



An Australian Government Initiative

Catchment Scale Evaluation of *Trees, Water and Salt*

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Foreword

Salinity is a major land management issue in Australia and reforestation is often advocated as part of its management. There has been considerable debate about the level of reforestation required to stabilize landscape hydrology, and in particular whether this can be achieved by strategically placed, integrated plantings. In 2002 the Joint Venture Agroforestry Program (JVAP) published *Trees, Water and Salt*, this summarizing knowledge of the use of trees to tackle salinity.

The study reported here followed the establishment of an integrated tree planting, on a farm near Wickepin, Western Australia, with 300 mm annual rainfall. These trees were established using the procedures outlined in *Trees, Water and Salt*. Not only were the hydrological effects of this planting monitored, but a range of tree species were assessed for biomass production and carbon sequestration. Although groundwater pressures have declined in 19 out of 20 piezometers in the study area in the 7 years since the study's commencement, it is not possible to ascertain whether this is due to the forestry treatment or due to a broader regional decline in groundwaters as a result of climate variability. This points to the need for long-term monitoring, as seen from reforestation and hydrological response studies elsewhere. The project was used as a forerunner for a broader monitoring program established in conjunction with the *Strategic Tree Farming* project, a \$64 m Australian Government and Western Australian Government program that is establishing 18,000 ha of trees across the medium rainfall zone (500-700 mm) of Western Australia. By mid-2009, 25 properties will have hydrological monitoring systems established, building on the experience gained in this project.

An issue with dryland reforestation has been the absence of economic drivers; however the emergence of climate change as an issue has seen carbon sequestration and bioenergy production emerge as two products with potentially strong demand. This will require solid underpinning growth data. Of particular interest here are the rates of biomass and carbon sequestration reported from belt plantings of *Pinus pinaster*, integrated with cereal crops, and from *Eucalyptus occidentalis* plantings in a salt scald; land that was previously considered unproductive.

This project ran for 5 years from 2003/4 and comprised \$161,367 of funding from the JVAP and \$160,458 of in-kind contributions from the WA Department of Conservation and Land Management, the Forest Products Commission, the University of Western Australia and CSIRO Land and Water. It built on installations established in 2000 and 2001 by the NHT-Farm Forestry Program project *Putting Trees in Their Place* (NHT 983297). JVAP is supported by three R&D Corporations - Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia (L&WA), and Forest and Wood Products Research and Development Corporation (FWPRDC). **The Murray-Darling Basin Commission (MDBC) also contributed to this project.** The R&D Corporations are funded principally by the Australian Government. **State and Australian Governments contribute funds to the MDBC.**

This project was funded by the Joint Venture Agroforestry Program (JVAP), which is supported by three R&D Corporations - Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia (L&WA), and Forest and Wood Products Research and Development Corporation¹ (FWPRDC). **The Murray-Darling Basin Commission (MDBC) also contributed to this project.** The R&D Corporations are funded principally by the Australian Government. **State and Australian Governments contribute funds to the MDBC.**

¹ Now Forest & Wood Products Australia (FWPA)

This report is an addition to RIRDC's diverse range of over 1800 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

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Contents

Foreword	ii
Acknowledgments	v
Executive Summary	viii
Introduction	1
Material and Methods	3
Site details	3
Climate	3
Farming systems	4
Experimental details	4
Results	9
Groundwater response to partial reforestation, 2001-2008	21
Introduction	21
The effect of climate/rainfall on piezometer water levels	21
Transects.....	22
Strategic Tree Farming: hydrological monitoring	27
Introduction	27
Implementation of a hydrological monitoring plan	27
Details of the hydrological monitoring program	28
Discussion and Conclusions	30
Salt scald.....	30
Pine belts	31
<i>E. globulus</i> spacing and fertilizer trial.....	32
Multi- species trial	32
Effect of reforestation on catchment hydrology	33
References	34
Appendix 1: Project outputs	38
Publications	38
Conference & seminar presentations	38
Appendix 2: Evaluation of existing hydrological experimental sites	41
Introduction	41
Sites visited.....	41
Sites recommended for reactivation of monitoring	45
Sites recommended for consideration of commencing research	46
Other recommendations.....	46
References	47

Tables

Table 1	Climatic characteristics for the experimental site from SILO (Jeffrey <i>et al</i> , 2001).....	4
Table 2	Total biomass production and survival for <i>E. globulus</i> at 4 and 5 years of age.	12
Table 3	Total biomass production (t/ha) and survival (%) for the multi-species plots between ages of 4 and 7 for upper, mid and lower landscape positions.	13
Table 4	Location of the Strategic Tree Farming Monitoring sites.....	29
Table 5	The sites visited, the reasons for not visiting certain sites, and where relevant and known their approximate location.	43
Table 6	Water levels at South's and Wooldridge/Wright's in 2005 and compared with 1995 and the groundwater salinities in 1995.....	46

Figures

Figure 1	Location of experimental site 25 km east of Wickepin, Western Australia.....	3
Figure 2	Image showing the location of the trials throughout the sub-catchment and their relation to hydrological influences in the landscape.	5
Figure 3	Total biomass and survival of <i>Eucalyptus occidentalis</i> planted at (a) 500 stems/ha and (b) 2000 stems/ha.....	9
Figure 4	Total biomass and survival of <i>Atriplex nummularia</i> planted at (a) 500 stems/ha and (b) 2000 stems/ha.....	10
Figure 5	Relationship between total biomass and (a) ECa and (b) soil extract conductivity (dS/m) measured in 2005 for the <i>E. occidentalis</i> 500 and 2000 stems/ha treatments.....	10
Figure 6	Change in the salinity, measured with an EM38 meter for the tops and troughs of mounds in relation to distance from the salt scald from Sim (2005)11	
Figure 7	Survival (%) and total biomass production (t/ha) for plots within the <i>P. pinaster</i> belts.....	11
Figure 8	Annual rainfall (mm) derived from SILO (Jeffrey <i>et al</i> , 2001).	14
Figure 9	Monthly rainfall (mm/month) for (a) 2002 which was a dry year and (b) 2005 which featured intense winter rainfall.	14
Figure 10	Mean soil water deficits for spacing and fertilizer treatments and paddock control to 4 metres depth.....	15
Figure 11	Average change in soil moisture content (mm/m) with depth for 555, 1111 and 2222 stems/ha <i>E. globulus</i> treatments.....	16
Figure 12	Average change in soil moisture deficit (mm) to 8 m depth for <i>P. pinaster</i> belts in comparison with average paddock values	17
Figure 13	Average change in soil moisture content (mm/m) with depth for <i>P. pinaster</i> belts.....	17
Figure 14	Average change in total soil moisture (mm) to 4 m depth for upper, mid and lower-slope positions under agriculture compared to that under the <i>P. pinaster</i> belts.....	18
Figure 15	Average change in total soil water deficit for a) upper b) mid and c) lower-slope multi-species plots, estimated to 4 m depth.....	19
Figure 16	The Wickepin Agroforestry Site showing the location of piezometer transects and planting design.....	21
Figure 17	Hydrographs of piezometers that are potential controls for change in climate/rainfall throughout the life of the project, using monthly averages of hourly water level data.....	22
Figure 18	Hydrographs for the seven piezometers on Transect 1 using monthly averages of hourly water level data.	23
Figure 19	Hydrographs for the five piezometers on Transect 2(3) using monthly averages of hourly water level data.	24
Figure 20	Hydrographs for the seven piezometers on Transect 4 using monthly averages of hourly water level data.	25
Figure 21	Hydrographs for the four piezometers on Transect 5 using monthly averages of hourly water level data.	26
Figure 22	Distribution of monitoring sites in STF Program	28

Executive Summary

Background

Rising ground-waters and resultant salinity threaten agricultural land, conservation reserves and water resources in southern Australia. Although revegetation with woody plants is often considered as a strategy to restore catchment water balances, farm forestry has not been adopted in low-rainfall environments to the extent of that in high rainfall zones. Similarly, there is some conjecture that the proportion of revegetation needed to restore catchment water balances may be as high as 80%.

The JVAP publication *Trees, Water and Salt* provides a set of guidelines for revegetation of farmland, however these have not been tested at the catchment scale in drier (<400 mm annual rainfall) environments that are representative of the wheat and wool-belt of much of southern Australia. Reforestation in these regions is often of limited scale, and thus at an inappropriate scale to assess catchment scale responses. This study measured the hydrologic response of an 80 ha catchment to partial reforestation, near Wickepin, Western Australia. This region, which has around 300 mm annual rainfall, has agriculture that comprises rotations of cropping and pastures. These trees were established using the procedures outlined in *Trees, Water and Salt*.

An issue with dryland reforestation has been the lack of clear economic drivers. The emergence of markets for carbon sequestration and bioenergy from trees, in response to national climate change policies may increase the future rate of reforestation. Key issues include understanding the rates of both sequestration and biomass production in drier environments such as Wickepin and also how best to integrate reforestation with agricultural production. Of particular interest are the interaction of belts of trees with agriculture and the utilization of land that is poorly productive, such as that which has been affected by salinity.

Aims/objectives

The aims of this research were to:

- 1) Field test the principles recommended in “Trees Water and Salt” for farmland revegetation, using a sub-catchment scale revegetation experiment/demonstration planting near Wickepin, Western Australia and improve existing catchment models for salinity prediction and tree placement;
- 2) Evaluate the suitability of several older revegetation experiments for strategic measurement and modelling; and
- 3) Extend the findings to landholders and extension workers and policy makers.

Methods used

The project involved a measurement program using established instrumentation (weir, conductivity, neutron access tubes, piezometers) and annual measurements of tree growth in existing plots. Honours level students undertook discrete data analysis projects, such as determining tree water use of different species, determining the effects of the treatment design on catchment response to rainfall and determining the proportion of recharge reduced by the different components of the revegetated system.

Results/key findings

The major findings of this study include:

- The lack of unequivocal response to the reforestation treatment, with this most likely being due to the short time elapsed since project commencement (7 years). It is thus not possible to recommend changes to the *Trees, Water and Salt* on the basis of these results and it is recommended that monitoring continue at this site for several years. The project was used as forerunner for the hydrological monitoring of the NAP funded *Strategic Tree Farming Project*.
- The rates of biomass growth and carbon sequestration estimated for a range of species. *Pinus pinaster* was grown in 20 row belts in mid and upper slope positions, with this achieving a mean value of 54 t/ha of biomass or 99 t CO₂-e/ha, after 7 years. Several woodland eucalypt species only achieved modest rates of growth, these including *E. salmonophloia* (7 t/ha biomass), *E. wandoo* (13 t/ha) and *E. kondinensis* (13 t/ha).
- On salt-land a high planting density of *Eucalyptus occidentalis* (2000 stems/ha) achieved 31 t/ha of biomass (57 t CO₂-e/ha) after 7 years. Growth rates were increased by stocking and decreased by soil salinity content. *Atriplex nummularia* only produced 9 t/ha of biomass, however this had also been grazed. Ongoing measurements of tree growth are required to determine both the sequestration potential of the sites and the sustainability of these plantings.

Implications for relevant stakeholders:

The development of the Carbon Pollution Reduction Scheme (CPRS) is likely to include carbon sequestered through the reforestation of farmland and a 20% Mandatory Renewable Energy Target, is likely to allow the use of biomass. Both will provide an impetus for reforestation. A key component of this market will be an understanding of growth rates and potential carbon sequestration and how to integrate this reforestation with agriculture.

Presently only reforestation is included in the CPRS, with this using Kyoto-style rules that define what is considered to be a forest. Trees, as planted in this study area, meet these definitions. In contrast, the cultivation of saltbush is considered to be revegetation, which is presently ineligible in the CPRS, as it falls within Kyoto Article 3.4. With the comparative rates of sequestration between *E. occidentalis* and *A. nummularia*, and the present ineligibility of the latter, this points to the need to design saltland agroforestry systems that will be allowed to participate in the CPRS. Much land has already been salinized in Australia, and such sequestration would provide a means of funding the treatment of this land. There are strong differences in growth across salt land and these will need to be taken into account.

Recommendations

Recommendations include:

- For the Wickepin site continue measurement of hydrological and tree responses for several more years to determine if partial planting can affect salinity,
- Design agroforestry layouts for saltland that will be eligible to participate in the CPRS and determine the likely rates of carbon sequestration and sustainability of these plantings, and
- Determine the interactions between treebelts and adjacent agricultural land.

Introduction

The replacement of native vegetation with agricultural systems has resulted in a hydrologic imbalance and expanding areas of dryland salinity across southern Australia. It is estimated that 1.1 million hectares of farmland is currently affected by salinity in south-western Australia with up to 1.9 million hectares affected nationally, with this likely to increase to 3.7 million hectares (George 2008). The National Land and Water Resources Audit (2001) indicated that all inland watersheds will be salinized, with other studies pointing to species loss (Keighery *et al*, 2004), loss of farmland productivity (Kingwell *et al*, 2003) and a significant threat to infrastructure (State Salinity Council 2000).

Annual crops are shallow-rooted and only transpire water for part of the year. As a consequence, recharge under agricultural systems is one to two orders of magnitude greater than under native vegetation (Allison *et al*, 1990), resulting in rising watertables and the mobilisation of salt stored within the regolith (Peck and Hatton 2002). To control salinity it is essential that groundwater recharge is controlled and it is known that this can be achieved with trees (Schofield 1990). Incorporation of deep-rooted perennial species into catchments dominated by annual crops and pastures forms part of the strategy for managing dryland salinity in southern Australia (State Salinity Council 2000; Stirzaker *et al*, 2002a) and such reforestation may also remediate other environmental problems such as erosion and loss of biodiversity through habitat removal.

The proposition that reforestation can reverse the salinisation of agricultural catchments has been supported by studies of both large (Bari *et al*, 2004) and small (Clarke *et al*, 2002) catchments in Western Australia. There is some conjecture that the proportion of reforestation needed to restore catchment water balances may be as high as 80% (George *et al*, 1999). There is thus a need to balance the scale of reforestation with the benefits that will be achieved.

The JVAP publication *Trees, Water and Salt* (Stirzaker *et al*, 2002a) provides a set of guidelines for revegetation of farmland, however these have not been tested at the catchment scale in drier (<400 mm annual rainfall) environments that are representative of the wheat and wool-belt of much of southern Australia. It is in these areas that the threat of salinity, and the need for treatment, is the greatest. Reforestation in these regions is often of limited extent, and thus at an inappropriate scale to assess catchment scale responses. For these lower rainfall areas, there are a number of questions that still require resolution:

- a) In what circumstances partial reforestation of farmland will most effectively help manage salinity,
- b) How these plantings should be integrated with agricultural systems (e.g. strips interspersed with agriculture, blocks rotated in time (Harper *et al*, 2000; Harper *et al*, 2001), and
- c) Where in the landscape they should be placed for optimal effect (dispersed across the landscape, planted in particularly leaky areas, planted adjacent to saline areas).

With the recognition of the scale of the salinity problem, and the scale of the required response, considerable effort has been made to evaluate potential new woody crop options in lower rainfall areas (Consortium 2001). Examples of products that have been evaluated include sawn-timber, firewood, biomass for electricity and eucalyptus oils (Zorzetto and Chudleigh 1999). Current products that appear promising include sequestered carbon (Harper *et al*, 2007) and biomass for bioenergy (Wu *et al*, 2008). Of some interest is an indication of

the rates of biomass production and carbon sequestration in lower rainfall environments, as information about the performance of different tree species planted in these areas and their effect on soil water levels is limited. Several species were chosen on the basis of their potential water use and carbon sequestration and planted in the catchment.

