. In other words, until stands are harvested, water use by that stand is not counted towards water constraints.

Key parameters in this representation of the forest estate including range of stand ages planted, site qualities, tree growth and production economics representing best estimates of the actual values are discussed in the supporting information available online.

4.1 | Scenarios evaluated

The scenarios tested were developed through consultation with the regional forestry industry to ensure a realistic portrayal of adaptation strategies to reduce economic loss from the water entitlement reductions under consideration in the region.

A *business-as-usual* (BAU) scenario provided a reference for comparison. This scenario assumed no cuts to water allocation, and all land held by forest companies is replanted to forest after harvest and remains in production in the current forest land use. Rotation length is a decision variable in this scenario and a profit maximisation objective identifies economically optimal rotation length for standing inventory and for subsequent rotations. Standard hardwood rotations in the region vary based on multiple factors, including commodity prices, growth rates and contractual arrangements. However, in line with regional common practice, we limit rotation lengths to between 10 and 15 years.

The *water cap reduction without trade* (reduction/no trade hereafter) scenario modelled a 50 per cent water allocation reduction in Coles as mooted under the LLC Water Allocation Plan (DEW, 2019a). In this scenario, a reduction in forest water allocation becomes binding on the harvest of standing plantations. Rotation length and locations to replant forest to maximise revenue (NPV) are the decision variables. This scenario does not allow for trade of any portion of the water allocation and assumes the remaining allocation is used for forestry and the reduced component is withdrawn by regulators. It is assumed that land not replanted to hardwoods is converted to non-irrigated pasture for beef production and earns the return to this enterprise.

The *water trade* scenarios also modelled a 50 per cent water cap reduction. Under this scenario, the reduction in forest water allocation becomes binding upon the harvest of standing plantations. However, forest extent can be further (voluntarily) reduced, and the water entitlement associated with the additional forest reduction sold in the market.[4] It is assumed that land not replanted to hardwoods is converted to dryland pasture and earns the return to this enterprise. Rotation length and locations to replant to forest versus convert to pasture, and volume of water to sell to maximise revenue (NPV) are the decision variables.

4.2 | Parameter sensitivities

An advantage of optimisation modelling, as opposed to econometrics, is the opportunity to assess novel markets and conditions outside the bounds of historical experience. The lack of historical precedent, however, also creates a challenge with the validation/calibration of such models.

[4]The option to move water allocation to an unallocated WMA and use it as a basis to establish new forest stands was discussed with industry representatives. This was seen as an unviable option due to constraints including land suitability and distance to processing and port infrastructure.

To address this and understand the sensitivities of the results to key uncertain parameter values, we solved the optimisation across variations in the size of the water allocation reduction, the water price and returns to agriculture, and the capacity of the water market to absorb additional water allocation sales.

4.2.1 | Water allocation reduction

The LLC WAP (DEW, 2019a) has made provisions for further reductions to forest water allocations in WMAs that are deemed to still be overallocated. The WMA of Coles (Figure 1) is earmarked for significant further reductions in the order of 50 per cent. Hydrological assessments are ongoing; however, these reductions are viewed as being at the upper end of estimates of eventual reductions in the LLC. As such, we tested reductions in forest water allocations of 10 and 30 per cent to compare potential impacts on NPV and estate area.

4.2.2 | Water sale price

The LLC has significant irrigated agricultural, horticultural and viticulture industries and water markets exist which allow the temporary or permanent trade of water allocations from forest water right holders to these agricultural water uses. Permanent water allocations commonly trade in the range of $600–$1300/ML (BOM, 2020; Waterfind, 2019). We tested water prices of $500, $1000 and $1500 per megalitre to capture a historically consistent range of low-to-high water prices for the LLC.

4.2.3 | Agricultural returns

We assumed that land not replanted to forest plantations is rehabilitated to permanent pasture. This is consistent with what is happening on the ground in the LLC in areas where plantations are not being re-established. Gross margins for dryland grazing enterprises in the study area were taken from the Department of Primary Industries Gross Margin Guides (PIRSA, 2020). The enterprises seen as most appropriate for newly rehabilitated pasture following forestry were cattle fattening and breeding enterprises. Fattening trade cattle had the lowest gross margin of approximately $52/ha while a beef breeding operation has an estimated gross margin of $266/ha. We tested gross margins of $100, $200 and $300/ha after reconversion costs are accounted for (Supplementary Material). We assume a 12-month fallow period after timber harvest allowing regeneration time before income can be generated from agriculture. During this period, an opportunity cost equivalent to the agricultural return is incurred.

