Water Authority

of Western Australia

Hydrology Branch

Stream Salinity Control by Increased Transpiration of Vegetation

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STREAM SALINITY CONTROL BY INCREASED TRANSPIRATION OF VEGETATION

1. INTRODUCTION

The impact of agricultural development on the salinity of water resources in the south-west of Western Australia has been dramatic. Recent updating of the water resources inventory of Western Australia indicates 35.3% of the divertible surface water resources of the South-West Drainage Division of Australia have salinities in excess of 1 000 mg/L TSS (brackish or saline). A further 17.0% are of marginal quality (500 to 1 000 mg/L) and only 47.7% remain fresh (less than 500 mg/L TSS). Prior to agricultural development virtually all the divertible surface water resources of the region were believed to be fresh.

The relationship between clearing native forest vegetation for agriculture and the subsequent increase in stream salinity has been clearly demonstrated in recent years although the first observations of the effects were reported early in the century. The permanent removal of deep rooted forest vegetation and its replacement with shallow rooted crops and pastures has led to an increase in the soil water passing the base of the root zone each winter. Consequently, groundwater levels rise and contribute additional groundwater discharge to the surface stream system. Increases also occur in the quantity of shallow subsurface seepage and surface runoff contributing to streamflow. The overall effect on stream salinity is a complex function of the quantity and particularly the salinity of the additional groundwater discharge, as well as the quantity and quality of the additional shallow seepage and surface runoff water.

The South-western Australian Darling Range landscape is characterised by porous lateritic soils and deep clay subsoils with a high potential to accumulate salts. Relative to other areas of the Darling Range only small quantities of salts have usually accumulated in areas where annual rainfall exceeds 1100 mm per annum. Consequently groundwater salinities are generally relatively fresh and the impact of agricultural development on overall stream salinity is usually low. In rainfall areas between 900 mm and 1100 mm moderate levels of salts are present in the landscape and, if mobilised by forest disturbance, can cause significant measurable changes in stream salinity. However few regions in the south west in this rainfall zone have been developed for agriculture and consequently little salinity deterioration has been observed.

It is in the region below 900 mm annual rainfall where large quantities of salts are present in the landscape and where the major agricultural development has taken place. This combination of agriculture and high soil salt storage has lead to very high salinities of discharging groundwater following clearing and has resulted in typical average stream salinities in excess of 3000 mg/L Total Soluble Salts.

River systems which drain extensive wheatbelt areas with annual rainfalls of less than 600 mm per annum have become so saline they are no longer usable as potable water resources.

River systems which drain areas which do not extend further inland than the 600 mm annual rainfall isohyet are generally of marginal quality and are high priority areas for protection and improvement of their water resource quality.

Consequently much of the current research work aimed at reducing stream salinity is being concentrated in the 600 mm to 900 mm rainfall zone of the south-west of Western Australia.

2. POSSIBLE APPROACHES

The best current estimates of the additional recharge to groundwater following agricultural development suggest that the quantities of water involved are relatively small. Estimates vary but are commonly 5 to 8% of rainfall and usually less than 10% of rainfall. Consequently only relatively small increases in the current vegetation water consumption are required to minimise groundwater recharge.

2.1 Recharge Minimisation by Agronomic Means

Research in the lower rainfall wheat belt region of Western Autralia has shown significant differences in water use between pasture and a range of crops and has clearly indicated that there is scope for much improved water use over current agricultural practices. This finding applies both to the wheatbelt and the 600 to 900 mm rainfall zone under discussion here.

Nevertheless the seasonal rainfall distribution with its relatively high winter quantities, the porous nature of the lateritic soils of the region and the general shallow rooting depth of agricultural pastures and crops will make the task of stopping all groundwater recharge with agricultural varieties very difficult.

It is for these reasons that trees with their much greater rooting depth, and their perennial nature have a major role in solving salinity problems in the 600 to 900 mm rainfall zone.

In the main wheat belt region of Western Australia (below 600 mm) where rainfall excess is much less, and where soils are less gravelly and more duplex in nature, agronomic options for reducing groundwater recharge are much more promising.