The aims of this project were to:

- Field test the principles recommended in *Trees Water and Salt* (Stirzaker *et al*, 2002a) for farmland revegetation, using a sub-catchment scale revegetation experiment/demonstration planting near Wickepin, Western Australia. Trees had been previously established (2000) in an 80 ha sub-catchment using these guidelines and monitoring equipment has been installed as part of NHT-Farm Forestry Program project *Putting Trees in Their Place* (NHT 983297);
- Improve existing catchment models for salinity prediction and tree placement;
- Evaluate the suitability of several older revegetation experiments for strategic measurement and modelling, and
- Extend the findings to landholders and extension workers and policy makers.

In this study we thus set out to determine (a) whether the strategic layout of species and density can amplify the effect of planting in recharge areas, (b) whether rapid soil water depletion can be achieved with the use of high rainfall species in conjunction with manipulating stand density and thus the tree rotation length and (c) whether the rates of biomass production and carbon sequestration could be manipulated by species selection or silvicultural management.

Material and Methods

Site details

Location

An experimental site was established in 2000 on a property 15 km east of Wickepin, which is 250 km south-east of Perth Western Australia, (S 32° 46' 52", E 117° 29' 60") (Figure 1).

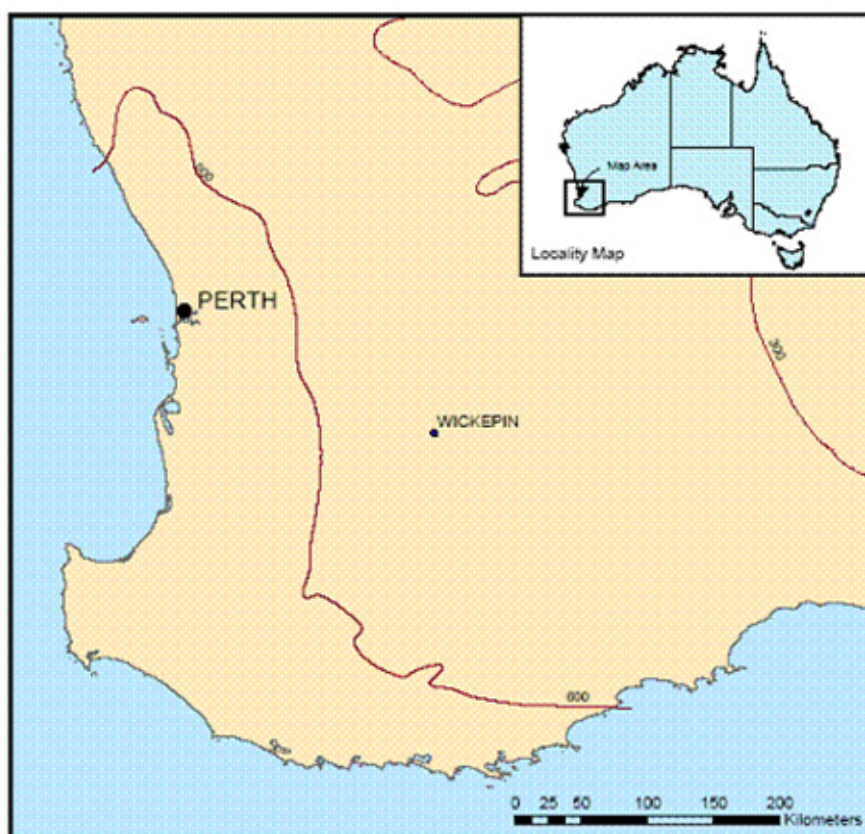


Figure 1 Location of experimental site 25 km east of Wickepin, Western Australia.

This experimental site comprised an integrated planting, designed using the principles outlined in *Trees, Water and Salt* (Stirzaker *et al*, 2002a), arrayed across an 80 ha sub-catchment, along with some plantings on a large, adjacent salt-scale. The primary aim of the work was to evaluate whether partial reforestation of a sub-catchment would affect the hydrology of the sub-catchment (Figure 2).

Climate

This region has a semi-arid Mediterranean climate, with a seasonal dry period from November to April, a mean annual rainfall of 300 mm/yr and mean annual evaporation of 1690 mm/yr (Table 1). Climatic data were obtained from SILO (Jeffrey *et al*, 2001).

Table 1 Climatic characteristics for the experimental site from SILO (Jeffrey *et al*, 2001).

Year	Temperature		Rainfall (mm)	Pan Evaporation (mm)
	Max. (°C)	Min. (°C)		
2000	23.3	9.8	318	1679
2001	23.1	9.3	296	1611
2002	23.8	9.8	220	1741
2003	23.6	10.3	363	1738
2004	23.6	10	268	1770
2005	23.0	9.7	344	1678
2006	23.7	9.8	314	1596
2007	23.7	10	335	1713

Farming systems

The property was cleared between 1910 and 1925. Farming practices employed are typical of broad areas of southern Australia and involve annual rotations of cereal (*Triticum aestivum*, *Hordeum vulgare*) or legume (*Lupinus angustifolius*) crops with improved annual legume (*Trifolium subterraneum*) and grass (*Lolium rigidum*) pastures, grown during the winter rainfall season.

Experimental details

Trial design

The planting design was developed in collaboration between CALM (Drs Harper, Robinson, McGrath), CSIRO Land and Water (Drs Tom Hatton, Richard Silberstein and Ramsis Salama) and the University of WA (Prof. Keith Smettem), and the design implemented with the Forest Products Commission's Maritime Pine Sharefarms Program. The design was based on the principles outlined in the JVAP publication *Trees, Water and Salt* (Stirzaker *et al*, 2002a), with two main aims, to (a) determine if trees planted in such a conformation do in fact reduce salinization and (b) to demonstrate the results to land-holders.

Approximately 20% of the sub-catchment was planted, as a series of belts, and the response of the salt scald in the lower part of the sub-catchment monitored. The catchment was instrumented to assess tree growth and water use, soil water content and groundwater and salinity levels.

A number of additional experiments have been incorporated both into the belts of trees in sub-catchment experiment, and in the areas immediately downstream, and the location of these is shown in Figure 2.

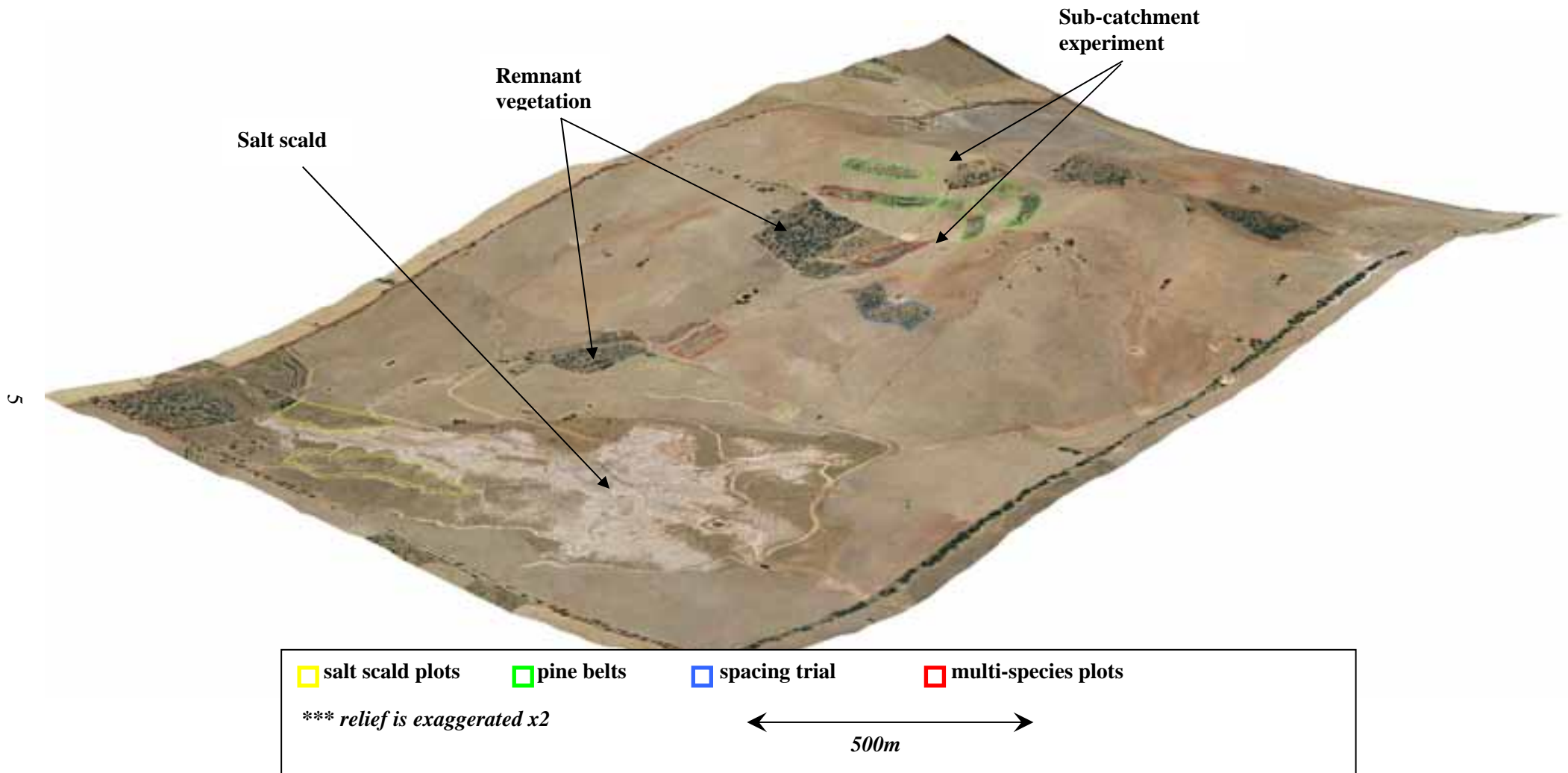


Figure 2 Image showing the location of the trials throughout the sub-catchment and their relation to hydrological influences in the landscape.

Treatments

Pine belts

Pinus pinaster (Portuguese race) was planted by the Forest Products Commission, Western Australia as part of a carbon sequestration project being undertaken for BP Australia. This species is typically grown in the 400-600 mm per year rainfall zone of south-western Western Australia (Ritson, 2004).

In the upper catchment three belts of *P. pinaster* were established to determine the suitability of this species and their effect on soil water. These belts were planted at 2000 stems/ha and are approximately 9 hectares in total area.

Salt scald trial

Eucalyptus occidentalis, *Atriplex nummularia*, *Allocasuarina huegeliana* and *Acacia celastrifolia* were planted adjacent to the salt scald, at planting densities of 500 and 2000 stems/ha. These species were planted in a randomized complete block design, consisting of two replicate blocks (one either side of the salt scald), each with eight treatments and three replicates.

Spacing and fertilizer trial

Evaluation of phase farming with trees (PFT), a system of using short phases of trees to dewater agricultural landscapes was undertaken at Corrigin, north of the Wickepin site (Harper *et al*, 2008). The aim of the PFT system is to both produce biomass and remove water as quickly as possible from the greatest possible soil volume. Techniques to increase the rates of growth and water use include high planting densities, the use of fertilisers to promote growth and the use of faster growing species from higher rainfall areas.

This experiment was set up to monitor the soil water content under fast growing blue gums (*Eucalyptus globulus*) planted at different densities to determine the time required to dewater the soil profile. This planting, established in 2001, consisted of a randomized complete block design in a single planting divided into three blocks with six replicates in each block. The six replicate treatments comprised of spacing densities of 555, 1111 and 2222 stems/ha with and without nitrogen. Nitrogen was applied at 100 kg N/ha in 2002, to determine whether the production of these stands and subsequent water use could be further increased.

Multi-species trials

Upper and mid-slope

This site consists of two plot areas, into which species of varying salt tolerance were planted to determine the effects of salinity levels, soil properties and slope position on rooting depth and water use over the first five to ten years growth. Species include *Eucalyptus sargentii*, *Eucalyptus loxophleba*, *Eucalyptus globulus*, *Eucalyptus occidentalis*, *Allocasuarina obesa*, and *Acacia saligna*. These plots comprised part of the belt design in the sub-catchment.

This trial was planted as a randomized complete block design with two blocks, each being situated in different landscape positions (Figure 2) with seven treatments in each block. These treatments consisted of the above seven species planted at 1000 stems/ha, replicated three times in each block.

Lower-slope

This site is situated in a lower position in the landscape to the above trial (Figure 2). The growth and water use of a range of native species was investigated. Species include *Eucalyptus salmonphloia*, *E. rudis*, *E. kondininensis*, *E. occidentalis* and *E. wandoo*.

This trial was planted as a randomized complete block design with two blocks and six treatments in each block. Treatments consisted of the above species planted at 1000 stems/ha.

Tree establishment

Trees were planted by 2000 and 2001. This was preceded by ripping and mounding and treatment with herbicides.

Monitoring

A range of monitoring equipment was installed, this included neutron access tubes for soil moisture, piezometers for groundwater pressures, and a weir to measure stream flow, and permanent sampling plots to measure tree growth and survival. Soil moisture content was measured twice a year (June and December), piezometric pressure and stream flow were measured using automatic loggers on an hourly basis, and trees were measured on an annual basis.

Biomass estimation

Measurements were made of all treatments on an annual basis, to obtain estimates of biomass. Predictor variables likely to be used in the allometric relationships were measured on all trees within 20 m by 20 m permanent measurement plots. Plots of this size were considered unlikely to be affected by edge effects between contrasting treatments. Attributes measured included diameter over bark at 10, 30 and 130 cm, tree height and crown volume. Survival was estimated as a proportion of the plants alive at the time of measurement compared to the number planted.

Allometric equations were applied to stand measurements to estimate stand production, however, species specific equations were not available for all species in this trial and therefore published general allometric equations were applied to some species.

For *E. globulus*, *E. occidentalis*, *P. pinaster*, *A. nummularia* and *A. saligna* species specific allometric equations were available, these had been derived through other studies by the Forest Products Commission, Western Australia (Ritson and Sochacki 2003; Sochacki *et al*, 2007). A general allometric equation published by Specht and West (2003) was applied to all other eucalypt species to estimate biomass production. Biomass of *A. obesa* was estimated by applying an allometric derived for *A. huegeliana*.

Measurement of water

Neutron moisture meter

Soil water content was estimated using a neutron moisture meter (530 NPR) and neutron access tubes (Greacen, 1981). Neutron moisture meter tubes were installed in selected treatment plots in 2001 in all landscape positions except the salt scald treatments, as here the groundwater levels were close to the surface and it was not possible to install the tubes. Neutron access tubes were also installed in the adjacent paddocks for comparison to treatments. Holes were drilled to eight meters depending on soil conditions and 50 mm polyvinyl chloride (PVC)

tubes were capped and inserted into a bentonite-soil slurry. PVC was chosen over other tube materials due to concerns of corrosion as a result of the saline soil profiles. The installation of a 50 mm PVC tube resulted in a clearance of less than 4 mm inside the access tube and thus reducing error due to eccentric positioning of the probe.

