GROUNDWATER RESPONSE TO PARTIAL PLANTINGS ON DISCHARGE ZONES AT FIVE SITES IN THE SOUTH WEST OF WESTERN AUSTRALIA.

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Abstract:
The effects of dryland salinity are prevalent across southwest Western Australia, particularly in discharge zones of cleared catchments with low relief topography. Results from discharge plantings (5-19% of catchment planted) established in 1991, on five 70 – 250 ha catchments within the 450 – 700 mm yr^{-1} rainfall zone of southwest Western Australia, show that there has been a decrease in groundwater levels over the last 15 years. It is considered unlikely that this change in groundwater is due to reduced regional rainfall. Whole catchment, median groundwater levels decreased across individual sites from 0.13 m to 1.26 m, the differences reflecting their hydrogeology and planting designs. Groundwater levels in lower landscape positions declined by between 0.24 and 1.59 m over the measurement period. There is a significant relationship between groundwater depletion and proximity to trees that is particularly evident for plantings on mid slope positions and in areas with regolith depths of up to 11 m. Little or no response was found greater than 17 m from trees. Moreover, it was found that growth rates of *Eucalyptus globulus* would not be profitable for timber/pulp at three sites. Although the remaining two, highest rainfall, sites showed little groundwater response to trees, they had the only economically productive *E. globulus* growth rates (>12 m^3 ha^{-1} yr^{-1}). It is speculated that the variable response to reforestation is also due to groundwater quality and subsoil properties.

Introduction

The clearing of previously forested land for cropping and grazing, has lead to the spread of dryland salinity across Australia (George *et al.*, 1999; NLWRA, 2001). Currently in Australia, seventy percent of land affected by dryland salinity occurs within Western Australia. This equates to over 1.8 million hectares of salt affected land, and this is predicted to rise to over 8.8 million hectares by 2050 (NLWRA, 2001; Hatton *et al.*, 2003). Secondary salinisation is particularly ubiquitous within south-western Australia, which has low hydraulic gradients associated with the predominantly low relief topography (Hatton *et al.*, 2003).

Studies on the effectiveness of plant-based management schemes for groundwater control and economic returns show that trees are one of the more effective solutions to excess groundwater commonly associated with salinity. However, water uptake by plants depends on a range of factors, such as species, rotation length (tree age), climate, growth and vigor, extent of plantings, positioning in the landscape and local geology (George *et al.*, 1999; Hatton *et al.*, 2003; Robinson *et al.*, 2006).

For short to medium term rotations (up to 20 years), the impact of trees on groundwater greatly depends on the proportion of trees and their position within the catchment. Studies show that plantings on discharge zones within low rainfall areas (<600 mm yr^{-1}) have poor growth and low transpiration rates, predominantly due to water logging and elevated soil salinity levels (George *et al.*, 1999). Past studies within Western Australia also demonstrate that increased tree cover proportionally reduces groundwater levels (Bell *et al.*, 1990; George *et al.*, 1999). However, there has been considerable debate regarding the area required to attain hydrologic control, with estimates ranging from 25 – 30% tree cover (Bell *et al.*, 1990; Salama *et al.*, 1993) to 70 – 80% tree cover (George *et al.*, 1999).

Remediation of dryland salinity has an abundance of interacting variables, and this has resulted in different plant-based management schemes. The aim of this project was to isolate major variables (proximity to trees, slope position, and tree growth rates) for minor discharge plantings (covering < 19 % catchment area) on small, first order catchments within the 450 – 700 mm rainfall zone of southwest Western Australia.

Methods

The study involved the reassessment of five sites established in 1991 by the then Department of Agriculture Western Australia (AGWA), as part of the High Water Use Agricultural Systems (HWUAS) project. The sites are located on private farms near the towns of Kojonup, Williams, Frankland, Dinninup and Darkan in southwest Western Australia (Figure 1). The five HWUAS sites were partially reforested (5 to 19% of the catchment) in discharge to lower slope areas with rows of mixed tree species and blocks of commercial trees (i.e. *Eucalyptus globulus*) to determine whether this amount of reforestation was adequate to control landscape hydrology (Table 1).