4.2.4 | Water market capacity

Data show that water markets in the LLC can often be thin (WaterConnect, 2020). Demand for water in the region is dependent on factors including seasonal weather conditions, allocation remaining in seasonal carry over provisions, limitations on trade across WMA boundaries and the need for hydrogeological assessment of transfers between WMAs (DEW, 2019a). To address this, we modelled scenarios that constrained the level of water sales to 30, 70 and 100 per cent of available allocation to better understand the effects on the results of small market capacity for additional water in the region.

4.2.5 | Discount rate

We chose a real discount of 7.5 per cent reflecting a cost of capital of 10 per cent less inflation at a rate of 2.5 per cent which approximates the annual average consumer price index in Australia between 2010 and 2017 (Glassock, 2018). This value falls near the midpoint of the 5–14 per cent range commonly applied in Australia and New Zealand forestry valuations (Ferguson, 2018; Manley, 2016).

5 | RESULTS

The results are reported in four parts: (1) business as usual scenario, (2) water cap (without sales scenario), (3) sensitivity analysis for water cap scenario and (4) water sales scenario.

5.1 | Business as usual (BAU) scenario

The BAU case represents a future without a cap on forest water. It is assumed all land currently under forest plantation would be replanted to forest on harvest and remain in hardwood production. This scenario optimises without a water cap constraint and provides a baseline to compare with water cap and trade scenarios. The NPV of continuing hardwood production at current levels in Coles is AU$297.1 million (Figure 2). The results showed that the optimal rotation length for most of the standing estate is 12 years. For plantations established in 2006 and 2007, the optimal harvest age is 14 and 13 years, respectively. For all subsequent rotations, the optimal rotation length is 10 years for all site qualities.

5.2 | Water cap reduction/no trade

The modelled impact of a 50 per cent entitlement reduction is an 11 per cent NPV loss from $297.1 million to $264.4 million (Figure 2). The estimated area of the forest estate in Coles declined markedly (48 per cent) under this level of allocation reduction from 11,200 ha of hardwood plantations currently to 5831 ha.

Reductions were primarily in low and medium site quality areas with plantation extent being reduced by 94 per cent and 74 per cent on those site qualities, respectively (Figure 3).

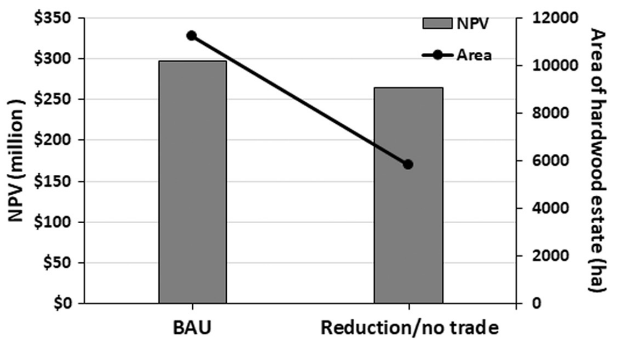

FIGURE 2 Net present value (NPV) from BAU hardwood forestry operations and NPV after 50 per cent reduction in forest water allocations implemented after harvest of standing estate assuming agricultural returns of $200/ha (no water sales considered).

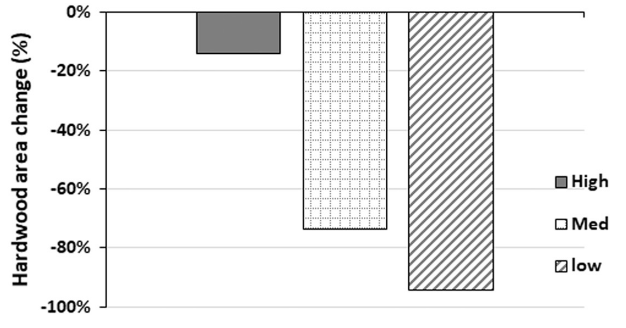

FIGURE 3 Reduction in estate size as a per cent after 50 per cent reduction in forest water allocations by site quality.