In the spacing and fertilizer trial a total of nine neutron access tubes were installed ranging from four to seven meters in depth, these including four tubes in the 555 stems/ha treatment, two in 1111 stems/ha treatment and three in the 2222 stems/ha treatment.

Neutron access tubes were also placed in each of the four pine belts to a depth of 8 meters and in the paddocks adjacent above and below the pine belts.

In the multi-species trials neutron access tubes were placed in all the treatment species except *E. kondinensis*. In the multi-species upper and mid-slope trials neutron access tubes were installed to a depth of 2.7 meters. In the lower-slope multi-species trial the depth of neutron access tubes ranged from 4.5 – 6 meters.

The first neutron moisture meter measurements were made in March 2002, with subsequent measurements made bi-annually. Soil water contents were also measured in several paddock positions adjacent to trial plots, these paddocks were subject to normal farming practices of cropping and grazing.

Estimation of soil water content

The neutron moisture meter presents results in terms of counts/second which need to be converted to volumetric values (mm^3/mm^3). This is achieved by calibrating the neutron meter to the soil type being investigated. Briefly, neutron meter counts are taken along with soil samples which are oven dried at 105°C, the water released is expressed as gravimetric soil moisture (g/g). By applying the soil bulk density to this value, it is then converted to volumetric values which are plotted to derive a relationship between neutron counts and volumetric soil water content in the form of:

$$\emptyset = bn + a \qquad \text{Eqn 1}$$

where \emptyset (mm^3/mm^3) is the volumetric water content, n is the ratio of the count rate in the soil to the count rate in water, b is the calibration coefficient and a is the intercept constant (Holmes 1956). Calibration curves applied to the neutron counts were derived from calibration values for soils on the experimental property. Soil water deficits were calculated from these data by assuming the measurements in June 2002 (i.e. at 1 year after establishment) represented a baseline, and subtracting the volumetric soil moisture contents for each subsequent measurement. Values were summed over the depth of measurement.

Soil assessment

Soil salinity measurements

Electromagnetic induction meters measure apparent soil electrical conductivity (ECa) in units of millisiemens per metre (mS/m). The electromagnetic induction meter used in this study was a Geonics EM38. The principles of electromagnetic induction and soil conductivity measurements are described in detail by McNeill (1980).

An EM38 was used to measure salinity of the salt scald in early winter 2005, as part of an Honours project at Curtin University of Technology (Sim, 2005). Ten random points were chosen within each treatment plot. At each point a horizontal and vertical measurement was taken on top of the planting mound (between trees) and also in the trough (between tree

rows). A 100 m transect was also measured starting at the salt scald (and perpendicular to it) across the treatment plots.

Soil description and analysis

Salt scald

Five soil samples were collected from a central strip in each plot to a depth of 10 cm using a tube sampler. This central strip was an area undisturbed by during planting (ripping and scalping) and therefore representative of the soil profile. Soil samples were bulked and submitted for analysis using the techniques of Rayment and Higginson (1992).

Upper catchment

The soils of the sites were examined following excavation with a backhoe. Soils and landforms were described using Australian standard techniques (McDonald and Isbell, 1990). Soils were sampled in 10 cm increments, with analyses using the techniques of Rayment and Higginson (1992) and presented in Appendix 1.

Results

Biomass

Survival and tree growth

A. huegeliana and *A. celastrifolia* performed very poorly and were not measured throughout the trial. *A. celastrifolia* was grazed by stock and some plots were completely destroyed. *A. huegeliana* survived grazing but growth was very poor in comparison to *E. occidentalis* and *A. nummularia*.

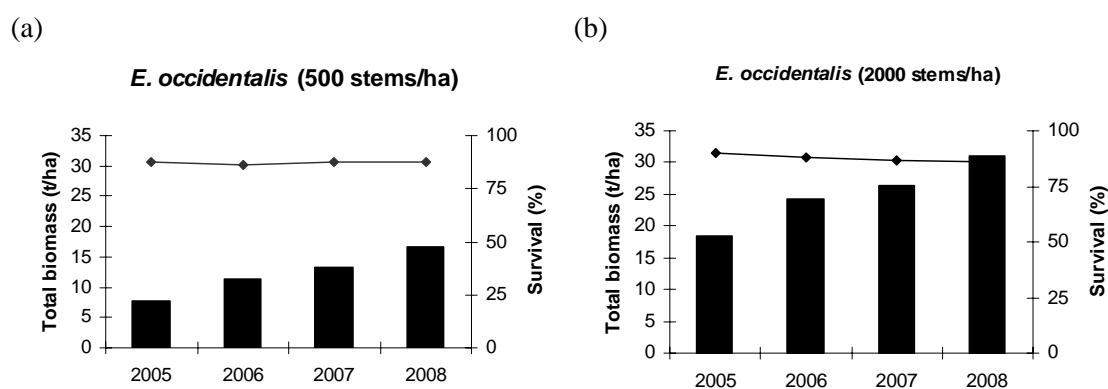


Figure 3 Total biomass and survival of *Eucalyptus occidentalis* planted at (a) 500 stems/ha and (b) 2000 stems/ha.

Survival for both *E. occidentalis* and *A. nummularia* over 2005 to 2008 ranged from 85 to 90% (Figure 3, Figure 4). The highest average total biomass yields for *E. occidentalis* were 17 and 31 t/ha for the 500 and 2000 stems/ha treatments, respectively, in 2008 (Figure 3). Total average biomass yields were significantly greater ($P < 0.05$) for the 2000 stems/ha, compared to the 500 stems/ha treatments for all years measured (2005-2008).

(a)

(b)

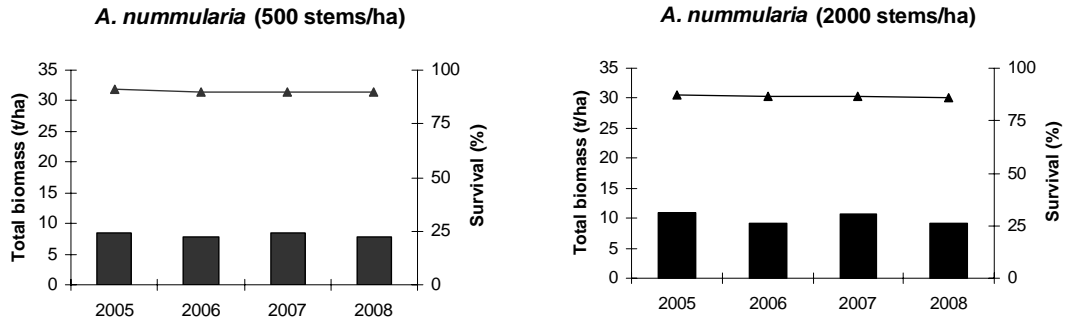


Figure 4 Total biomass and survival of *Atriplex nummularia* planted at (a) 500 stems/ha and (b) 2000 stems/ha.

Biomass yields for *A. nummularia* did not increase over time (Figure 4) as these plots were grazed by sheep. The greatest total biomass yields were achieved from the 2000 stems/ha treatments, with yields of 11 t/ha in both 2005 and 2007. The greatest mean total biomass for the 500 stems/ha treatment of 9 t/ha was achieved in 2005. There were no significant differences in average total biomass yield between the two planting densities for any given year measured (2005-2008).

Total biomass yields of *E. occidentalis* for the 2000 stems/ha treatments were significantly ($r^2 = 0.77$, $P < 0.05$) correlated with salinity as measured with the EM38 (ECa (mS/m)). A negative linear correlation is evident for both the 500 and 2000 stems/ha treatments (Figure 5). Total biomass of *E. occidentalis* was also significantly correlated ($r^2 = 0.80$, $P < 0.05$) with soil extract conductivity (dS/m) for 2000 stems/ha treatments. By contrast, there was no statistical relationship between *A. nummularia* growth and either ECa (mS/m) or soil extract conductivity (dS/m).

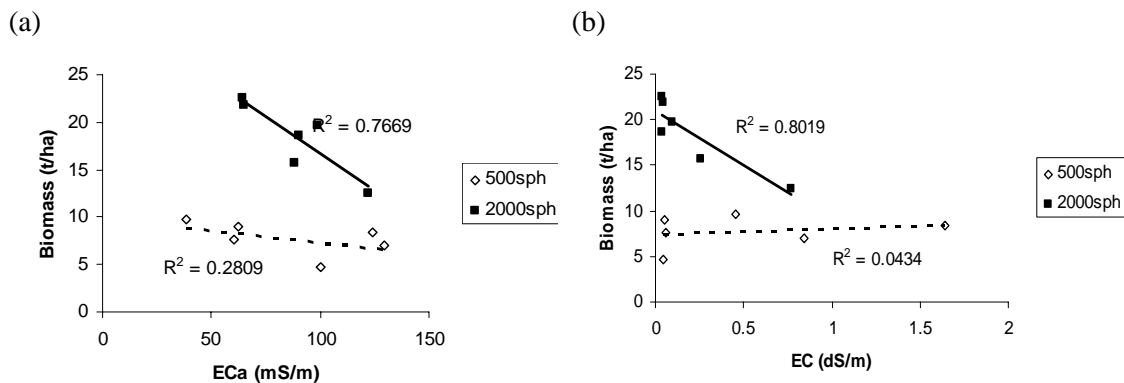


Figure 5 Relationship between total biomass and (a) ECa and (b) soil extract conductivity (dS/m) measured in 2005 for the *E. occidentalis* 500 and 2000 stems/ha treatments.

ECa (mS/m) readings taken along a transect across treatment plots perpendicular to the salt scald were negatively correlated with distance from the salt scald for both the top of mounds ($r^2 = 0.57$, $P < 0.0001$) and for readings taken in the troughs ($r^2 = 0.71$, $p < 0.0001$) of mounds (Figure 6). ECa (mS/m) for the troughs of mounds are also significantly ($p < 0.0001$) higher than the tops of mounds, this indicating that the mounds have been leached since establishment.

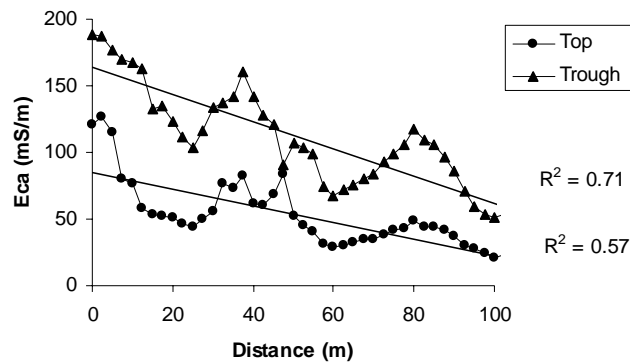


Figure 6 Change in the salinity, measured with an EM38 meter (ECa (mS/m)) for the tops and troughs of mounds in relation to distance from the salt scald from Sim (2005).

***P. pinaster* (pine belts)**

Survival of *P. pinaster* was excellent remaining above 90% throughout the period of measurement. Cumulative total biomass production reached 54 t/ha in 2008 (Figure 7).

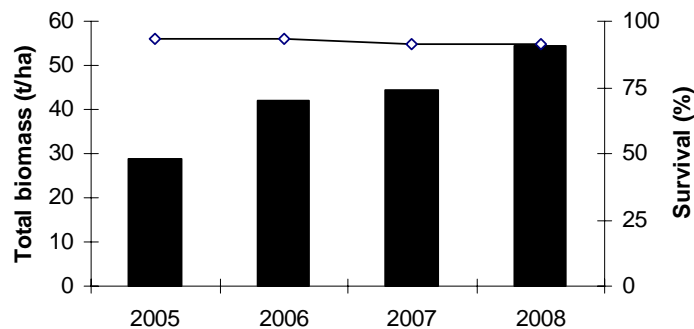


Figure 7 Survival (%) and total biomass production (t/ha) for plots within the *P. pinaster* belts.

***E. globulus* (spacing and fertilizer trial)**

Tree survival at age five years varied from 30% for the 2222 stems/ha treatment to 61% for the 2222 stems/ha nitrogen treatment (Table 2). Although the 2222 stems/ha nitrogen treatment yielded the highest average total biomass in both years four and five, there was considerable variability between replicates at this site and differences in yield and survival, as a result of differences in density or fertilization were not statistically significant.

Table 2 Total biomass production and survival for *E. globulus* at 4 and 5 years of age.

Density (stems/ha)	Nitrogen (kg/ha)	Total biomass (t/ha)		Survival (%)	
		4 years	5 years	4 years	5 years
555	0	6.8	11.4	66	48
1111		7.3	10.9	74	44
2222		8.7	14.6	56	30
555	100	5.6	9.1	44	31
1111		9.1	14.3	64	47
2222		11.1	19.3	78	61

Multi-species trial

Survival of *E. loxophleba*, *E. occidentalis* and *E. sargentii* was greater than 90% throughout the period of measurement in the upper-landscape position (Table 5). For *E. globulus* and *A. saligna* survival was 69% and 58%, respectively. In the mid-slope position survival decreased marginally for *E. loxophleba*, *E. occidentalis* and *E. sargentii* to 81%, 90% and 83%, respectively, but increased by 5% for *A. saligna*. Survival of *E. globulus* decreased significantly ($r^2=0.76$, $p<0.001$) to 35%. Survival in the lower slope position ranged from 48% for *E. occidentalis* to 73% for *E. rudis*. *E. kondinensis*, *E. salmonophloia* and *E. wandoo* had survivals of 55%, 59% and 63%, respectively.

Maximum total biomass yields in 2008 reached 36 t/ha for *E. globulus* in the upper-landscape position followed by *E. occidentalis* and *E. sargentii* with 33 and 21 t/ha respectively (Table 5). *E. loxophleba* achieved 14 and 11 t/ha in the upper and mid-slope position, respectively. *A. saligna* biomass estimates were for above ground biomass only and were 9 and 7 t/ha for the upper and mid-slopes respectively. Biomass production decreased significantly ($r^2=0.57$, $p<0.05$) for *E. globulus* in the mid-slope position to 20 t/ha whereas *E. occidentalis* remained similar at 29 t/ha. Biomass for *E. sargentii* increased from 21 t/ha for the upper-slope position to 27 t/ha for the mid slope position. *C. obesa* was only present in the mid-slope position and produced 17 t/ha above ground biomass. *E. occidentalis* was the only species common to all three landscape positions and had the highest biomass yield in the lower-slope position of 20 t/ha. *E. rudis* was similar with 18 t/ha. *E. kondinensis* and *E. wandoo* both produced 13 t/ha and *E. salmonophloia* achieved 7 t/ha. These values can be contrasted with the 54 t/ha achieved by *P. pinaster*.

Table 3 Total biomass production (t/ha) and survival (%) for the multi-species plots between ages of 4 and 7 for upper, mid and lower landscape positions.

