Long term monitoring of groundwater levels at 24 sites in Western Australia shows that integrated farm forestry systems have little impact on salinity

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Introduction

Since the mid-1980s, farmers have been encouraged to revegetate cleared agricultural land to reduce groundwater recharge and the area of dryland salinity. Adoption has been influenced by the success of extensive commercial forestry trials in high rainfall, water supply catchments where groundwater and salinity levels were lowered by almost complete reforestation (Schofield et al., 1989) and the attractive prices paid by companies where whole farms are converted to trees. However, where smaller proportions are planted because the dominant income is from agriculture, farmers are becoming increasingly reluctant to plant extensive areas to control salinity without better knowledge. In particular, farmers want to know how much revegetation will be required and in what format it should be planted to reduce their risk and extent of salinity. They are also requesting guarantees on the likely financial returns from farm forestry so they can better analyse the cost benefit of implementing farm forestry. Additionally, governments are currently investing in the development of a farm forestry industry (Anon., 2005). Salinity management is proposed as a major outcome of both public and private schemes.

George et al. (1999) reviewed all available watertable response data from a wide range of sites in Western Australia. While many of their 80 sites were not designed to affect salinity and some were at a comparatively early stage, the review concluded that; trees are best planted in recharge areas; discharge plantings rarely reclaim saline areas; responses are generally confined beneath the planting; and extensive plantings (perhaps influencing as much as 80% of the landscape) are required to significantly reduce watertables and significantly reduce the area of salinity. Despite these findings from almost a decade ago, the promotion of salinity focused, small, so-called integrated farm forestry systems, has continued.

To improve our predictive capacity to forecast the effect of integrating trees in agricultural landscapes on groundwater levels and salinity, and update earlier work, trials established on 24 sites within discrete groundwater catchments on 15 farms between 1990 and 1996 in south-western Australia, were analysed. These trials were mostly established within upland catchments, using a range of designs such as contour belts, linear and contour alleys, blocks and targeted plantings in hydrologically discrete areas. The area planted varied from almost complete revegetation (over 98%) to less that 5% (on or near saline seeps).

Methods

The sites investigated (Table 1) are all within the medium rainfall (500-800 mm) "woolbelt" region, south-east of Perth. Groundwater systems are local-scaled and formed within weathered Archaean granitoid regolith (which at some sites is overlain by Cenozoic sediments), 2-40 m deep. Sites were cleared for agriculture between 1935 and 1981. At most sites the planting design (area, layout, species, etc) was developed by the landholders in consultation with plantation managers, "Landcare" officers and hydrologists, using the best available knowledge, however ultimately the landholder selected the final design on practical considerations. The revegetation comprised various proportions of commercial forestry species, mainly *Eucalyptus globulus*, *E. saligna*, and *Pinus pinaster* as well as mixtures of salt tolerant species such as *E. camaldulensis, E occidentalis* and *Casuarina spp.* in discharge areas.

The 'water table response' to revegetation was calculated from regular measurements made from 226 piezometers and observation bore sites. These were installed at, or just prior to, the time of planting using a rotary airblast drilling rig. At many bore sites, a series of multiple depth bores was installed so that groundwater salinity profiles and aquifer pressure relationships could be determined. The responses reported here are for time periods of between 10 and 21 years following revegetation. Changes in saline areas were determined by a combination of site inspection and interpretation of aerial photography. The possible influence of rainfall variations was determined by comparing the accumulative monthly residual rainfall (AMRR) during the period of investigation, with the AMRR from 1975 onwards at a number of locations within the study area. Because AMRR remained similar for both time periods rainfall variability was determined not to be a major influence on watertable response.