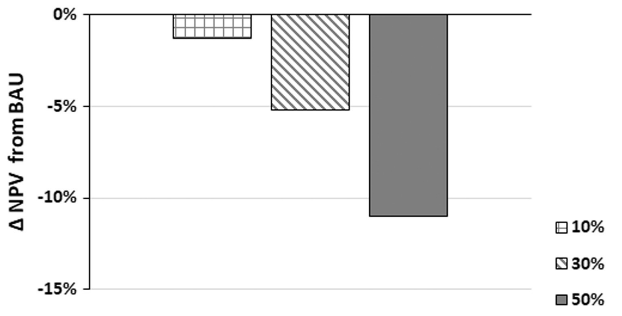

FIGURE 4 Change in NPV from BAU hardwood forestry operations under different forest water cap reduction scenarios (10, 30, 50%).

The results showed that high site quality stand area reduced by 14 per cent, which equated to approximately 1000 ha reduction in the plantation area.

The size of the water allocation reduction had a large effect on declines in NPV (Figure 4). A 30 per cent reduction in forest water allocations only reduced NPV by 5.2 per cent to $281.6 million. While a reduction in water allocation by 10 per cent reduced by only 1.2 per cent ($3.8 million) to $293.4 million.

The effect of smaller allocation reductions on replanting schedule (Figure 5a) and total area replanted to forest by 2030 (Figure 5b) were more pronounced in comparison with the 50 per cent cap scenario and BAU than effects on NPV. The 10 per cent allocation reduction saw little difference with the BAU scenario replanting schedule apart from 2023, when 232 ha of low site quality land was not replanted. By 2030, 1072 ha (9.4%) less land was replanted compared with the BAU case (Figure 5b). All reductions came from low site quality land.

A similar trend was observed with the 30 per cent reduction. As expected, the size of the initial cuts to replanted areas is larger than the 10 per cent reduction scenario and came from not just low-quality sites but also medium-quality sites. Replanting on medium-quality sites under a 30 per cent was reduced by approximately 32 per cent from 3360 ha over the decade to 2030 under the BAU scenario to 2244 ha under a 30 per cent water cap. Total area remaining in forest plantation by 2030 reduced by 28.5 per cent to 7984 ha compared with a BAU case (Figure 5b).

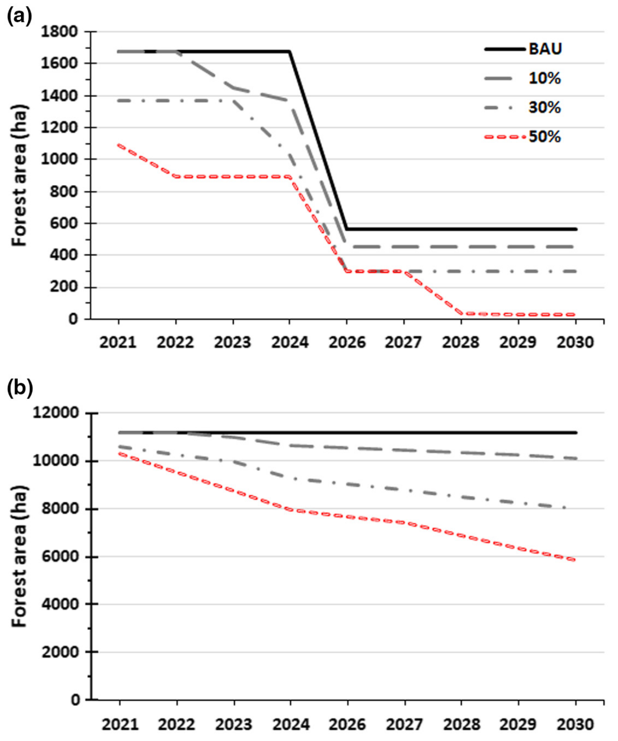

FIGURE 5 (a) Impact of the water trade on forest area replanting for BAU forestry and a 50%, 30% and 10% forest water cap and (b) the total area remaining in forest to 2030 under BAU forestry and 50%, 30% and 10% forest water cap. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Effect of agricultural returns on NPV for different forest water allocation reduction scenarios (% of BAU forestry operations).