Species		Biomass (t/ha)				Survival (%)			
		4 years	5 years	6 years	7 years	4 years	5 years	6 years	7 years
<i>A. saligna</i>	upper-slope	5	6	9	9	61	61	58	58
<i>E. globulus</i>		17	28	31	36	69	69	69	69
<i>E. loxophleba</i>		2	5	9	14	95	95	95	95
<i>E. occidentalis</i>		16	25	27	33	93	93	93	91
<i>E. sargentii</i>		4	11	14	21	98	96	93	93
<i>A. saligna</i>	mid-slope	4	5	6	7	68	65	67	63
<i>E. globulus</i>		13	18	19	20	65	61	46	35
<i>E. loxophleba</i>		2	6	9	11	84	81	81	81
<i>E. occidentalis</i>		16	22	23	29	93	93	90	90
<i>E. sargentii</i>		7	17	21	27	88	87	87	83
<i>C. obesa</i>		7	12	15	17	88	88	86	86
<i>E. kondinensis</i>	lower-slope	3	9	11	13	65	56	54	55
<i>E. occidentalis</i>		9	14	15	20	58	53	51	48
<i>E. rudis</i>		8	9	14	18	80	76	74	73
<i>E. salmonphloia</i>		1	3	6	7	62	61	59	59
<i>E. wandoo</i>		4	8	10	13	90	65	63	63

Water

Average annual rainfall over the trial period was 302 mm. Annual rainfall for the trial period varied with below average falls in 2002 of 220 mm to above average falls of 361 mm in 2003 (Figure 8). Patterns of rainfall also varied with some winter falls being intensified over a shorter period of time (Figure 9).

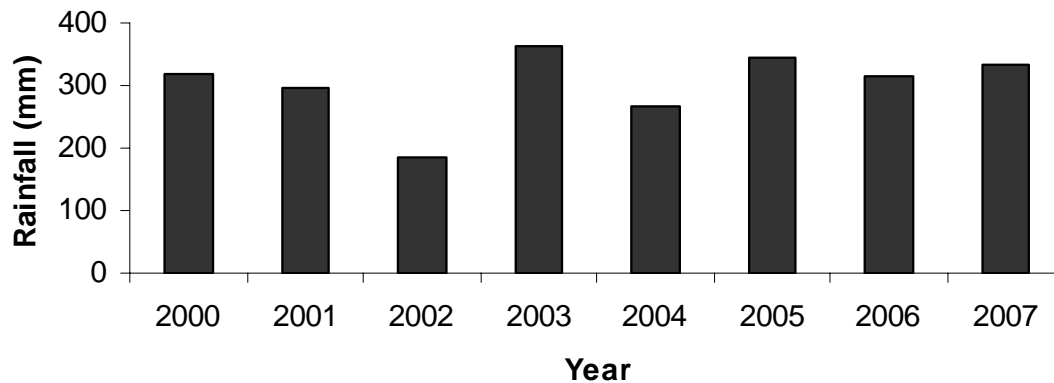


Figure 8 Annual rainfall (mm) derived from SILO (Jeffrey *et al*, 2001).

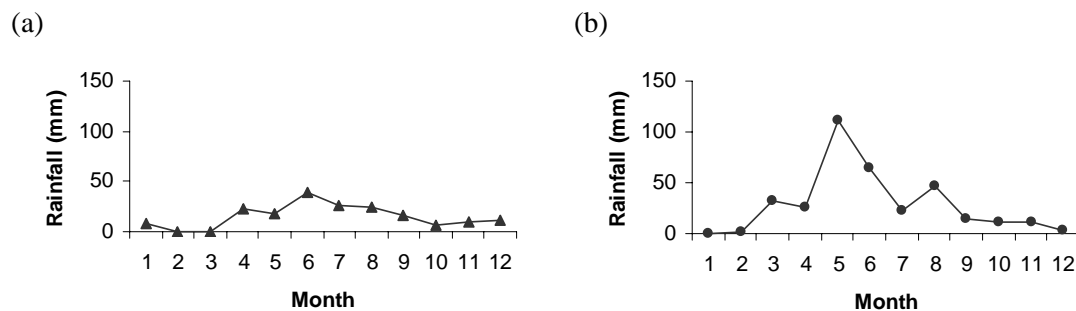


Figure 9 Monthly rainfall (mm/month) for (a) 2002 which was a dry year and (b) 2005 which featured intense winter rainfall.

Soil moisture contents

Results for soil moisture contents under the different treatments, as measured using the neutron moisture meter are presented as change in soil water deficit over the period of the experiment and as soil moisture change with depth. Measurements were taken bi-annually (summer and winter) and due to this low frequency of measurement precaution must be taken in interpreting results. Neutron moisture access tubes were inserted in to a range of depths dependant upon the soil conditions at the time of drilling. The aim was to insert access tubes to a depth of 8 m however, some soil profiles were very wet and access tubes were only inserted to a depth of 2.7 m.

Two obvious features are evident in soil moisture trends, firstly, the decline in soil moisture from March 2002 to August 2002 and secondly, large re-wetting trends for July 2005 and to a lesser extent in August 2003 and September 2006. The decline in soil moisture content has occurred in both treatment and control measurements, and this may be due to (a) lower than average annual rainfall in 2002 and (b) settling in of the neutron tubes. There also appear to be exaggerated wetting trends for July 2005 in treatment plots as compared with control neutron access tubes. Re-wetting of the soil profile appears to be amplified beyond the amount of moisture that may have entered the profile via rainfall, and this may be an experimental artefact, due to the entry of water at the sand/clay interface in duplex soils, or due to air cavities along the length of the access tube (Greacen 1981). Some access

tubes will be excavated to determine whether there is seal at the sand/clay interface and to also check for cavities which may have affected neutron counts.

E. globulus spacing and fertilizer trial

Higher stocking densities resulted in greater biomass production (Figure 7) and higher levels of soil water depletion (Figure 10). Throughout the period of measurement treatments with greater stocking density removed greater amounts of soil water. At the final measurement of biomass in 2006 the soil water deficits were 339 mm, 386 mm and 419 mm for the 555, 1111 and 2222 stems/ha treatments, respectively. To allow a comparison across treatments, these values are the soil water deficit to 4 m only, with some access tubes inserted to greater depths.

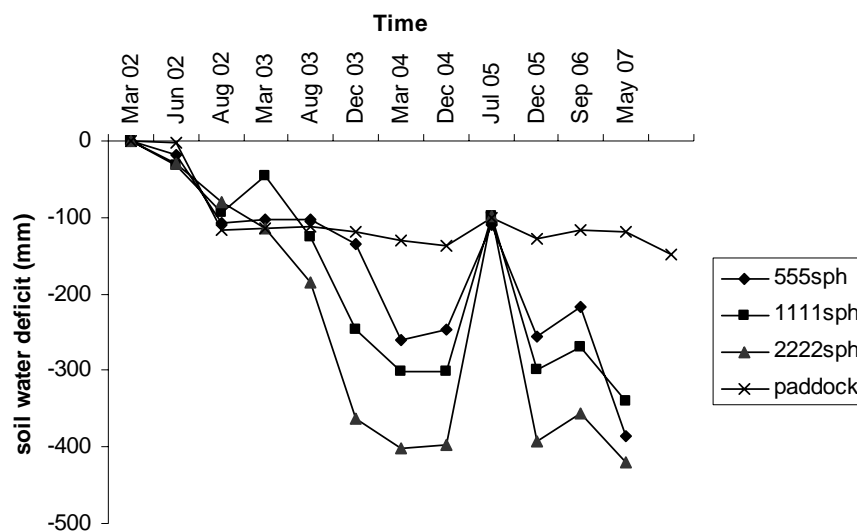
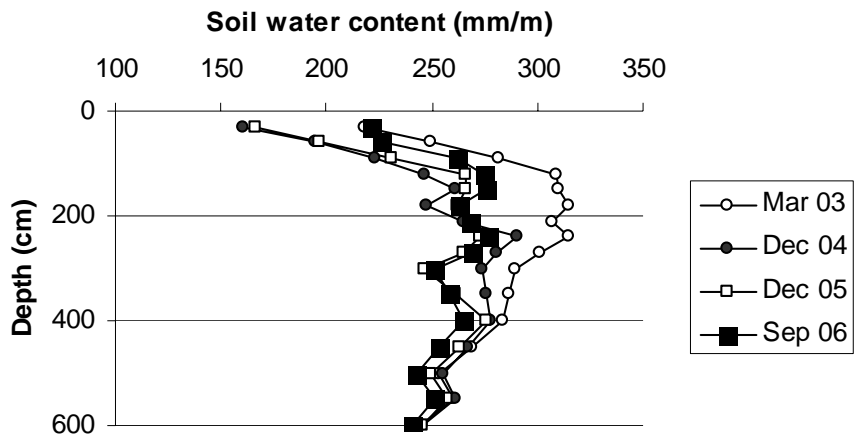


Figure 10 Mean soil water deficits for spacing and fertilizer treatments and paddock control to 4 metres depth.

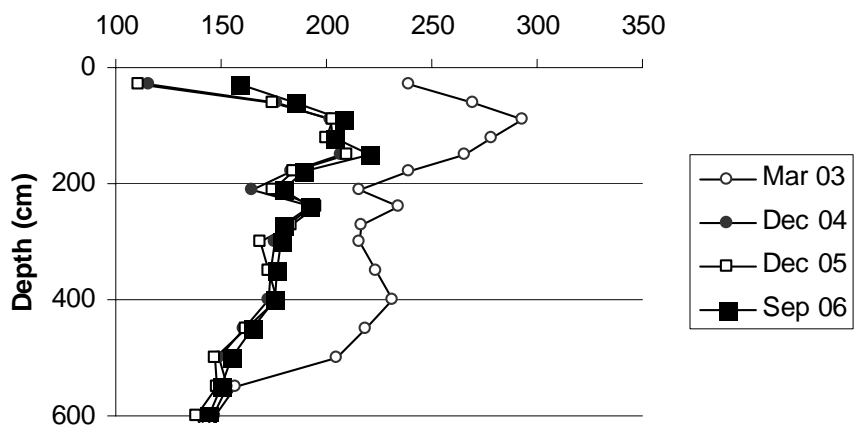
Although trends of water depletion appeared to relate to planting density, there was no significant relationship between biomass production and soil water deficit.

Examining the soil moisture content in relation to depth and measurement time gives an indication of the depth to which tree roots have reached and depleted soil moisture (Figure 11). Late autumn (March) and early spring (September) measurements indicate the depth to which tree roots have reduced the soil water. Soil water depletion appears greatest for the 2222 and 1111 stem/ha treatments, with roots reaching approximately 5 m by September 2006 (5 years of age). Soil water depletion for the 555 stems/ha treatment occurred to approximately 4 m.

(a)



(b)



(c)

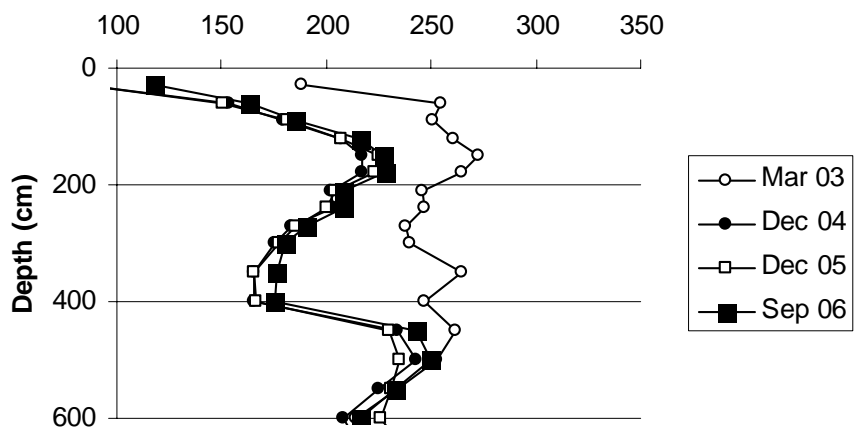


Figure 11 Average change in soil moisture content (mm/m) with depth for 555, 1111 and 2222 stems/ha *E. globulus* treatments.

Pine belts

The total soil water deficit produced by the pine belts was approximately 450 mm, however, when compared to adjacent paddock values this deficit is reduced to 350 mm. Below average annual rainfall in 2002 appears to be reflected in the soil moisture deficits for both paddock values and pine treatments (Figure 12).

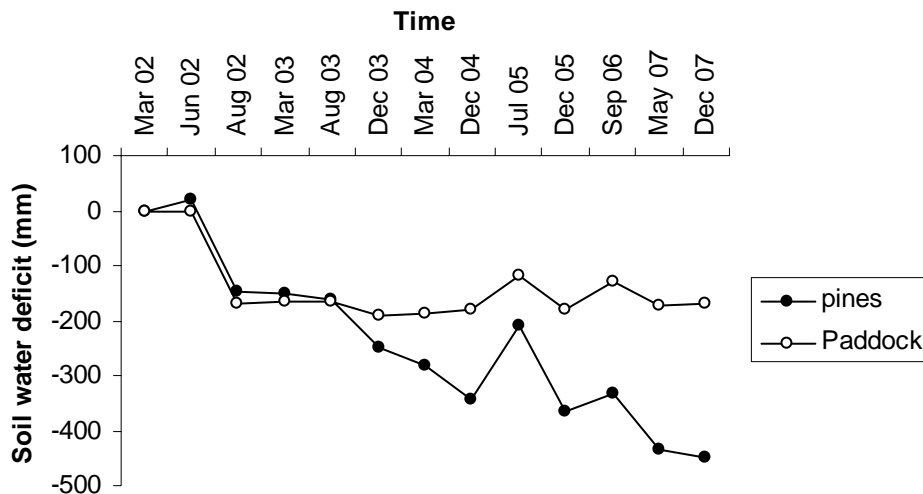


Figure 12 Average change in soil moisture deficit (mm) to 8 m depth for *P. pinaster* belts in comparison with average paddock values (upper and mid slope positions only for paddock).

Drying of the soil profile appears evident between March and August of 2002 and has occurred throughout the profile to the maximum measurement depth of 8 m (Figure 13). Seasonal measurements indicate that the pine belts have dried the soil profile to approximately 4 m. Subsequent winter rains in 2006 did not appear to refill the soil profile occupied by *P. pinaster* roots.

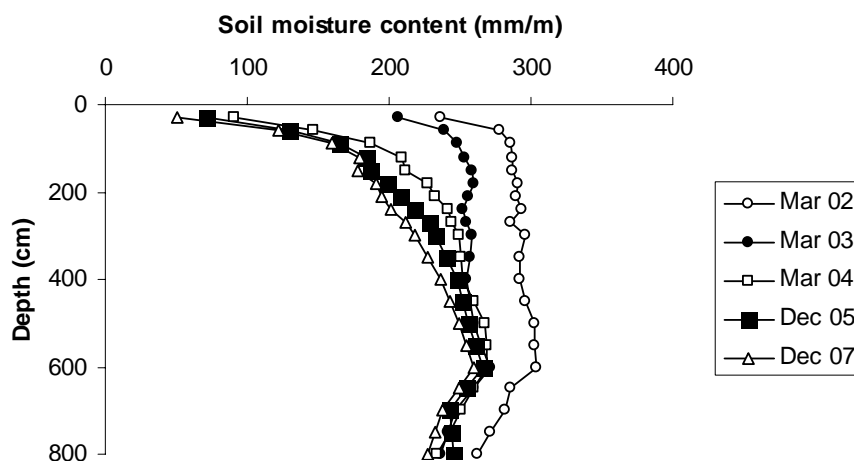


Figure 13 Average change in soil moisture content (mm/m) with depth for *P. pinaster* belts.