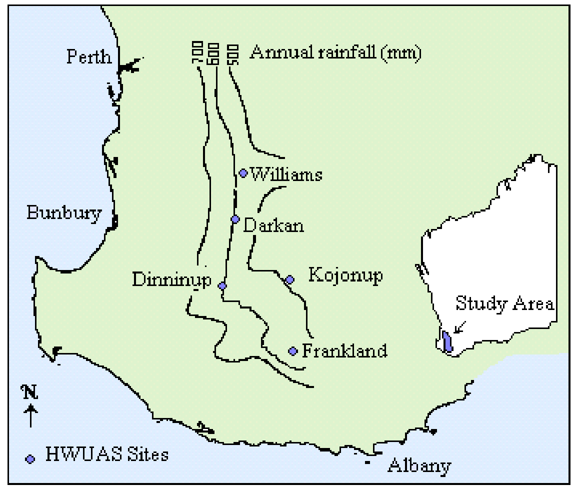

Figure 1: Locality of sites in south-western Australia.

The groundwater levels were measured in December 2006, with these data used in conjunction with historic groundwater data, which covered the period of 1990 – 2001 for the five sites. The data were used to calculate the linear summer groundwater change over the 15 years since establishment for all bores (including bores measured as dry in 2006). Groundwater change was statistically analysed for the 111 bores using the Kruskal Wallis non-parametric test, with groundwater change categorized by site, proximity to trees, slope position, depth to bedrock and water parameters (pH and EC). The impact of climate variation over the 15 years was evaluated by comparing groundwater trends for control bores (untreated sites on upper slopes, in remnant vegetation and on adjacent catchments) with treated bores.

Economic analysis of the 15 year old stands of *E. globulus* involved measuring the volumes of trees in ten or more 100 m^2 plots per site, in December 2006. Volumes were used to calculate the mean annual increment (m^2 ha^{-1} yr^{-1}) in order to estimate stand profitability based on standard stumpage returns and harvesting costs for the region.

Results and Discussion

The effects of dryland salinity were prevalent at the five sites in 1990, with all sites possessing shallow water tables, elevated groundwater and soil salinity levels, and visible accumulations of water within the discharge zones (Smith *et al.*, 1998). Today, the sites show decreased surface water flow and erosion, as well as either reduced or constant soil salinity levels and decreased water table levels (Table 1). A comparison between treated and untreated areas at the five sites shows that despite a decrease in rainfall over time, climate change has had little effect on groundwater levels (Figure 2a).

Since the establishment of the trees in 1991 until December 2006, the minimum[1] median overall catchment groundwater level has decreased by 0.65 m for all sites combined. This differs to the earlier findings of Smith *et al.* (1998) who reported an average rise in groundwater levels for the sites of 0.23 m yr^{-1} (1991-1997).

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[1] Minimum as calculations include the change in groundwater for bores measured as dry in December 2006.

The plantings at the Kojonup site had the greatest impact on groundwater levels (0.084 m yr^{-1}, followed by those at the Frankland and Williams sites (0.056 and 0.053 m yr^{-1}, respectively (Table 1). There were small decreases at both Darkan (0.012 m yr^{-1}) and Dinninup (0.009 m yr^{-1}). In the lower landscape zone the decrease in groundwater levels varied between 0.106 m yr^{-1} at Kojonup to 0.016 m yr^{-1} at Dinninup. These results are insufficient to show a relationship between the proportion of catchment planted and groundwater response, with the Kojonup site, which had the greatest lowering of groundwater, only having 8% of its total area treated.

The results also show a significant relationship between the impact on groundwater levels and proximity to trees, particularly for plantings located on mid and lower slope positions (Figure 2b). These results support findings by several authors, who found that groundwater levels are best managed by addressing the region of water input (recharge zone) (McConnell 1998; George *et al.*, 1999).