	Agricultural returns		
Water allocation reduction (%)	**100 ($/ha)**	**200($/ha)**	**300($/ha)**
10	−1.7%	−1.3%	−0.9%
30	−6.5%	−5.2%	−4.0%
50	−13.1%	−11.0%	−9.0%

5.3 | Sensitivity of water cap scenario outcomes to agricultural returns

Table 1 presents the loss in NPV for the water cap (without water trade) scenario for different combinations of water allocation reduction levels and agricultural returns. The results suggest that the role of agricultural returns on buffering declines in NPV across all the water allocation reductions is likely to be comparatively small (Table 1). For example, considering the 50 per cent allocation reduction scenario, increasing expected agricultural returns from $200/ha to $300/ha increased NPV by 2 per cent, or approximately $6 million. Likewise, reducing expected agricultural returns by $100/ha reduced NPV by ~2 per cent. The effect of agricultural returns became smaller as the size of the allocation cut was reduced.

5.4 | Water sale scenarios

5.4.1 | NPV impacts

The water sell scenario tested the benefit of selling remaining water assets to maintain NPV. As an NPV-optimising strategy, this option may allow forest companies to maintain or improve NPV when compared to a BAU scenario. However, the results are sensitive to water price and agricultural returns (Figure 6). Considering a 50 per cent allocation reduction, $200/ha agricultural returns and $500/ML water price (consistent with the lower range observed in the regional water market), the option to sell water had almost no impact on NPV. This option increased returns by less than half a per cent from $264.36 million (Figure 2) under the water cap scenario without trade to $264.48 million under a water trade scenario (Figure 6a).

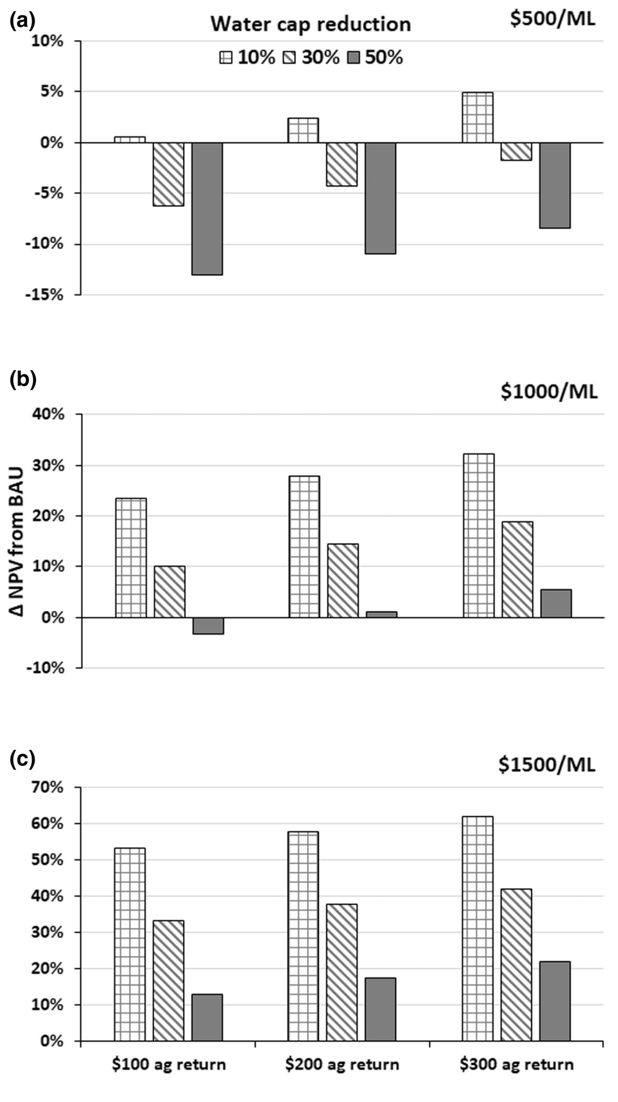

FIGURE 6 Change in NPV after forest water cap reductions of 10%, 30% or 50%, with the option to trade remaining water at prices of $500/ML, $1000/ML, $1500/ML and agricultural returns of $100/ha, $200/ha and $300/ha.

When higher water prices were considered, the option to sell remaining water entitlements improved NPV when compared to BAU forestry. In the $1000/ML, $200/ha agricultural return scenario, NPV improved by 1.1 per cent from the BAU scenario ($297.1 million) to $300.4 million. At the highest water price tested of $1500/ML, NPV increased by 17.4 per cent to $348.8 million compared with the BAU scenario.