To allow comparison between changes in soil water deficit for *P. pinaster* and paddock values, soil water values were calculated to 4 m and comparisons made on the basis of slope position (Figure 14). Soils under both agriculture and *P. pinaster* apparently dried in the period March to August 2002. After this, the soil water deficit did not change significantly between the different slope positions, whereas the soil moisture content decreased beneath *P. pinaster*, as reported earlier.

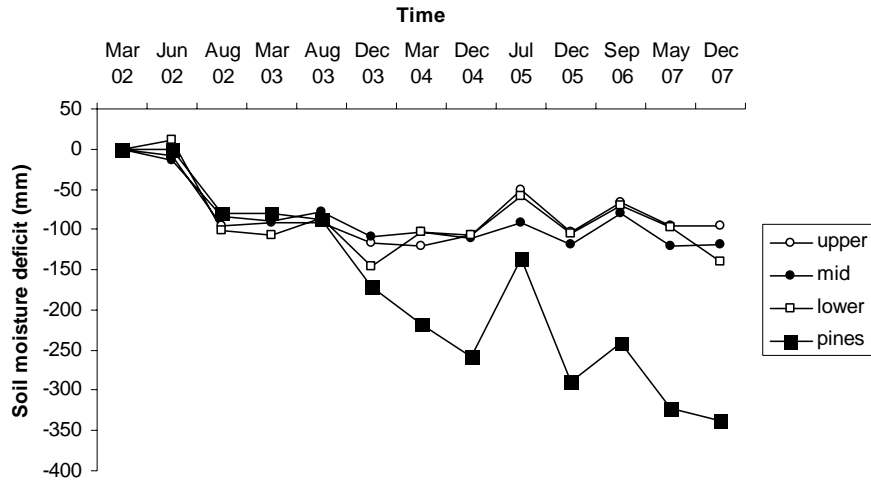


Figure 14 Average change in total soil moisture (mm) to 4 m depth for upper, mid and lower-slope positions under agriculture compared to that under the *P. pinaster* belts.

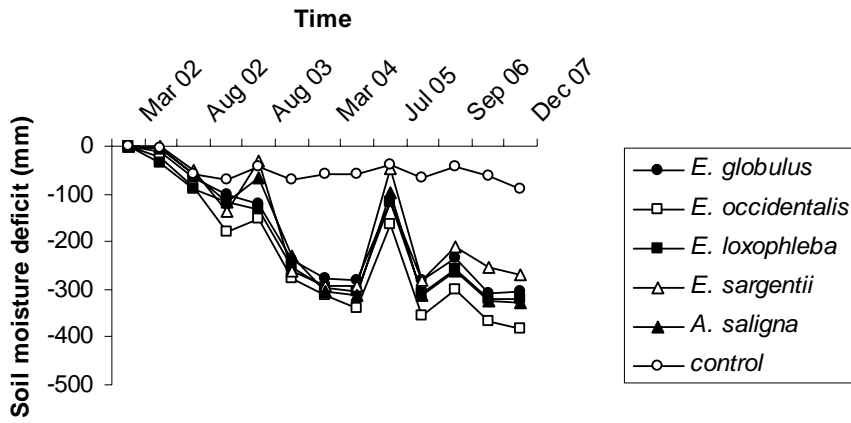
Multi-species trial

For all three landscape positions an intense wetting of the soil profile is evident for July 2005 and to a lesser extent in August 2003 and September 2006. This re-wetting of the soil profile is evident in all three landscape positions. Highest average total soil water deficits were 383 and 222 mm for *E. occidentalis* treatments in the upper and mid-landscape positions and 369 mm for *E. rudis* treatments in the lower landscape position (Figure 15).

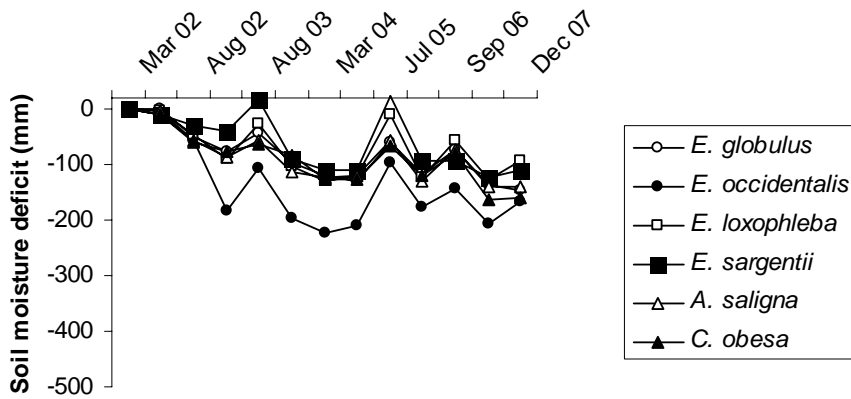
In the mid-slope position *E. occidentalis* reached a maximum soil water deficit of 222 mm in March 2004, and this fluctuated throughout the remainder of the period diminishing to -167 mm in December 2007.

For the lower-slope position the maximum soil moisture deficit was achieved in March 2003 of 369 mm by *E. rudis*, however, this deficit fluctuated throughout the trial and was reduced to 300 mm, a value shared with *E. salmonophloia*.

(a)



(b)



(c)

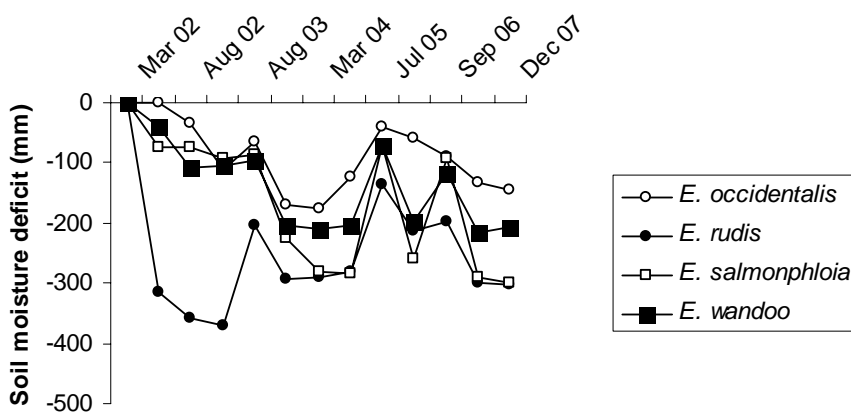


Figure 15 Average change in total soil water deficit for a) upper b) mid and c) lower-slope multi-species plots, estimated to 4 m depth.

Changes in soil moisture with depth during winter and summer indicate that tree roots have dried the soil profile beyond the depth of the neutron access tubes (2.7 m) in the upper-slope position for all species. There is some re-wetting of the upper soil profile, following winter rainfall, however this does not extend beyond approximately 1 m in depth.

In the mid-slope position, *E. sargentii* was the only species to dry the soil profile throughout the depth measured (3 m). All other species dried the soil profile to between 1 and 2 m depth, with *A. obesa*, the least effective.

In the lower-landscape position drying of the soil profile does not appear evident except for *E. salmonophloia*, which showed a profile drying of approximately 2 m. However, seasonal changes in soil moisture content showed the profile refilled during winter measurements. This may be an indication of an abundance of soil moisture in this landscape position.

Groundwater response to partial reforestation, 2001-2008

CJ Clarke²

Introduction

Twenty piezometers were established along four transects. The location of the piezometer transects and the planting layouts are shown in Figure 16.

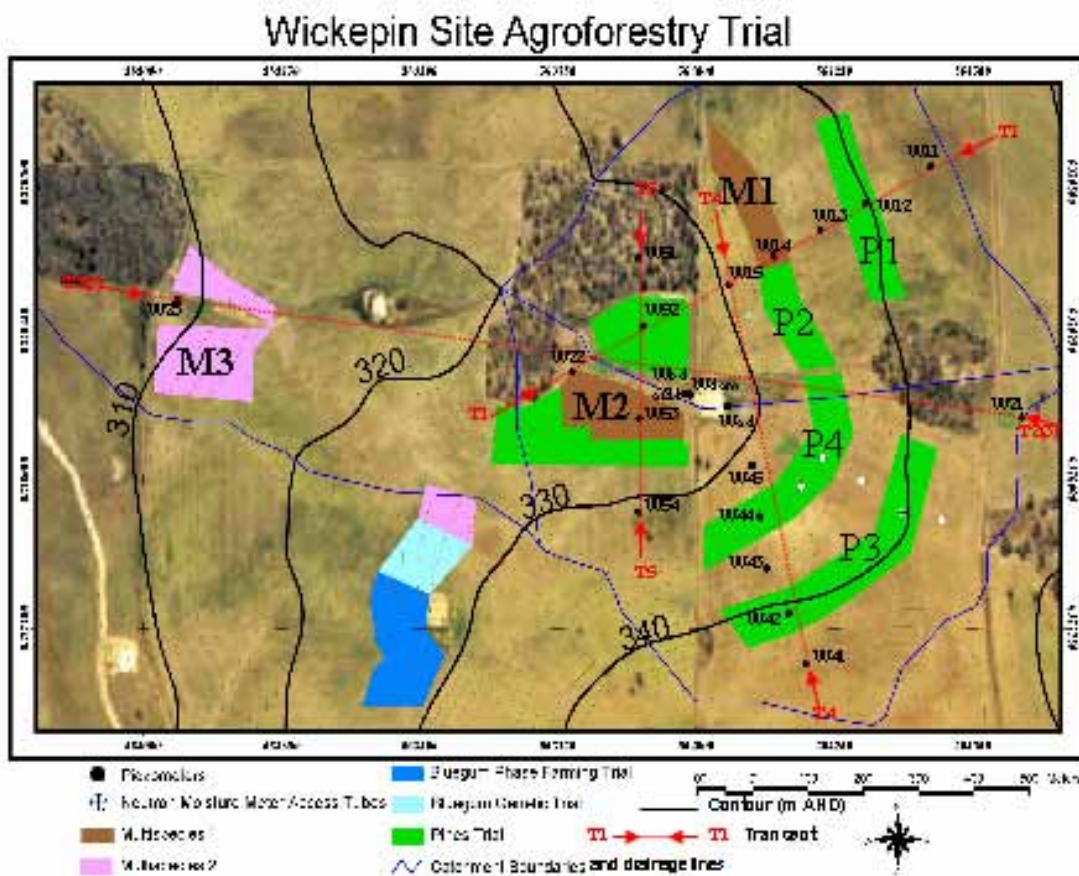


Figure 16 The Wickepin Agroforestry Site showing the location of piezometer transects and planting design.

Water level data were collected by automatically recording loggers from January 2001 to August 2008 on an hourly basis.

The effect of climate/rainfall on piezometer water levels

Piezometers W11, W21 and W41 were originally designated as controls for the impact of climate/rainfall change on the water levels. They are located in cleared land above the plantings, close to the catchment divide and at similar elevations; ~341.5 m, ~343.2 m, and ~341.8 m, AHD

² Retired research fellow Murdoch University, School of Environmental Science, now a part-time consultant to the Forest Products' Commission Western Australia, and Geological Investigations Pty Ltd.

respectively. Unfortunately, for control purposes they each have distinctive characteristics as shown in Figure 17^{3,4}. The hydrograph of W11 has a gentle downward trend, that of piezometer W21 also trends downwards, but that of W41 trends upwards. Piezometer W51 might also potentially be a control, however, it is at a lower altitude ~324m and its water level is much shallower with a range of 5.46-6.01 m below ground level (range <0.5 m) (the others are ~17 m, ~15 m and ~17 m, respectively), and its trend is horizontal with zero slope for the regression line ($r^2=0.79$).

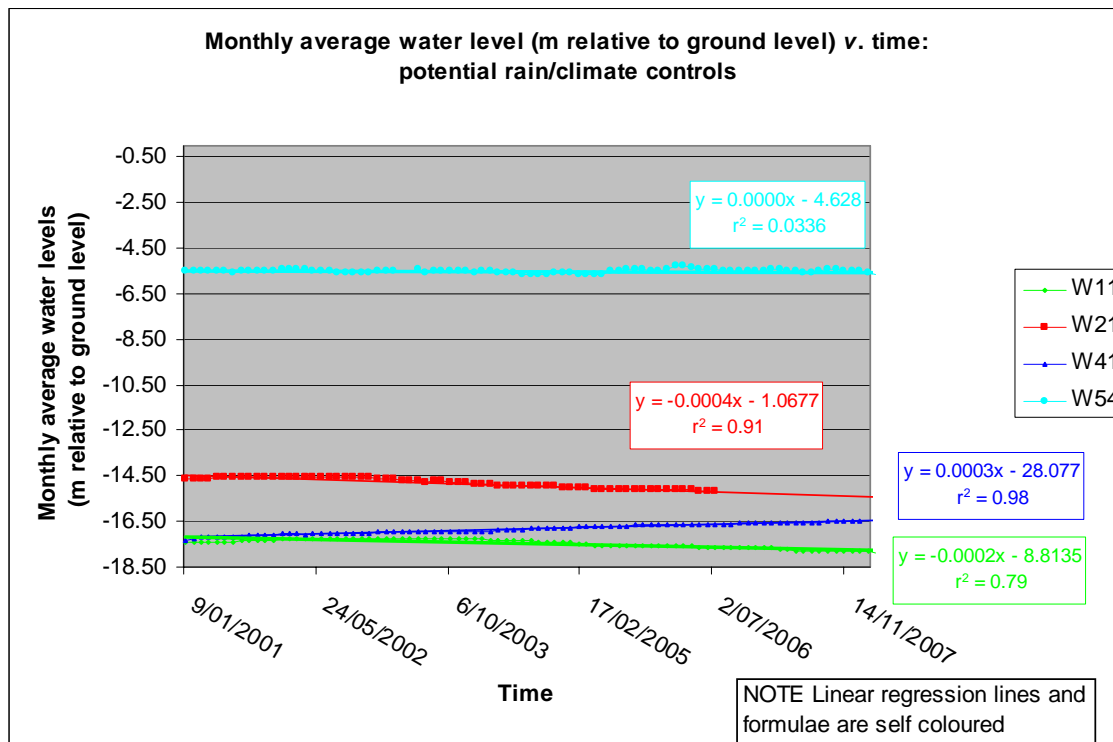


Figure 17 Hydrographs of piezometers that are potential controls for change in climate/rainfall throughout the life of the project, using monthly averages of hourly water level data.^{2,3}

In view of the different patterns displayed by these potential control hydrographs it is concluded that it would be unsafe to make any correction for the impact of rain/climate on piezometer water levels during the course of the project. It remains a mystery, however, why W41 is the only hydrograph to show a rising trend.

Transects

The piezometers were laid out in five transects by the project managers and for the purposes of reporting this nomenclature has been retained. I have, however, included piezometers on more than one transect where this could yield a better interpretation. The piezometers and the transects are shown in Figure 16. The apparently missing third transect comprises the two piezometers in the vicinity of the dam, Wad (above dam), Wbdb (below dam), and I have reported on these results in my discussion of Transect 2(3) since they are almost precisely located on that transect.



³ The same colour scheme is used for each of the hydrographs, with the highest piezometer in the landscape being red, and then successively downslope, blue, bright green, turquoise, pink, teal, and dark red.

⁴ Please note that the hydrograph figures except for Figure 6 have the same x and y axes to allow ease of comparison.