Analysis of the distance to trees and groundwater change found that to achieve a decrease of at least 0.5 m over a 15 year time period, trees need to be located within 17 m. This supports findings by George *et al.* (1999) that the impact of trees on groundwater is restricted to within 10 – 30 m for areas with shallow expressions of the deep aquifer. Robinson *et al.'s* (2006) findings also show similar results, with drying depths reaching 4 to 10 m vertically and 15 m laterally after 8 years of tree growth. Groundwater results for the Kojonup site also indicate that groundwater uptake increased with increasing depth to bedrock, from 3 m to a maximum of 11 m regolith depth: beyond which, effective uptake by roots appears to become inhibited. This supports findings by Harper *et al.* (2000), who found that *E. globulus* plantings, for phase-farming within Western Australia, would have greater water uptake on deep (>9 m) clay regolith sites.

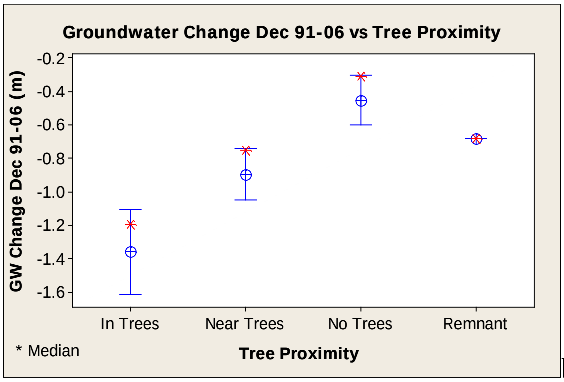
Site analysis also revealed that the groundwater uptake by trees was limited by groundwater quality (pH levels <5.2 and by possible aquicludes (clay-pan layers impenetrable to tree roots). This was particularly apparent for the Darkan and Dinninup sites, which showed only minor changes in groundwater levels, despite having the only economically productive blue gum growth rates (>12 m^3 ha^{-1} yr^{-1}). These two sites had the highest rainfall in a region where Harper *et al.* (1999) reported a strong relationship between rainfall and stand productivity.

Economic analysis of the stands of *E. globulus* found that growth rates could be profitable for timber/pulp for plantings covering >10 ha, with 450 – 700 mm yr^{-1} rainfall, soil salinity levels below 2000 dS m^{-1} (15 years post-establishment) and within 150 km of a mill. However, these results are based on timber profits only: non-productive plantings that decrease groundwater levels still provide numerous other economic and intangible benefits. These include environmental benefits for land and river systems, and improved longevity of surrounding productive farmland.

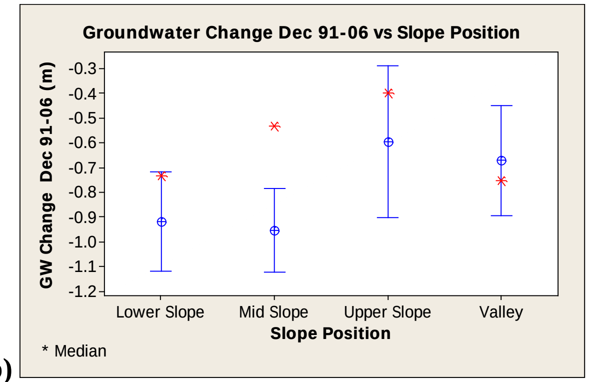
Table 1: Groundwater change (median and mean) over the period 1991-2006 for all bores at each site