The NPV maximising strategy under the 10 per cent or 30 per cent allocation cap was to sell a very large proportion of the remaining water allocation at water prices of $1000/ML or above. As seen in the 50 per cent allocation cap scenario, NPV of the company increased at $1000/ML and $1500/ML (and NPV decrease in the case of $500/ML water price).

As seen in the reduction/no trade scenario, the effect of agricultural returns on NPV was marginal but did increase at higher water prices. At $500/ML, the effect on NPV of increasing agricultural returns was approximately 2–2.5 per cent across the water cap scenarios. At $1500/ML, the impact of higher agricultural returns on NPV was approximately 4.5 per cent across the water cap scenarios.

5.4.2 | Land use impacts of forest water trade

The option to sell water on to the water market had a significant impact on replanting schedule and areas replanted to forest over the next decade when compared to both the BAU and reduction/no trade scenarios (Figure 7). Reduction in annual areas replanted was observed immediately (Figure 7a). At a water price of $500/ML, the option to sell water did not alter the results substantially from the reduction/no trade scenario with 895 ha replanted compared to 1090 ha

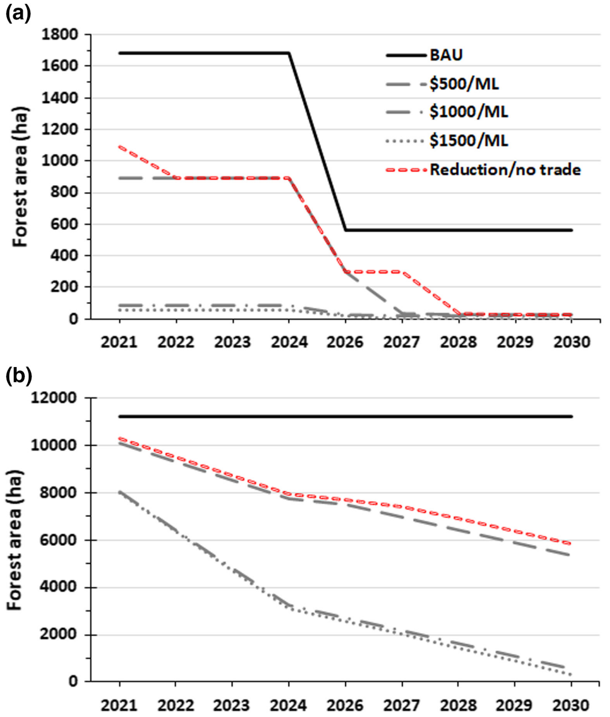

FIGURE 7 (a) Impact of the water trade on forest area replanting for a 50% forest water cap and (b) the total area remaining in forest to 2030. [Colour figure can be viewed at wileyonlinelibrary.com]

in the reduction/no trade scenario. However, the option to sell water at $500/ML did provide an economic opportunity to convert a further 269 ha to dry in 2027–2028.

At higher prices of $1000/ML and $1500/ML, substantial reductions in area replanted were observed. At these prices, only 88 ha of the possible 1366 ha available under the reduction/no-trade scenario was replanted to forest in 2021. By 2030, little-to-no area was replanted to forest under all water reduction scenarios in contrast to 560 ha that would have been replanted under the BAU case.

The option to sell additional water entitlement had a significant impact on the total area remaining in forest by 2030 (Figure 7b). The option to sell water at $500/ML resulted in 465 ha (8%) less area remaining in plantation forestry by 2030 when compared to the reduction/no trade scenario. The annual rate of forest area loss to 2030 was approximately 550 ha per year with 5367 ha remaining in forest by 2030 compared with yearly forest area loss of approximately 500 ha per year in the reduction/no trade scenario with 5832 ha remaining in 2030. At water prices of $1000/ML and greater, the reduction in forest area was extreme compared with both the $500/ML and reduction/no trade scenarios. Under these water price assumptions, remaining forest area by 2030 was reduced to 541 ha ($1000/ML) and 326 ha ($1500/ML). The annual reduction in forest area to 2030 was approximately 900 ha per year for both water price scenarios. However, annual reduction in forest area was far greater in the first half of the decade with rates of forest area reduction being approximately 1300 ha per year in the years 2021–2024.

5.5 | Constrained water market capacity

The above-mentioned results assume that the water market can absorb all additional water placed for sale. The water market in the LLC can be thin, depending on factors including limitations on trade across WMA boundaries and trends in the competitiveness of irrigated agriculture in the region compared with other locations. To address this, we modelled scenarios that applied a 50 per cent water allocation reduction but constrained the level of water sales to 30, 70 and 100 per cent of available allocation to better understand the effects of small market capacity on the strategy to sell water to maintain NPV.