Transect 1 (T1)

Transect 1 runs from east-northeast to west-southwest down the slope of the catchment and comprises in order from upslope to down, piezometers W11, W12, W13, W14, W15, W52 and W22. The hydrographs for these piezometers are shown in Figure 17.

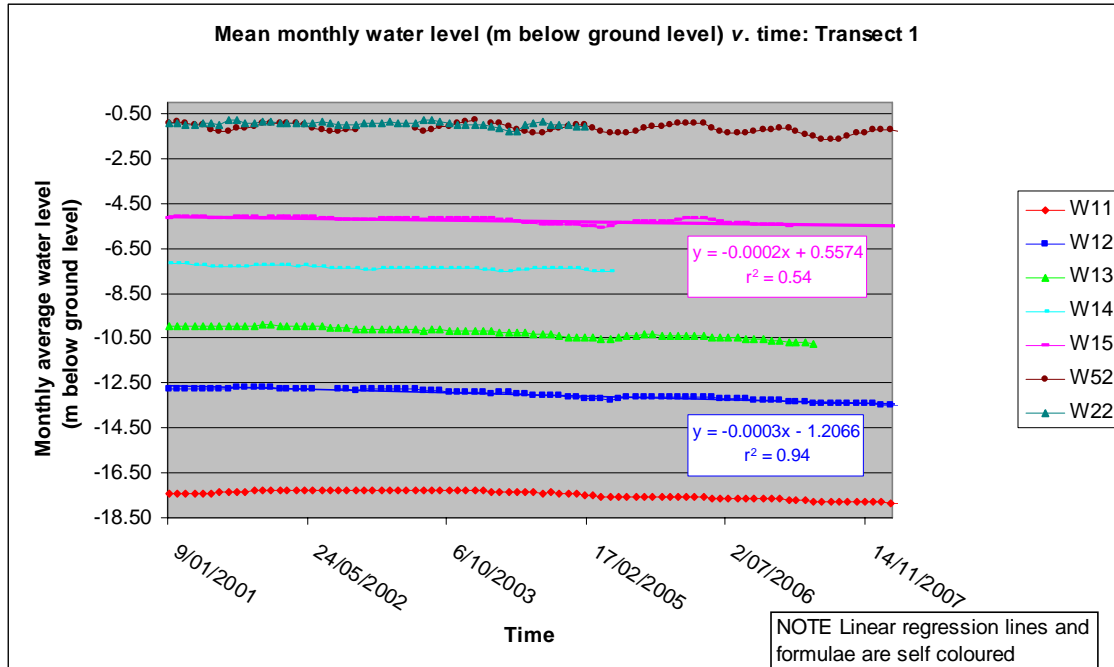


Figure 18 Hydrographs for the seven piezometers on Transect 1 using monthly averages of hourly water level data.^{2,3}

Piezometers W12 and W14 are in tree belts, W52 is within a pine plantation and W22 is on the corner of a multi-species plantation. Holes W13 and W15 are in the bays between tree plantings. Hydrographs of piezometers W11, 12, 13, 14, and 15, in spite of their differing situations in relation to the plantings have a generally similar pattern with a gently declining trend. The ranges in depths below ground level for these piezometers is 17.26-17.99 m, 12.70-13.58 m, 9.93-10.73 m, 7.17-7.50 m, and 5.08-5.51 m, respectively. As is to be expected the lower in the landscape these piezometers are the shallower are their water levels, and all the reductions are <1 m.

Piezometers W52 and 22 which are the lowest in the landscape have water levels ~1 m below the ground surface, and as is to be expected for piezometers with such shallow water levels they show a gently oscillating pattern, however, their respective ranges are 0.91-1.67 m, and 1.08-1.79 m, respectively; still <1m.

Transect 2(3) [T2(3)]

Piezometers W21 is at the top of Transect 2(3) which runs east-southeast to west-northwest down the slope of the catchment. Piezometer W21 is on the catchment divide although from the air photograph it would also seem to be on the edge of a seep just below the divide (see Figure 16), and is reportedly developed on an area of shallow bedrock (S Crombie pers. comm.), although its water levels at ~15 m below ground level would appear to belie these reports. The remainder of the transect comprises in order downslope Wad (above dam), Wbdb (below dam), W22, and W23. Wdam shown on Figure 16 is not a piezometer but a water level logger in the dam itself and Wbda is an electrical conductivity logger. The hydrographs for five piezometers on Transect 2 are shown in Figure 18^{2,3}.

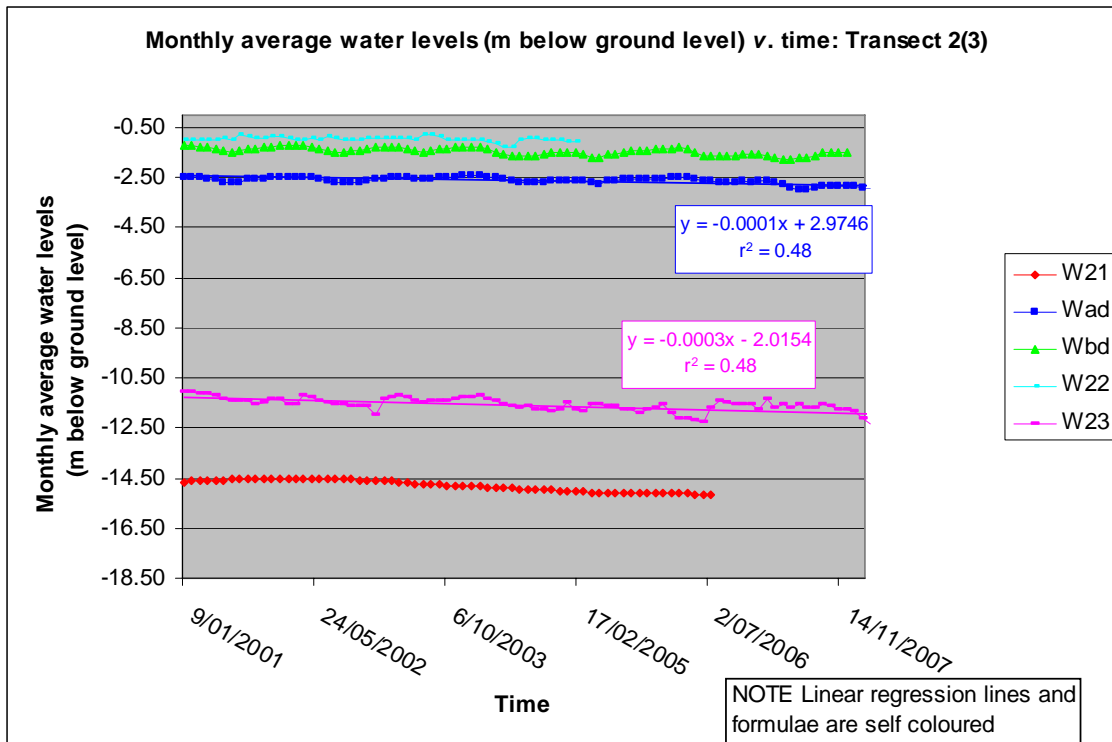


Figure 19 Hydrographs for the five piezometers on Transect 2(3) using monthly averages of hourly water level data.^{2,3}

The hydrograph for piezometer W21 rises slowly initially but subsequently slowly declines. However, the amplitude of these changes is small with the range of depth of water level below ground being 14.54-15.14 m, < 1m. Piezometers Wad Wbd and W22 have shallow water levels which, as is to be expected oscillate gently in an essentially horizontal pattern. The slope of the regression for piezometer Wad ($r^2=0.48$) which is typical of these three bores is $1 \times 10^{-4} \text{m day}^{-1}$. The respective depth ranges for water levels for these piezometers are 2.45-3.16 m, 1.17-1.67 m, and 0.82-1.07 m, again all < 1 m. The fact that piezometer Wad is located in a bay between plantings, and the other two are in close proximity to plantations and/or remnant native vegetation appears to make no difference to their hydrographs.

Piezometer W23 is by far the lowest in the landscape; ~311 m AHD, the next lowest bore being W22 at ~321 m AHD. Its hydrograph is unique amongst those from this site in that it oscillates irregularly, and it is also surprising since despite its relatively low elevation its groundwater depths below ground are deep, ranging from 11.04-12.26 m. This amplitude is the largest at the study site but is still < 1.5 m. The bore is close to plantations and remnant native vegetation, similar to Wbd and W22, but as stated above, unlike these two bores its water levels are much deeper.

Transect 4 (T4)

Transect 4 is much more oblique to the drainage direction of the catchment (generally westerly), running in a south-southwest to north-northeast direction downslope and comprising in order downslope piezometers W41, W42, W43, W44, W45, Wad, and W15. For the last two piezometers the transect is essentially parallel to the contour. The hydrographs for these piezometers are shown in Figure 19^{2,3}

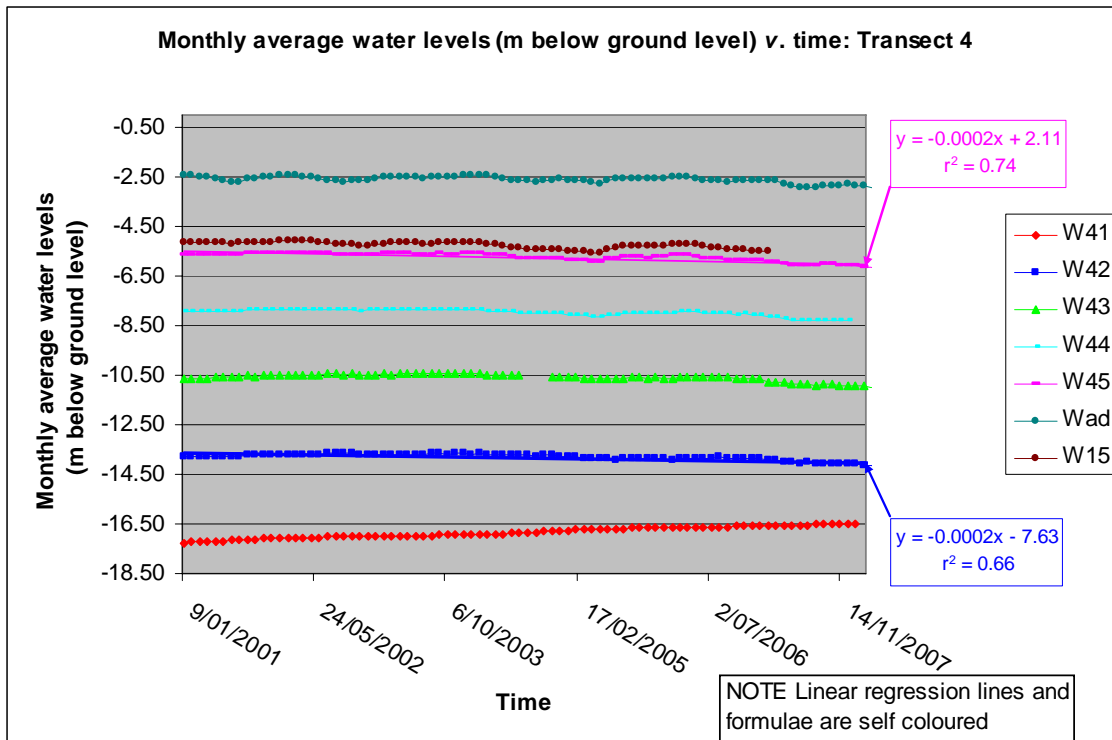


Figure 20 Hydrographs for the seven piezometers on Transect 4 using monthly averages of hourly water level data.^{2,3}

Piezometer W41 is ~75 m slope distance above the first tree belt on the transect and ~100 m slope distance below the catchment divide and is unique for this study site in that its water levels show a rising trend as noted in Section 2 above. The remaining water levels all show a gently falling trend, with not surprisingly the three piezometers with the shallowest water levels (W45, Wad and W15) having slightly oscillating trends. Piezometers W42 and W44 are located within tree belts whilst the remaining bores are in the bays between belts. This difference in vegetation cover appears to have no influence on the hydrograph pattern as the regression for W42 ($r^2=0.66$) representing bores within tree belts, and W45 ($r^2=0.74$) representing bores within bays between tree belts, both have the same gentle downward slope of $2 \times 10^{-4} \text{ m day}^{-1}$.

Transect 5 (T5)

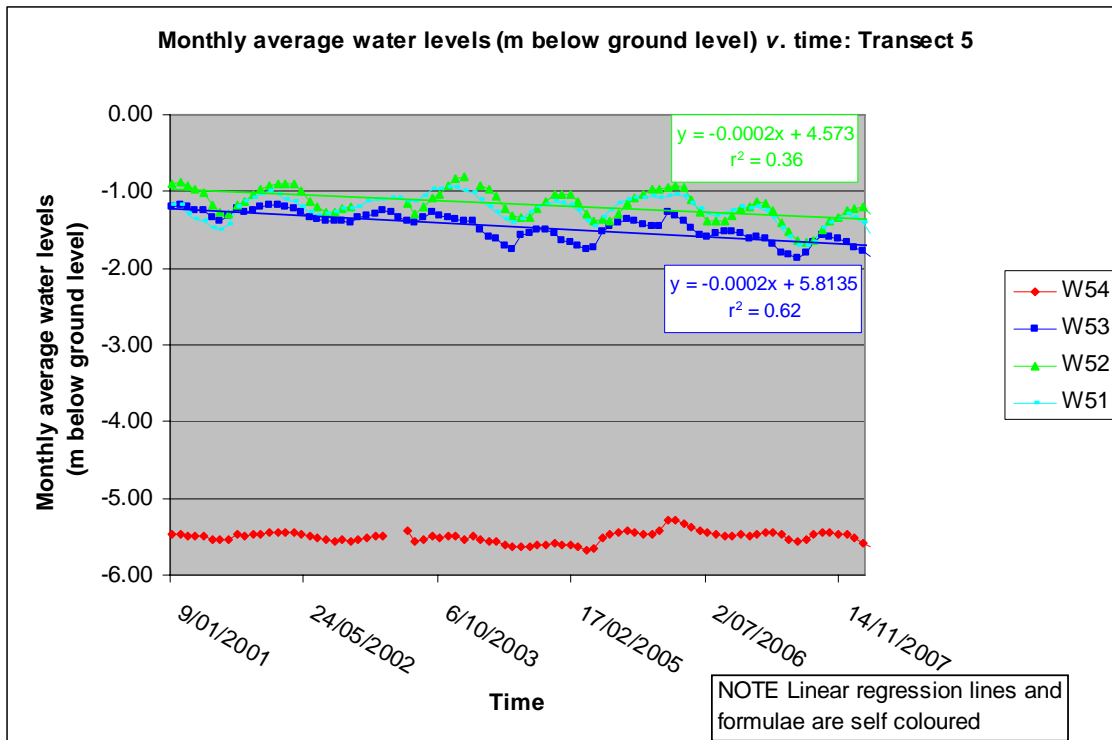


Figure 21 Hydrographs for the four piezometers on Transect 5 using monthly averages of hourly water level data.^{2, 4}

Transect 5 runs from south to north with piezometer W54, at the southern end, being at the highest elevation, ~329 m AHD. The remaining three piezometers (W52, W53 and W54) being at more or less the same elevation being between 322 and 324 m AHD⁵. The hydrographs of the four piezometers on Transect 5 are shown in Figure 20^{2, 4, 6}.