Table 1 Site characteristics and results

Site	Post 1975 a.a.r. (mm)	No. of bores	Record length (years)	Revegetation age (year)	Watertable salinity (mg/L)	Catchment area (ha)	Remnant vegetation (%)	Revegetation (%)	Total vegetation (%)	Revegetation layout*	Landscape position of revegetation#	Mean watertable response within revegetation (m)	Mean watertable response down-slope (m)	Groundwater gradient at commencement (%)	Groundwater gradient in 2007 (%)	Area of salt (change)~	Severity of salt (change)~	Watertable response type@
CochraneSA	517	16	15	12	6130	6651	0.1	<0.1	0.1	la	l	-0.04	-0.08	0.19	0.19	nc	r*	nt
CochraneHS	517	5	15	14	2960	10	0.1	21.0	21.1	b	m	-1.1	0	0.94	0.53	nc	nc	ne
CochraneHB	517	10	13	14	14240	122	10.2	5.2	15.3	cb	m	0.2	0.06	2.56	2.55	nc	nc	nt
Coffey	583	7	13	12	9710	73	<0.1	5.9	5.9	la	c	-0.9	-0.16	2.40	2.17	i	i	ne
Darkan	553	7	15	16	9620	97	8.4	11.9	20.4	b, la	l, m	0	-0.02	3.69	3.68	nc	r*	nt
Dinninup	513	12	15	16	2260	276	13.8	8.3	22.1	b	l, m	-0.38	0.32	1.56	1.56	nc	nc	ne
Frankland	519	17	15	16	12750	90	3.2	24.8	28.0	b	l	-0.12	-	3.25	3.13	nc	r*	nt
Gordon	583	5	9	10	7260	51	20.4	11.9	32.3	b	m	0.14	0.14	1.91	1.79	nc	i	nt
Harrington	567	9	10	12	4720	47	2.1	21.4	23.6	ca	c	-1.85	-	3.94	3.94	r	r	ne
Hilder Alley	536	9	12	13	3070	83	10.3	31.4	41.8	la	c	-0.88	0.16	1.11	1.12	nc	nc	ne
Hilder Seep	536	3	12	18	2230	54	8.2	14.8	23.0	b	l	-0.23	-	0.16	2.27	i	i	ne
Jenkins	819	9	15	20	4230	72	76.5	7.4	83.8	la	c	-2.10	-	3.72	4.27	r	r	ne
Kojonup	465	43	15	16	5560	129	<0.1	16.0	16.0	b, la	l, m	-1.96	-0.28	1.53	1.61	r	r*	ne
Mayanup	583	11	19	21	11880	94	<0.1	10.1	10.1	b	l	0.13	0.07	1.27	1.25	nc	nc	nt
Purse1	583	5	11	11	8900	15	<0.1	41.8	41.8	b	c	-1.60	-	-	-	nc	r	ne
Purse2	583	4	11	11	7490	10	<0.1	31.7	31.7	b	u	-	-0.58	6.34	4.79	nc	nc	-
Purse3	583	5	11	11	7680	25	8.0	45.8	53.8	b(s)	l, u	-3.06	-	1.97	1.06	r	r	ne
Purse4	583	8	11	11	6590	134	7.1	10.7	17.7	b(s)	l, m	-1.99	-	2.51	1.77	nc	nc	ne
Ritson1	583	5	13	13	5140	72	6.3	29.7	36.0	ca	u, m	-2.44	-0.70	4.38	4.32	nc	r	lr
Ritson2	583	4	13	13	410	28	16.0	22.7	38.7	ca	m, u	-1.54	-	7.64	7.62	nc	r	lr
Uren	714	8	12	10	770	8286	95.8	2.8	98.6	b	m, u	-5.26	-1.10	0.74	0.21	r	r	-
Wardle1	508	4	12	13	3530	33	<0.1	9.7	9.7	ca	m, u	-1.24	0.29	3.67	3.40	nc	i	ne
Wardle2	508	4	12	13	5100	63	10.2	5.0	15.2	ca	m, u	-1.91	0.1	2.76	2.39	i	i	ne
Williams	519	16	16	16	3850	61	7.2	23.0	30.2	b	m, l	-0.92	-	1.60	1.48	nc	r*	ne

* la = linear alley, b(s) = block(s), cb = contour belt, ca = contour alley; ~ nc = no change, r = reduction, i = increase; # l = lower slope, m = mid slope. c = entire catena, u = upper slope; @ ne = new equilibrium, nt = no trend, lr = linear reduction.