Figure 8 displays the changes in NPV from BAU forestry considering different market depths for water sales in the LLC. At a $500/ML water price, a reduced water market capacity had very little impact on NPV. The results showed that selling water allocations at this price, regardless of market capacity, would increase NPV by only 0.05 per cent compared with the reduction/ no trade scenario. At this price, the strategy of using water sales to buffer against economic loss caused by a water allocation cap could be seen as ineffectual, regardless of the regional water market's capacity to absorb the addition of additional water volumes on to the market from forest water licence holders.

At $1000/ML, the ability to sell a proportion of remaining allocations was seen to improve NPV when compared to the reduction/no trade scenario. A market capacity able to absorb 30 per cent or available remaining allocations would improve NPV by approximately 4.8 per cent compared with the reduction/no trade scenario. While a market capacity of 70 per cent would be sufficient for water sales to almost compensate for lost revenue from a 50 per cent forest allocation reduction with NPV calculated to be 1.5 per cent below BAU. At $1500/ML, a reduction in NPV of 1.2 per cent on BAU was seen at the 30 per cent water market capacity level. However, if up to 70 per cent of remaining allocations could be sold, NPV was seen to increase by 10.5 per cent compared with the BAU scenario.

In terms of the area of hardwoods remaining by 2030, the ability to trade water further reduced plantation area even when market capacity constrained water sales (Figure 9). When a 30 per cent market capacity was tested, a $500/ML water price reduced the area remaining

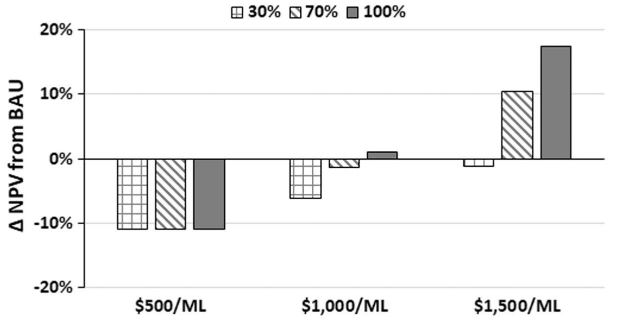

FIGURE 8 Net present value (NPV) of returns to forestry (millions $) assuming a 50% reduction in water allocation and market capacity to absorb 30%, 70% and 100% of remaining forest water allocations as water sales.

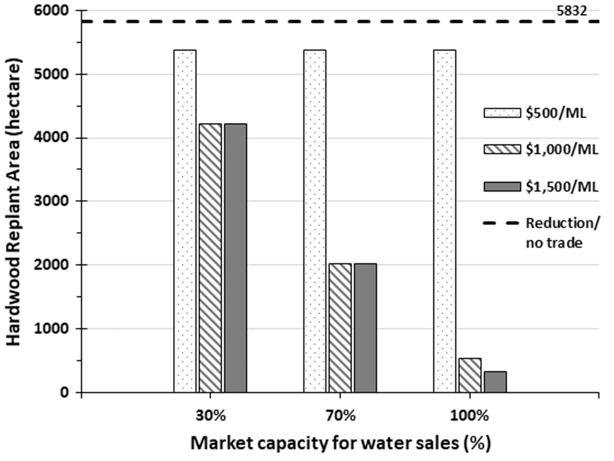

FIGURE 9 Areas replanted to hardwood assuming a 50% reduction in allocation with the option to trade water assuming market capacity of 30%, 70% and 100% of remaining forest water allocations.

in hardwood by an additional 464 ha compared with the reduction/no trade scenario. This was consistent regardless of market capacity. At higher water prices of $1000/ML and $1500/ML, the area reductions were identical with area remaining in hardwood reduced from 5832 ha in the reduction/no trade scenario to 4210 ha.

In the scenario where market capacity was constrained to 70 per cent, forest area by 2030 was 2023 ha for both higher water price scenarios. The assumption of 70 per cent market capacity resulted in 274 per cent ($1000/ML) and 520 per cent ($1500/ML) increase in forested area compared with a scenario where 100 per cent of available water allocation could be sold where economically viable.