2.2 Recharge Minimisation Using Trees

Reestablishment of trees is clearly the most obvious long term solution to stream salinity problems. However widespread conversion of current farmland to forests and woodlands in the 600 to 900 mm rainfall zone will have profound social and economic consequences. Clearly it is desirable to control stream salinity with the minimum disruption to agricultural production as possible.

Using trees to reduce groundwater recharge implies knowledge of where groundwater recharge takes place. The groundwater systems which develop following clearing are known to be relatively localised. They form between the streamline and ridgeline of most small catchments and are strongly influenced by the bedrock topography. The available evidence suggest that recharge to these systems can occur anywhere in the landscape by a method termed "preferred pathway" flow. That is old root channels and other irregularities in the subsoil can conduct water very rapidly past the root zone of agricultural crops and pastures deep into the soil profile, towards the groundwater system. As the old root channels can occur anywhere within the landscape, potentially, recharge can occur anywhere throughout the landscape. While some sections of the landscape may well lead to a higher unit area recharge than others, a recharge minimisation strategy using trees would have to cover most if not all of the landscape if the groundwater recharge was to be stopped completely.

Because of the large areas involved recharge minimisation strategies have to be economic to the individual landholder before they could be advocated on a catchment wide basis. In this sense agroforestry schemes offer considerable promise.

Schemes which involve growing trees (usually pine) to produce a highly valued saw log product over a 20 or 30 year rotation, while continuing to enable grazing on cropping between the trees, have the potential to be more economic than either conventional agriculture or forestry practices. They also have the potential to reduce groundwater recharge, depending on the density of trees growing throughout the rotation.

It should be remembered that agroforestry schemes can be managed to favour agricultural production, timber production and groundwater recharge minimisation. While these three objectives are compatible to a large degree they are also partly competitive. The larger the timber production and recharge minimisation, the lower the agricultural production. There are likely to be, therefore, trade offs between the economic benefits for the individual farmer and the external benefits of recharge minimisation and eventual reduced stream salinity.

Much research is required in terms of forestry and agricultural management practices, hydrologic implications and economic analysis to develop appropriate agroforestry strategies for recharge minimisation in the 600 to 900mm rainfall region.

2.3 Discharge Reduction by Lower Slope Planting

The fact that the quantity of additional recharge following agricultural development is relatively low implies that trees with a capacity to transpire water at high rates could actively lower water tables around stream lines. In this way groundwater discharge to streams could be controlled, and depending on the species water pumping capacity, significantly less than the whole recharge area would need to be reforested. Conventional agricultural development could take place on areas upslope from the replanted area.

The problems with this approach are finding the appropriate species and defining the required area necessary to consume all the incoming soil water, both fresh and saline. Also the species selected must be able to tolerate the slow accumulation of salts which will result in the long term by leaching of upland salts from continued upslope recharge. The approach however, does have the advantage of actively lowering water tables directly where it is most critical and, if successful, will have a much quicker effect on reducing stream salinity than recharge minimisation strategies.

In the long term (50 years plus) upslope recharge minisation will be required if long term salt accumulation is be avoided. Lower slope discharge plantings can provide the time necessary to enable development of economically attractive recharge minimisation strategies and provide a means of consuming any small amounts of recharge which may pass through the root zone of upslope vegetation in wet years.

3. RESEARCH

Quantifying vegetation water usage and determining its impact on groundwater responses involves difficult and long term research. Co-operative studies between CSIRO, the Department of Conservation and Land Management and the Water Authority of Western Australia over the last 7 to 8 years are beginning to bare fruit. Hydrologic research in the 600 to 900 mm rainfall zone has concentrated on the problem of determining the responses of groundwater to various levels of reforestation and to determining the most appropriate species for lowering water tables in lower slope locations. Some of the results are briefly summarised below.

3.1 Groundwater Responses to Reforestation

Table 1 shows the reductions in minimum groundwater levels over the stand age for reforestation of different portions of the upslope cleared land and for different planting densities. Not surprisingly the larger the area planted and the denser the plantings the greater the reduction in groundwater level. Hillslope planting (80% of landscape) at a high planting density (1200 stems per hectare) showed significant reductions in groundwater level within three years of planting.