As noted in section 2 above the regression line for piezometer W54 is horizontal with zero slope for the regression line ($r^2=0.79$) as shown in Figure 17. The other three piezometers have gently oscillating and declining hydrographs. The slopes of the hydrographs for W53 ($r^2=0.62$) and W51 ($r^2=0.36$) which have been taken as representative of all three bores, are the same at $2 \times 10^{-4} \text{ m day}^{-1}$. Piezometer W51 is in remnant vegetation, W52 and W53 in plantations, and W54 in cleared land. The respective ranges of groundwater depth below ground for these four bores are 0.94-1.79 m, 0.88-1.67 m, 1.17-1.85 m, and 5.43-6.01 m.

⁵ Although the three most northerly piezometers on this transect are at approximately the same elevation they are colour coded in Figure 5 as if they were at decreasing elevations below the highest piezometer W54, as described in footnote².

⁶ Unlike the other hydrographs (y axis range 0-18.5m below ground level) the y axis in Figure 5 has been expanded (y axis range 0-6m below ground level) as the greatest water levels on this transect are shallower than those on the other transects.

Strategic Tree Farming: hydrological monitoring

Introduction

The Strategic Tree Farming (STF) Project is funded jointly by the Commonwealth and Western Australian Governments under the \$1.4 billion National Action Plan for Salinity and Water Quality (NAP). The STF is being implemented through a partnership between regional Natural Resource Management (NRM) groups - Northern Agricultural Catchments Council (NACC), Avon Catchment Council (Avon), South West Catchments Council (SWCC) and South Coast Natural Resource Management (SCNRM), the Forest Products Commission, and individual landowners.

The STF project sets out to demonstrate how the production of commercial wood and fibre, the mitigation of salinity and other environmental services (e.g. carbon sequestration) contribute to sustainable and commercially viable farming systems, providing lasting socio-economic benefits to rural communities. STF plantings are aimed at producing timber from species such as *Pinus pinaster*, *Eucalyptus saligna* and *E. cladocalyx*. Private investment has subsequently commenced in the region.

STF has been the single largest initiative being undertaken under the NAP, and commenced with plantings in 2005 and will establish 18,000 hectares of new tree farms across the medium rainfall areas (400-650 mm/yr) of Western Australia by 2008. With the support of four natural resource management (NRM) groups, funding of \$64 million was allocated, enabling FPC to achieve these targets by entering into tree farming agreements with rural landholders within the state.

Implementation of a hydrological monitoring plan

A hydrological monitoring plan has been implemented to determine the hydrological benefits of the STF project, and this has built on the experience developed with the Wickepin sub-catchment.

The monitoring plan has not been designed to monitor the effect of every STF planting on local and regional hydrology, but rather describes a structured sampling method which will provide robust estimates of the effect of tree plantings on watertables and recharge in landscapes representative of those targeted in the STF.

The aims of the long term, comprehensive monitoring program and an effective modelling and evaluation regime is to help to answer several questions relating to the effective management and mitigation of salinity and/or water logging by the restoration of tree cover, such as:

- How much of the catchment needs to be planted?
- Which parts of the catchment should be planted?
- How long will it take to see an affect from tree planting?
- Which planting configurations are most effective?
- Which tree species are the most effective?
- What are the economic implications of strategic tree farming?

25 sites have been identified to represent a range of major river basins, geographical areas, and rainfall zones associated with the STF activities. Monitoring is at the sub-catchment scale with the majority of

sites are contained within a single farm. Figure 22 shows the distribution of the monitoring sites, with a summary of key features of these sites in Table 4.

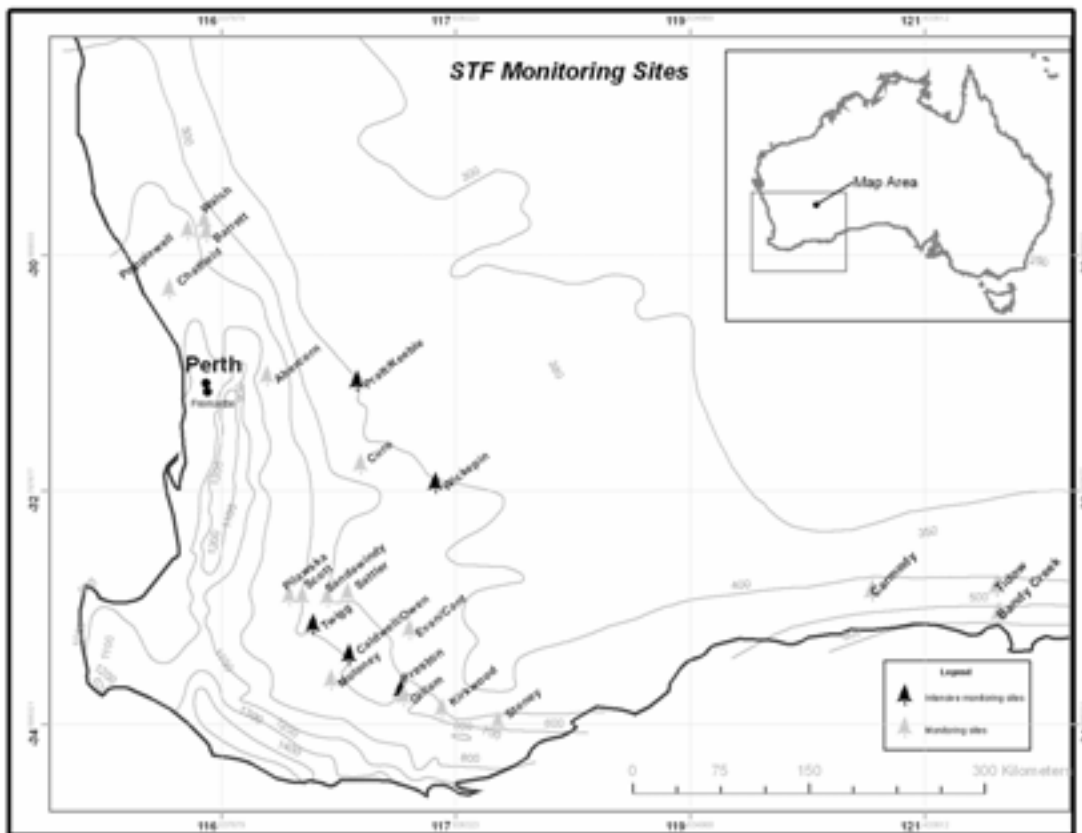


Figure 22 Distribution of monitoring sites in STF Program

Details of the hydrological monitoring program

A range of monitoring methods has been implemented with the installation of piezometers to measure water table head being the primary method of measuring ground water change over time. However, the suitability of sites to monitoring methods has led to a scale of monitoring intensiveness with a number of 'intensive' sites being equipped with a wider range of instrumentation.

The intensive monitoring has favoured sites where a sub-catchment is substantially contained within the farm or plantation area. These sites have been equipped with fully automated weather stations and stream discharge gauging points to allow the opportunity to calculate and model total water balance responses to tree plantings.

For robust evaluations to be made regarding the effect of plantings on hydrological systems a data set of at least 10 years is required. Only after this time scale is it expected that trees will have grown sufficient leaf areas and root systems to have appreciable effects on groundwater. Once long term data sets are available it is hoped that the monitoring infrastructure will then offer the basis for more detailed studies and evaluations.

Table 4 Location of the Strategic Tree Farming Monitoring sites.

Property	Catchment	Planting area (ha)	Mean annual rainfall (mm)	Planting Year	Intensive Monitoring	Number of peizometers	Year drilled
Abercorne	Swan / Avon	137		08	N	3	08
Bandy Creek	Bandy Creek	140		05	N	22	05
Barrett	Middle Moore	168		06	N	8	07
Caldwell / Owen	Frankland / Gordon	125		06	Y	10	07
Carmody	Young River	105		06	N	8	08
Chatfield	Moore River	304		05	N	6	05
Curo	Peel	61		06	N	8	07
Evan/Cant	Warren	124		06	N	6	08
Gillam	Kent	103		06	N	5	07
Kirkwood	Kalgan River	149		05	N	15	05
Moloney	Warren	161		08	N	6	08/09
Pillawska	Blackwood	130		08	N	10	08/09
Popplewell	Middle Moore	103		06	N	2	08
Pratt / Keeble	Avon South Branch	158		06	Y	11	07
Preston	Warren	70		08	Y	13	08/09
Sandawindy	Blackwood River	404		05	N	12	05
Sattler	Blackwood	1050		08	N	TBC	09
Scott	Blackwood	90		06	N	4	07
Stoney	Willyun Creek	17		98	N	23	99
Tidow	Esperance Lakes	66		06	N	3	08
Twigg	Blackwood	22		07	Y	6	08/09
Walsh	Middle Moore	611		06	N	8	08
Wickepin	Avon	-		01	Y	19	00

Discussion and Conclusions

The ability to grow trees in conjunction with standard farming practices without displacing traditional crops is crucial for the integration of trees into lower rainfall farming landscapes (Harper *et al*, in review). This can be achieved through a landscape approach, targeting particular landscape situations with the species and management practices such as niche planting. In this study, a sub-catchment was planted with several treatment designs in an attempt alleviate problems associated with dryland salinity on a landscape level and in the process explore the potential products from associated treatments.

Salt scald

The salt scald experiment illustrated that *E. occidentalis* planted on salt affected land, which is typically abandoned, can potentially produce approximately 20 t/ha average yield of dry biomass within four years of planting and over 30 t/ha if grown for seven years, with values ranging as high as 40 t/ha. When converted to carbon dioxide equivalent values, and assuming a carbon content of 50% (Gifford, 2000), this site is sequestering a mean of 55 t CO₂-e/ha, and up to 75 t CO₂-e/ha, after 7 years. Changes in soil carbon content were not measured. A key factor for carbon sequestration will be whether trees can persist on such sites and not die at a later stage. This will be less of an issue if the material is harvested for bioenergy, perhaps on a short rotation basis (Harper *et al*, 2008; Harper *et al*, 2006). Archibald *et al* (2006) report on the growth and survival of trees adjacent to salt scalds in this region, with these still persisting 25 years after establishment, despite some accumulation of salt in their root zones.

Biomass production was affected both by the stocking and also soil salinity, with an interaction between these factors. Biomass production of *E. occidentalis* planted at 2000 stems/ha was affected by soil salinity levels but not at 500 stems/ha. The response of *E. occidentalis* to conductivity differs from the observations of Benyon *et al* (1999) who reported no effect of soil salinity on this species. Although *E. occidentalis* grows naturally adjacent to saline playas biomass yield did show some signs of being affected by salinity at higher planting densities. There is also a strong gradient of salinity across the site, and this also affects tree growth. Relationships between water use and possible concentrations of salt within the root zone (Stirzaker *et al*, 2002a) or in groundwater (Heuperman, 1999) is beyond the scope of this study.

Although no water monitoring was in place within these plots, it can be assumed that in this landscape position a relatively shallow water table would be present. A high demand on soil moisture during dry summer months may have caused some concentration of salt in the ground water and may ultimately limit the sustainability *E. occidentalis*, however, an annual cycle of fluctuating groundwater level has been shown to flush salt from the root zone.

The sustainability of plantations on saline discharge sites is dependant on many interacting factors, which can only be resolved through further investigation. In this landscape position the effect of revegetation is most likely to have a minimal, if any, effect on ground water levels (George *et al*, 1999). However, the level of production achieved is a good example of the possible utilization of otherwise unproductive land, without the displacement of valuable farmland.

The salt scald was also treated with *A. nummularia* with this planted into large mounds which resulted in strong growth and subsequent production of fodder for dry summer months. *A. nummularia* produced approximately 10 t/ha of woody biomass over the trial period. Fodder production from this species was not measured, however with appropriate grazing practices this is considered to make a substantial supplement to summer stock feed (Ken Martin, land owner, pers. comm.). In conjunction with other pastures *Atriplex* plantations have provided maintenance nutrition for sheep during autumn (Barson *et al*, 1994). There was no significant effect of soil salinity levels on biomass production of *A.*

nummularia in this study, although some halophytes show improved growth under mildly saline conditions (Stirzaker *et al*, 2002a).

Reduced salinity levels in the mounds were evident from EM38 readings taken on top of mounds and in troughs along a transect approximately 100 metres long, commencing from the salt scald edge. The lack of any salinity effect may be due to mounding techniques used during planting. By planting into large raised mounds tree roots are subject to winter flushing by fresh water from seasonal rains. Salt concentrations are reduced following winter rains due to leaching of salt back into the subsoil, an effect apparent in Figure 6 and also reported by Barrett-Lennard and Malcolm (1995). This leaching will affect the production of annual pastures, however these were not measured in this study. Despite annual grazing reasonable levels of biomass have been maintained this illustrating the potential to productively use saline discharge land. *A. nummularia* could possibly have been planted closer to the salt scald and therefore utilized more of the discharge area, however, as seen in Figure 2, some of this land has not only been salinized, but also eroded, with the exposure of sodic subsoils and removal of surface fertility.

Again assuming a carbon content of 50% for the saltbush, this species represents a carbon store of 15 to 20 t CO₂-e/ha. An issue with salt-bush is that it is considered as revegetation under the Kyoto Protocol and thus falls under Article 3.4 of the Kyoto Protocol (Sampson and Scholes 2000). The Australian Government (2008) has indicated that this may not be included in the Carbon Pollution Reduction Scheme, in contrast to reforestation which is likely to be included.

Pine belts

George *et al* (1999) in their study of recharge and discharge areas found that for recharge areas the magnitude of water table response due to tree planting increased as trees were located further upslope from valley floors where there is less affect from ground water salinity. *P. pinaster* was planted in four belts in the upper-slope in an attempt to intercept recharge. This planting configuration effectively removed on average an estimated 350 mm of soil water after 6 years growth in comparison with adjacent paddock soil moisture values (Figure 12). The potential effect trees can have on an area of land is relative primarily to the planting layout (Stirzaker *et al*, 2002a). Tree belts have a greater tree/crop interface than block plantings and therefore have access to more soil water. Drying of the soil profile reached approximately 4 m, this has not at this stage markedly affected ground water levels.

A major concern with tree belts is the competition with adjacent pasture and crops. Stirzaker *et al* (2002b) reports on the complexity of the hydrology of the tree-crop interface and with the wide range of possible tree-crop-soil-climate combinations, mixing trees and crops can have positive effects on the soil water status with the smallest possible displacement of traditional agricultural land. No visible signs of competition were observed in the crop adjacent to the *P. pinaster* belts, when the paddock was cropped to wheat in 2007. This would bear further measurement, particular as the belts become older and compete more vigorously for water and nutrients.

Average total biomass produced by the *P. pinaster* belts was 54 t/ha (99 t CO₂-e/ha) at seven years of age, and this was greater than any other species grown in this area. This is likely an under estimate for the yield from belts as trees as those in the outer edge rows have access to extra soil moisture and nutrients from the adjacent paddock and have been shown to produce greater biomass than inner rows (Ritson and Sochacki 2003). *P. pinaster* is an important species grown in lower rainfall areas (400-600 mm) for timber production and has been shown to produce high levels of biomass. Already established markets for products derived from *P. pinaster* (e.g. thinnings for treated pine poles, MDF) has the potential to provide extra farm income while providing hydrological benefit in preventing leakage in recharge areas. Again, carbon sequestration will provide additional income.