Site	*Annual Rainfall (mm)*	*Area Planted (ha)*	*Catchment Size (ha)*	*% Planted*	*n bores*	*Median GW Change (m yr^{-1})*	*Mean GW Change (m yr^{-1}) ± s.e.*	*P Slope*	*P Proximity to Trees*
Darkan	667	10	90	10%	10	-0.012	-0.013 ± 0.012	0.30	0.11
Dinninup	667	13	250	5%	23	-0.009	-0.023 ± 0.014	0.09	0.75
Kojonup	461	13	170	8%	42	-0.084	-0.092 ± 0.010	0.24	0.11
Williams	525	13	70	19%	18	-0.053	-0.057 ± 0.013	0.20	0.02
*Frankland**	526	14	80	18%	18	-0.056	-0.076 ± 0.030	0.50	0.01

s.e. = standard error
*Frankland site results for first rotation (1991-1998).
** GW: Groundwater



a)



b)

Figure 2: Plot of all sites (excluding Frankland), showing mean summer groundwater (GW) change (1991-2006) with standard error bar and median, categorised by a) proximity to trees and b) slope position.

Conclusions & Recommendations

Overall, the reassessment of the HWUAS Project found that, despite climate variability, groundwater levels did decrease locally at the five sites in response to establishment of plantings in discharge zones. The groundwater response to plantings varied with slope position and proximity to trees; the greatest responses to plantings occurred in recharge zones (lower to mid slope positions), particularly within 17 m of trees and with regolith of 3 - 11 m depth. Within these recharge zones at the five sites, the groundwater decreased between 0.24 and 1.59 m after 15 years. The longer term effects of this reforestation on groundwater levels bear further investigation.

The project also provided some insights into the requirements for long-term hydrological field experiments. Several obstacles were encountered in relation to on-site conditions, non-continuous sampling and insufficient screen depths (dry bores). Establishment of a long-term study site is costly; therefore, to get sound returns on this investment, careful consideration of the future of the project should be taken into account. While many variables, such as slope position, proximity to trees, plant species, soil types and geological variations, are known, their interactions and processes still require further long-term investigation to properly understand the factors that can contribute to remediation of dryland salinity.

References

Bell R.W., Schofield N.J., Loh I.C. and Bari M.A. (1990). *Groundwater response to reforestation in the Darling Range of Western Australia.* Journal of Hydrology 115: 297-317.

George R.J., Nulsen R.A., Ferdowsian R. and Raper G.P. (1999). *Interactions between trees and groundwaters in recharge and discharge areas - A survey of Western Australian sites.* Agricultural Water Management 39: 91-113.

Harper, R. J., Edwards, J. G., McGrath, J. F., Reilly, T. J. and Ward, S.L. (1999). *Performance of* Eucalyptus globulus *plantations in south-western Australia in relation to soils and climate factors.* "Balancing Productivity and Drought Risk in Blue Gum Plantations" Karri Valley Resort, Pemberton, Western Australia, 9-10 November, 1999.

Harper R.J., Hatton T.J., Crombie D.S., Dawes W.R., Abbott L.K., Challen R.P. and House C. (2000). *Phase Farming with Trees.* Joint Venture Agroforestry Program, RIRDC Publication No 00/48, Western Australia.

Hatton T.J., Ruprecht J. and George R.J. (2003). *Preclearing hydrology of the Western Australia wheatbelt: Target for the future?* Plant and Soil 257: 341-356.

NLWRA (2001). *Australian Dryland Salinity Assessment* 2000. National Land and Water Resources Audit; Extent, Impacts, Processes, Monitoring and Management Options, Land and Water Australia, Canberra.

Robinson, N., Harper, R. J. and Smettem, K. R. J. (2006). *Soil water depletion by Eucalyptus spp. tree belts integrated into dryland agricultural systems.* Plant and Soil 286:141-151.

Salama R.B., Farrington P., Bartle G.A. and G.D., W. (1993). *The role of geological structures and relict channels in the development of dryland salinity in the wheatbelt of Western Australia.* Australian Journal of Earth Sciences 40: 45-56.

Smith A.D., George R.J., Scott P.R., Bennett D.L., Rippon R.J., Orr G.J. and Tille P.J. (1998). *Results of Investigations into the Groundwater Response and Productivity of High Water Use Agricultural Systems, 1990-1997.* Summary of all sites, Resource Management Technical Report 172, Western Australia.