Reductions in groundwater pressures at depth in lower slope bore holes were also noted together with the first signs of shallow groundwater salinity improvements and some return of grass to previously bare areas.

In valley reforestation strategies (about 30% of landscape planted) reductions in groundwater level of about 0.6 metres were apparent within 4 and 5 years of planting. In the case shown in Figure 1 reductions in the water levels beneath the stream line are apparent relative to increases that have occurred beneath the upslope pasture.

Measurements of the groundwater pressure at different depths within the valley groundwater system indicated that larger reductions in water pressures occur at shallower depths (about 5 metres) than at greater depths (about 20 metres). The trees are clearly consuming water from the water table at shallow depth but recharge from upslope areas is continuing to contribute to the pressure head at depth in the valley.

A vertical upwards component of groundwater flow has therefore been increased and indicates that the trees must continue to transpire the inflowing groundwater if water tables are to be maintained at levels which will not enable salt to contribute to the surface stream.

In the long term salts will continue to accummulate beneath the replantings unless upslope recharge minimisation strategies are introduced. Observations of increases in the groundwater salinity at about 5 metres depth have already been observed at this site.

When smaller portions of the landscape are planted (6 to 20% and about 10% average) only small reductions in groundwater levels (0.3 metres) are apparent after 7 years of plantings. It has proved difficult to isolate these reductions from the natural variations of groundwater responses to yearly and seasonal rainfall variations.

The table also suggests that, when thinning occurs within the first 6 years before crown closure, to stem densities of 300 per hectare or less, groundwater reductions are decreased.

The general implications of these initial research results of reforestation are becoming clear. If significant reductions of groundwater levels are to be apparent in the first 5 years, up to 30% of the landscape needs to be reforested and stem densities of over 600 to the hectare need to be maintained at least until crown closure. Plantings on around ten percent of the landscape provide local small reductions in groundwater levels but appear unlikely at this stage to be sufficient to reduce groundwaters enough to halt saline discharge to surface stream systems. The required replanting represents a substantial area of agricultural land and implies that the area that needs to be reforested for salinity control purposes is likely to be substantially larger than the actual area of salt affected land. Maintenance of relatively high stem densities before crown closure also implies conflict with grazing within the stand in the early years. Nevertheless experience has shown that useful grazing can be carried out beneath young eucalypts some 3 years after planting. This is also useful in terms of fire hazard reduction. With careful stock management some grazing is possible at age 2 and younger.

3.2 Water Use Characteristics of Particular Tree Species

The general effectiveness of reforestation can be identified by long term groundwater monitoring. This approach however, does not lend itself to studying a whole range of tree species in combination with different densities of planting and with reforestation of different portions of cleared land. An alternative approach is to develop a knowledge of the pumpage capacity of different tree species and design reforestation layouts using this knowledge together with knowledge of the amount of water required to be consumed.

Trees planted to stop groundwater recharge must be capable of consuming the annual rainfall even in wet years. Trees planted to reduce groundwater discharge must, in addition, be capable of transpiring any shallow water drainage and all saline groundwater discharge from upslope.

The direct measurement of the transfer of water vapour from tree communities to the atmosphere is very difficult. A number of different approaches have been developed and all have their strengths and weaknesses. One of the most promising approaches is to use "porometers" to measure the leaf water conductance characteristics of different eucalypt species.

Porometers are hand held instruments which clip into individual leaves and measure the amount of water vapour diffusing from the tiny stomata openings on the leaf. Literally thousands of individual readings are required to develop a picture of tree water use behaviour.

Trees open and close the stomata on their leaves in response to sunlight, the dryness of the air and the dryness of the soil. In this way they regulate the assimilation of carbon dioxide and sunlight necessary for photosynthesis and control the loss of water vapour to the atmosphere. By quantifying these factors which affect leaf water conductance, by measuring continuously the micro meterological environment around the leaves and tree community and by accurately measuring the total leaf evaporating surface, calculations of the water vapour transfer to the atmosphere can be made.