Results and discussion

Regression analysis was undertaken between the proportions of the catchment vegetated (PV) and the mean change in water tables both within the revegetated area and within the adjacent, untreated (down slope discharge) area. Figure 1 shows that PV accounts for 49% of the variability in water table response within the revegetated area ($P < 0.0005$). Within this area, maximum mean watertable response to revegetation is -5.26 m at the Uren site (98% vegetated, Table 1), with near zero response at Cochrane SA, (saline valley, alley revegetation on <0.1% of larger catchment. The relationship between PV and response indicates that more than 50% PV is required to reduce watertables by more than 2 m beneath the revegetation system for all forestry layouts. The maximum observed variability (of approximately +/- 2 m) is modest given the range of factors that could be expected to influence response across all sites and indicate that PV is likely to be the major influence.

Inclusion of watertable salinity and aquifer gradient (as an indictor of transmissivity) with PV to the relationship explained an additional 5% of variability.

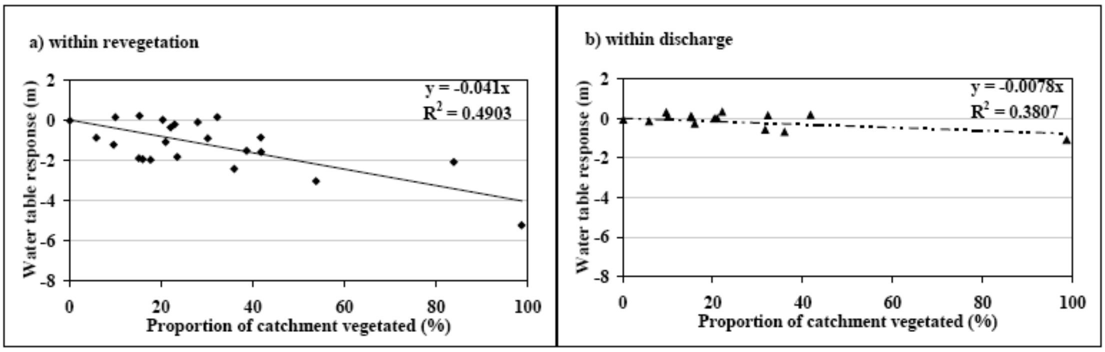

Figure 1 Relationship between the proportion of the catchment vegetated (including remnant vegetation) and (a) the watertable response within the revegetated area and (b) at the downslope, adjacent unplanted discharge

Watertable response in adjacent, downslope, untreated discharges was minor and not as well correlated with PV ($P < 0.01$; described 38% of the variability). For example, at the Uren site which has > 98% PV the response in a bore within the discharge located 100 m from the lower edge of theplantation was -1.1 m. At PVs of between 30 % and 50 % responses ranged from -0.7 m to +0.16 m, with no reductions greater than 0.3 m for PV < 30%. These results are not surprising given that the limited watertable reduction caused almost no change in groundwater gradients (Table 1.). Also, even small quantities of recharge occurring *in situ* and in adjacent unplanted areas could provide enough groundwater to maintain watertables given only modest (if any) groundwater throughflow reductions from the upslope plantings.

Revegetation resulted in small reductions of saline land at 5 sites (Table1), although at 4 of these the revegetation extends into the saline area. However at 3 sites, salinity increased during the period of revegetation. Of the 16 sites with no obvious change in the area of salinity, 5 had apparent reductions in severity. At all of these sites it is likely that changes in agricultural management, such as controlled grazing and introduction of perennial and other salt tolerant pastures (often facilitated by re-alignment of fencing during tree establishment), were responsible for the improvement.

Visual assessment of the extent of salinity further downslope at the confluence with the next, adjacent catchment showed no reduction attributable to the revegetation at any site (Table 1), suggesting that land salinity benefits are likely to be localized near areas of revegetation.