6 | DISCUSSION AND CONCLUSION

This paper is one of the first studies that has examined the impact that caps on forest water interception and their inclusion in a cap-and-trade mechanism for groundwater can have on plantation extent and forestry returns. While there are currently few places globally where forestry plantations require water extraction rights, given the prospects of growing global water scarcity (van Vliet et al., 2021), it is likely that more forestry regions will face water management regulations. Using a case study in South Australia's GT region, we studied the impact of water entitlement reductions with and without water markets and the sensitivity of the results to assumptions about water market price, market size and returns to forestry versus agricultural land use.

Our analysis reveals that in a base case scenario, representing a 50 per cent reduction in water extraction rights, the loss in forest business profit would be around 11 per cent. This represents a 0.22 per cent profit loss for every 1 per cent reduction in water allocation. As this is the first time such an analysis has been performed for the plantation forestry industry, making a comparison with other forestry regions is difficult. However, such analyses are more common for irrigated agriculture. For example, Iftekhar and Fogarty (2017) found that for a 25 per cent reduction in groundwater extraction rights for irrigated agriculture, net revenue fell by 14 per cent for horticulturists in the Gnangara groundwater region in Western Australia. This equated to a 0.56 per cent profit loss for 1 per cent reduction in water allocation. The result shows that the impact of forest water allocation reductions in forest industry profit is likely to be smaller than agriculture and highlights the adaptive capacity of the forest to adjust to changing water regulations. This is partly due to the flexibility that arises from the capacity of the forestry industry to prioritise high-quality sites for replanting, the ability to adjust optimal rotation lengths under changing circumstances and the temporal production horizons of forestry vis-à-vis irrigated horticulture delaying the effect of any allocation reductions into the future.

Operating water markets exist for the region and provide an opportunity to potentially mitigate the effects of water allocation reductions through the liquidation of water assets. However, the potential for forest industry participants to utilise this option is reliant on water sale price. Examination of the impact of different possible water market prices reveals that the water price for permanent water entitlement must be at least $1000/ML to make participation in the water market through selling water extraction rights worthwhile for the local hardwood industry. Compared with the BAU case without water allocation reductions or water trade, the net benefit would be 1 per cent higher at this price. As expected, the net benefit will increase for higher water prices, and substantially so under some scenarios.

The finding that enhancing the tradability of water rights can introduce considerable benefit is consistent with experience of introducing trade provisions in the Australian MDB, which greatly facilitated adaptation to reduced water availability. In the *Millennium Drought* (2000–2010), up to a quarter of all allocations were traded in some years, most to higher value irrigation such as for viticulture and horticulture away from less valuable and more easily mothballed irrigated broadacre crops and pasture (Connor & Kaczan, 2013). The flexibility that this introduced in that region during the severe 2006–2007 drought is estimated to have saved AU$ 1.3 billion when regional economy follow-on impacts are also accounted (Dixon et al., 2008).

Our analysis reveals that the presence of a properly functioning water market, capable of absorbing supply would likely provide substantial financial benefit for forestry plantation asset owners faced with forest allocation reductions. Most of the benefit comes from the conversion of low- and medium-quality forestry sites to dryland agriculture. However, negative effects of such extensive land use change are likely through follow-on impacts in timber mill employment and regional economic outputs. Our results show that under some combinations of water price and agricultural returns, the best economic strategy for a profit-maximising forest plantation owner was to substantially reduce plantation area. This course of action may deliver private financial benefits; however, timber processing is a large contributor to the regional economy, worth over AU$1.2 billion in the study area (Schirmer et al., 2018) when including follow-on benefits. The impacts of such plantation area reductions are complex to model because the alternative land use activities also create regional employment. There is some limited evidence from the region that shows, in the case of dairy production, at least (which we did not model) the value add potential is higher than for *E. globulus* plantations (O'Toole et al., 2008). We do not include any negative externality impact of land use conversion into the profit function of the business, we assumed a profit maximising firm mostly concerned with their own profits. However, from a social welfare perspective, the negative and other social impacts of changes in forestry operations could be modelled to understand the regional economic impact of a water market better. Finally, we do not include the option value of retaining water entitlements as part of a portfolio. Consideration of this issue should be evaluated in future research.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are explained in detail in the supporting information. These data were derived from public domain sources freely accessible on the web. URLs linking to these data are provided in the references of the main article and supporting information. The authors can provide relevant spatial data sets upon request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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