While a number of assumptions are involved the approach enables quantification of plant physiological properties believed to be characteristic of a particular species. It also enables quantification of the seasonal water use response of species. This is an important characteristic when determining whether trees are actually extracting water from a saline water table. Such extraction may take place only at the end of summer when the shallow fresh soil water from the previous winter rains has been depleted.

A major leaf conductance study of trees considered to be suitable for reforestation is being carried out at a site with a 750 mm average annual rainfall in the Wellington Reservoir Catchment, Western Australia. It is sponsored by the Australian Water Resources Council under its research programme.

Approximately the lower third of the hillslope at the site was developed for agriculture over fifteen years ago. It is characterised by sandy clay soils in varying proportions and is underlain by subsoils of high salinity. A saline groundwater discharges along the creek line near the lower boundary of the site. In 1979 some 70 different eucalypt species were planted and in the 1984/85 summer some 20% of the more promising performers were selected for the leaf conductance study.

Initial results have shown significant differences in leaf conductance behaviour between species. Many of the fast growing species such as E. globulus, E. botryoides and E. viminalis have high leaf areas but relatively low leaf conductances at the end of the summer. It would appear that these species consume considerable quantities of water in the spring when moisture is abundent in the shallow soils but cannot extract water from the deeper soil profile when this moisture is depleted during summer. Whether this is because these trees are not adapted to extract water from a saline groundwater or whether they are not capable of sending down roots through harsh soil conditions is unknown at this stage. Fast growing trees with high leaf areas and strong spring transpiration rates are clearly desirable for minimising recharge. Thier value for actively dewatering saline discharge areas however must be questioned.

While all species showed reductions in leaf conductance through the summer drying period many continued to consume significant amounts of water throughout the summer. Particularly encouraging species in this regard were E. sideroxylon, E. microcarpa and E. melliodora. Species which maintained good transpiration rates considering the harsher and saltier conditions they had to endure were E. polyanthemos, E. woolsianna, E. wandoo and to a lesser extent E. mannifera. E. largerflorens and E. leucoxylon, which have relatively small leaf areas showed good unit leaf conductance.

Full evaluation of the differences in local site conditions which may contribute to the observed behaviour has not been carried out to date. Caution must therefore be exercised when comparing species at this stage. It should also be noted that other reforestation studies in similar landscapes but on different sites have indicated different relative performances of species.

Groundwater monitoring at the arboretum site has clearly shown major reductions in groundwater levels beneath the species with the highest leaf conductance characteristics and the highest computed transpiration rates. This independent confirmation of the high transpiration rates of the most promising species is most encouraging.

Most significantly the leaf conductance studies at the arboretum site have identified promosing species not originally planted in the first experiments of reforestation in the mid-1970's.

3.3 Summary

What have we learnt over the last 5 to 7 years of reforestation research? It is now clear that reforestion can lower water tables and thereby contribute to reducing stream salinity. However the areas necessary to be replanted are substantial (30% or more of the upslope cleared area) and inevitably will have an impact on agricultural production. Species with the ability to transpire significantly throughout the year have been identified and provide encouragement for the concept of planting the lower third of the landscape where groundwaters are likely to discharge to the surface stream system.