Twenty five years is considered the maximum practical planning horizon for most land managers, and this coincides with approximately 2 rotations of a pulp timber forestry regime or a (projected) single rotation of a saw log management regime. Because many of the sites in this study are younger than 25 years, the temporal pattern of watertable response was examined to determine if further reductions in watertables are likely (Table 1). At 14 sites "new equilibrium" groundwater conditions appear to have been reached (e.g. Wardle 2, Figure 2) meaning further response would not be expected. This may be because the vegetation has achieved near maximum water use at canopy closure (close to maximum leaf area - known to be a good surrogate for water use), and/or the catchment is at a new hydrologic balance. It is also indicates that the vegetation has most effect on reducing recharge, and does not indicate any significant transpiration of groundwater. Of the remaining sites 6 with "no trend", 2 were indeterminate and only 2 sites (Ritson1 & 2) had "reducing linear" trends, indicating that further reductions are possible.

In addition to the responses measured it maybe argued that revegetation may have prevented additional watertable rises had the areas not been planted. To assess this we examined the average change in water table in control bores (13 sites) and found this to be -0.06 m, with a range of -0.66 to 0.52 m. This data and the observation of mean time since clearing (45 years), suggests either most sites were at/near equilibrium or that the revegetation may have slightly brought forward the date of equilibrium.

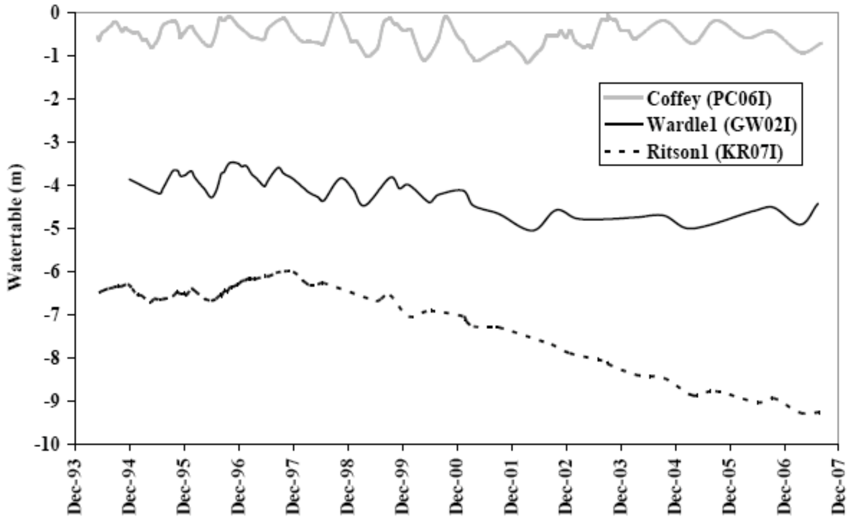

Figure 2 **Examples of "PC=no trend", "GW=new equilibrium", and "KR=reducing linear" responses**

Conclusions

- At the 24 sites measured, PV is the most significant factor influencing groundwater reduction, with large PVs in any design or layout required to produce large reductions in groundwater levels beneath trees.
- Reductions are localized beneath the revegetation system, with little impact on measured groundwater levels or extent of saline land, either immediately downslope of the revegetation or at the confluence of adjoining catchments at PVs < 98%.
- Typically, < 50% PV is unlikely to result in significant, measurable on-farm salinity benefits.
- PV levels that are high enough to provide significant salinity benefits at the farm scale are unlikely to be attractive to "mainstream" farmers unless the relinquished annual income derived from agriculture is at least replaced by annual income derived from the revegetation.
- PV levels required for significant on-farm salinity benefit will be far in excess (3-5 times) of the proportion of land affected by salinity at hydrologic equilibrium.
- Regional to catchment-scale stream salinity benefits may accrue at moderate PVs through reduced discharge, however at sites studied here, this appears unlikely given the PV, limited reduction in gradient and saline area; this benefit could also be counter-balanced by the reduction in fresh runoff.
- The bulk of the hydrologic impacts appear to have been reached after 10 years of revegetation, some 15 years before harvest for some tree crops.
- The generally limited watertable and salinity impact at low PV is of similar magnitude to that previously reported in George et al. (1999).

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