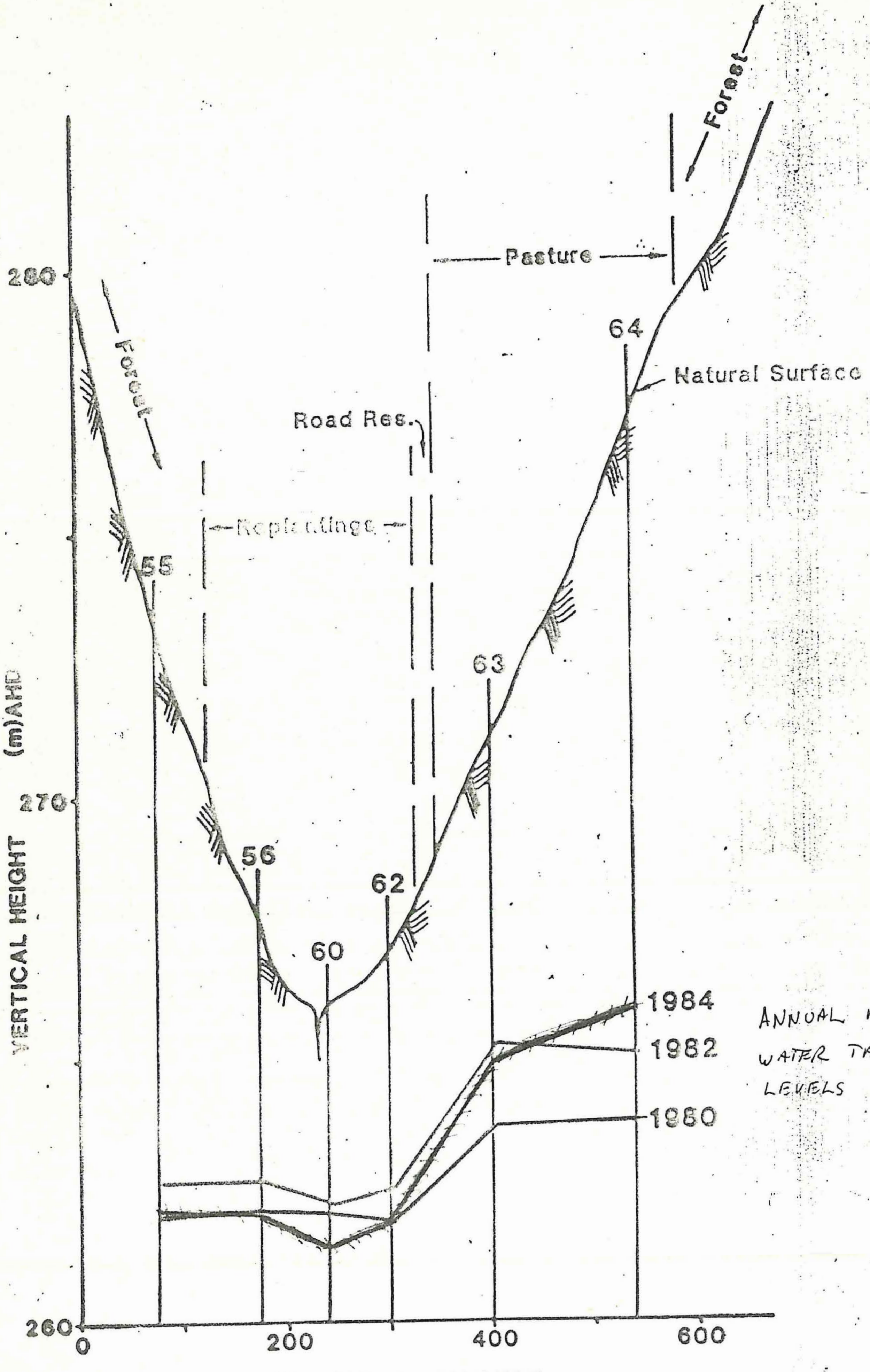
Nevertheless issues of long term salt accumulation in the lower slope regions and many problems of site establishment have yet to be solved. Research on transpiration behaviour of tree species has really only just commenced and much more information is required.

In the years to come more effort will need to be placed on studying the effects of different agronomic and agroforestry methods of recharge minimisation.

TABLE 1

REDUCTIONS IN GROUNDWATER LEVELS FOR DIFFERENT DEGREES OF REFORESTATION

	PORTION REPLANTED	STEM DENSITY INITIAL (STEMS/ha)	STEM DENSITY JUNE 84 (STEMS/ha)	REDUCTION IN ANNUAL MINIMUM LEVELS (metres)	SPECIES PLANTED	STAND AGE (years)
Mundaring	80%	1200	1200	2.2	E. camaldulensis E. wandoo	6
	50-60%	900	600-900	1.3	E. camaldulensis E. wandoo	6
W/ton.	31%	625	625	0.6	E. wandoo E. rudis	5
	42-55%	900	150-300	0.5	E. camaldulensis	6
Mundaring.	6-20%	667	667	0.3	E. wandoo E. camaldulensis P. radiata P. pinaster	7



ANNUAL MINIMUM WATER TABLE LEVELS.