***E. globulus* spacing and fertilizer trial**

Harper *et al.*, (2000) proposed phase farming with trees (PFT) as a means of both producing biomass and rapidly depleting soil water stores, and thus enabling continued farming for 10 to 15 years post-tree phase. Apart from the presence of deep soil profiles, another assumption of the PFT system is that tree roots can reach several meters depth within three to five years. *E. globulus* is a species which is usually planted in high rainfall areas (>600 mm) for pulpwood production (Harper *et al.*, in press), but in this trial the aim was to promote high water use over a short period of time to de-water the soil profile.

The soil water deficit was highest under the 2222 stems/ha treatment and reached -401 mm in less than three years after establishment. At this time, the soil water deficits for the 1111 and 555 stems/ha treatments were -300 and -261 mm, respectively. At four years (July 2005) the soil profiles appeared to re-fill to the same soil water levels in the paddock control by an amount which exceeds rainfall. We attribute this response in part to a) the mounding which had been employed during planting and the effect this may have had in concentrating surface flow onto the experimental site and b) the effectiveness with which the neutron access tubes were inserted into the lateritic profile, the lack of a bentonite plug at the sand clay interface and the possibility of voids around the neutron access tubes filling with water and resulting in exaggerated soil moisture values. The soil water deficit reached maximum values of 419 mm, 339 mm and 386 mm for the 2222, 1111 and 555 stems/ha treatments. The soil water deficit for 2222 stems/ha treatments after 5 years (September 2006) was approximately the same as in March 2004 but in the 1111 and 555 stems/ha treatments have also approached the same amount of soil water deficit implying that a soil water balance has been achieved with respect to site production. A relationship between biomass and soil water deficit was not observed, however, leaf area index (LAI) is perhaps a more appropriate parameter or direct measure for comparing site water use to soil water availability. Importantly though, it was shown that the soil profile was rapidly dried as also seen at Corrigin (Harper *et al.*, 2008) and the expected effect of high water use species was confirmed. The length of persistence of the dry soil buffer under the agricultural system is the next stage in investigating the efficacy of the PFT system.

Planting trees on previously pastured land has the advantage of utilizing the existing soil fertilizer store and excess soil moisture, enabling good levels of tree growth and subsequent biomass production. Approximately 19 t/ha of dry biomass was produced after 5 years growth from the 2222 stems/ha treatments. Although planting density did not significantly affect yield, landscape position in conjunction with planting density have been shown to effect biomass yield for *E. occidentalis* and *E. globulus* (Harper *et al.*, 2008). Here, the treatments were isolated to a single mid-landscape position.

Multi- species trial

The multi-species trial consisted of two components namely, the effect of landscape position and species. Upper and mid- landscape positions utilized the same species for the comparison of biomass yield and soil water use, and the lower-slope trial investigated biomass production and water use but incorporated four different species to test their suitability for dryland salinity amelioration.

Survival of *E. globulus* dropped from 69% to 35%, and biomass yield decreased 44%, a reflection of this species intolerance to salinity (Table 3), as reported elsewhere (Bennett and George 1995). The mid-slope position was located close to a stream-line and possibly subject to saline discharge. *E. sargentii* however, showed an increase in biomass production of 28% despite a small decrease in survival (Table 3). *E. sargentii* is a species typically associated with salt lakes and salt creeks, floodways and wetter end of flood-fringes around saline waterways (Marcar and Crawford 2004). *E. sargentii* has been shown to be a promising species in the reduction of groundwater levels (Greenwood *et al.*, 1992) and is recommended for remediation of saline seeps (Biddiscombe *et al.*, 1989). *E.*

sargentii was also the most effective species in soil profile water use, the only species to dry the profile beyond the depth of the neutron access tubes in the mid-slope position.

E. occidentalis was the only species present in all the landscape positions and showed very promising biomass yield over the range of sites. In the lower-landscape position it produced 20 t/ha after 7 years, followed closely by *E. rudis* with 18 t/ha. Unfortunately *E. sargentii* was not included in the lower-landscape position as this would have been an interesting comparison to *E. occidentalis*.

The decrease in biomass production with slope position is possibly related to salinity and not the soil water status. In the mid-slope position *E. sargentii*, a highly salt tolerant species, was able to dry the soil profile to depth without the profile refilling, the rooting depth of the other species was less and the soil profiles contained higher levels of soil moisture. Soil moisture levels for *E. sargentii* were below 200 mm/m throughout the profile depth whereas all other species had wetter soil profiles of 250 mm/m of soil water. The water deficit estimated for the upper-slope treatments were calculated to a depth of 2.7 metres and seasonal changes in soil moisture indicate that drying occurred beyond this depth. Water use in *E. occidentalis* treatments in this landscape position was in fact greater than 383 mm. Soil water deficits under tree plantations can be variable and obviously dependant on a many factors. Sudmeyer and Goodreid (2007) reported a 447 mm soil water deficit to 4 m under *E. globulus* after 12 years growth and 1350 mm of soil water deficit under *Eucalyptus polybractea* to 10 m after just 6 years growth.

Effect of reforestation on catchment hydrology

Site hydrology has been assessed at this site over the seven years since establishment. There are 20 piezometers at the site and of these most show gently falling trends, one (W41) shows a rising trend, and one (W54) is essentially constant. There seems to be no relationship in any of the hydrographs between the water levels and their position in relationship to the reforestation at the site, although it is possible that one will develop in the future as the trees grow and fully occupy the site. The three or possibly four potential control bores for climate and rainfall effects of the water levels in the other piezometers each show different patterns, so it was considered unsafe in these circumstances to make any corrections to the measured (average) values. The bores with shallow water levels tend to have oscillating trends whilst the rest tend to be monotonic. Only one of the bores (W23) has an amplitude of variation in water levels below ground level >1m and that is <1.5 m.

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Broad-scale restoration of landscape function with timber, carbon and water investment⁷

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Abstract

Salinization threatens up to 3.7 million hectares of Australian farmland, major fresh water resources, biodiversity and built infrastructure. In higher rainfall (>600 mm/yr) areas of south-western Australia a market based approach has resulted in the reforestation of over 280,000 ha of farmland with *Eucalyptus globulus* plantations. This has had significant collateral environmental benefits in terms of reducing salinity in several watersheds. This model has not been replicated in the lower (300-600 mm/yr) rainfall areas of this region, which is a global biodiversity hotspot. In this area, conventional forestry species have lower wood yields and longer rotations, compromising profitability, and reinforcing land-holder preference to maintain existing agricultural activities.

Two complementary strategies are being used to restore landscape function across this drier region, through increased reforestation. The first is to shift from the paradigm of forestry comprising tall trees grown in relatively long rotations and producing timber to one based on the production of a range of biomass products (bioenergy, chemicals, sequestered carbon), and environmental services such as providing fresh water. As a consequence of breaking this paradigm, silvicultural practices such as stand densities and rotation length can also be redefined. The second strategy is to integrate these new systems into the existing dryland farming systems. Four broad approaches are being assessed *viz.* (a) belts of trees with farming maintained in interrow alleys, (b) blocks of trees located on areas of water accumulation or of high recharge, (c) adjusting species selection to soil conditions, such as those that are shallow or saline, and (d) alternating short phases (3-5 years) of trees with farming. These systems offer the prospect of sequestering carbon, and producing wood or biofuels from farmland without displacing food production.

⁷ Harper, R.J., Smettem, K.R.J., Townsend, P.V., Bartle, J.R and McGrath, J.F. (in review). Broad-scale restoration of landscape function with timber, carbon and water investment. In "Forest Landscape Restoration: Integrating Social and Natural Sciences", J. Stanturf (Ed) (Springer: New York).

Tree placement strategies for salinity control in dryland farming systems of southern Australia

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Abstract

Salinization threatens up to 17 Mha of Australian farmland, major fresh water resources and biodiversity. In Western Australia alone up to 450 species are threatened with salinity-induced extinction. The integration of woody perennials into farming systems is often advocated as a method of reducing recharge and remediating dryland salinity. Whereas complete revegetation is feasible in higher rainfall catchments where improved water quality is an outcome, such a planting strategy is impractical in lower rainfall areas due to the need to maintain cereal cropping. It is thus necessary to consider methods of integrating trees with agriculture that allow agricultural production whilst also improving the water balance. In low rainfall areas (<400 mm yr⁻¹) two options for incorporating trees have been proposed, alley farming between belts of trees and short phases of trees rotated with agriculture.

A survey of rooting depths of belts of farm forestry species (oil mallees (*Eucalyptus* spp.), *Eucalyptus astringens*, *Acacia acuminata* and *Allocasuarina huegeliana*) aged 4 to 11 years old found soil was dried to depths ranging from 4 to 10 m, with evidence of drying up to 15 m laterally. Phase farming with trees reduces recharge via the creation of a dry soil buffer to capture the leakage under subsequent annual crop rotations. In 2001, *Eucalyptus globulus*, *E. occidentalis*, *Acacia celastrifolia*, *Pinus radiata* and *Allocasuarina huegeliana* were planted at four densities 500, 1000, 2000 and 4000 stem ha⁻¹, as well as 500 stem ha⁻¹ plus fertiliser. Species survival and growth were predominately affected by site characteristics and slope location as well as density in the second year of growth. Soil water content under high density *Eucalyptus* plantings was depleted to depths of 4 m after 2 years. The implications of these results for the use of deep-rooted perennials for recharge reduction and salinity control are discussed.

Additional Keywords: agroforestry, recharge, desertification⁸

⁸ Robinson, N, Harper, R.J., Smettem, K.R.J. and McGrath, J.F. (2004). Tree placement strategies for salinity control in dryland farming systems of southern Australia. Paper 459, 13th International Soil Conservation Organization Conference (ISCO 2004), 4 - 9 July 2004, Brisbane, Australia.

Appendix 2: Evaluation of existing hydrological experimental sites

A summary of visits to and assessment of certain experimental farm forestry sites
in the wheatbelt of Western Australia.

Dr CJ Clarke and Ms NC Mouat,

29 03 05.

Introduction

As part of its research and development application to the Rural Industries Research and Development Corporation (RIRDC), *Catchment scale evaluation of Trees, Water and Salt* (RIRDC reference CAL-8A) the Western Australian Department of Conservation and Land Management (CALM), proposed under Component II: Dormant hydrological revegetation experiments,

“A range of catchment treatment experiments have been established across the Western Australian wheatbelt. Locations include instrumented catchments established by CALM/FPC [Forest Products Commission] in 2000 in Moora and Wooroloo, and five agroforestry experiments established by CSIRO in the period 1976-1982 (Boddington, Popanyinning, Dryandra, Cuballing and Kellerberrin). Ongoing monitoring of these catchments has ceased. There is an ideal opportunity here to extend value to the Wickiepin study by virtue of the wider geographic range and longer life of these plantings. In this project, we will undertake at least two visits to the other sites, in years 1 and 3, to measure growth and measure the piezometers and soil salinity meters. We will compile a report that assesses the feasibility and desirability of re-instrumenting the sites, the value of the information for enhancing hydrologic modelling and estimates of cost.”

The aim of this present report is to partially fulfil these aims for the sites mentioned above, and some others. The other sites included five sites established by the Department of Agriculture Western Australia (DAWA) for which DAWA Resource Management Technical Reports were available (Nos 174-178, Smith *et al*, 1988a-e), these sites were Hunt’s Catchment (Frankland), South’s Catchment (Darkan), TTK Engineering’s Catchment (Williams), White/Beatty’s Catchment (Dinninup), and Wooldridge/Wright’s Catchment (Kojonup). Also there were seven sites established by CALM (some of which were established under the HANSOL banner). These sites were Caldwell P95, Charlesworth P95, Noonan, Owen, Ritson P95, Putland, and Wardle.

Sites visited

For various reasons it was either not necessary, or in some cases not possible, to visit all the sites described above and Table 5 lists the sites visited, the reasons for not visiting certain sites, and where relevant and known their approximate location. As can be seen from Table 1, 12 sites were field visited for assessment as part of this project and these will be dealt with in alphabetical order below.

Caldwell P95

A transect was carried out down Kulicup South Road and alley plantings with 6 rows of trees separating the alleys, and plantation blocks were observed. There was no sign of any monitoring installations and nor were any recorded on the map, so although the trees seemed to be in good

condition there seems no point in initiating monitoring at this late stage given the costs of such installation.

Charlesworth P95

The alley system shown on the CALM map has been filled in with *Eucalyptus globulus* (Tasmanian blue gum) so the age distribution of the trees is bimodal, and the resulting plantation has been extended much further east. This combined with observed lack of any monitoring installations leads us to recommend that monitoring should not be commenced at this site.

Cuballing

This site has been being researched for a long time, first being one of the research sites for Dr Richard George's (DAWA) PhD and subsequently research was taken over by Dr Ramsis Salama CSIRO who instigated some tree planting, installation of some piezometers, and a windmill in the seep area (Salama *et al*, 1993a). The site is typical of the geomorphology of an east west strip running through Williams where there is shallow bedrock which outcrops in the upper parts of catchment, as distinct from the more typical wheatbelt weathering profile which is much deeper, and where the upper parts of catchments consist of outcropping laterite hard cap. It is the shallow nature of the weathering profile in the Cuballing Catchment combined with its consequent low salt store that made it amenable to restoration by the minimal treatment that was applied, one windmill and a few belts of trees.

The site visit showed that the replantings were in excellent condition and that the piezometers appeared to be intact. As such the site would be suitable for reinitiating monitoring, but because of the shallow nature of the groundwater and the time it has been developing it is likely that the catchment is at or near hydrological equilibrium, thus further monitoring should only be carried out if it is desired to investigate this state.

Dryandra

This site's location was shown on a sketch map which also included the Popanyinning site (see below) and whilst the latter was easy to find, the location of the former was ambiguous. This ambiguity was exacerbated by the many, decades old, *Eucalyptus astringens* (brown mallet) plantations to be found in the Dryandra Forest.

A possible arboretum type site was found on the old football oval to the north of the Lions' Dryandra camp, that would have fitted the limited information provided by the sketch map, however, its species composition according to the on site labels did not match that shown in the species distribution maps: there were numerous plots labelled *E. brockwayi* but this does not occur in the species distribution maps.

Notwithstanding the possibility that we were in the wrong place (although we made to quite wide ranging searches in the most likely region indicated by the sketch map) the site showed that many of the trees were in poor condition and the many gaps suggested numerous fatalities. This combined with the lack of any observed piezometers and neutron tubes leads us to recommend that this site is not worthy of further investigation, but if more precise details can be obtained about its location it would be worth assessing whether or not we were in the right place.

Table 5 The sites visited, the reasons for not visiting certain sites, and where relevant and known their approximate location.

Site	Location	Visited	Reason for not visiting
CALM/FPC			
Moora	Not known	✘	Location not known
Wooroloo	Not known	✘	Location not known
CSIRO			
Bannister*	Adjacent to NE of North Bannister	✓ ^A	Site subsumed into plantation
Cuballing	~5 km NE of Cuballing	✓ ^B	
Dryandra	~25 km NW of Narrogin	✓ [?]	
Kellerberrin (Wallatin)	Adjacent to N of Doodlakine	✘	Part of an extensive rehabilitation programme under the National Action Plan
Popanyinning	~13 km NE of Popanyinning	✓	
DAWA			
Hunt	~15 km NE of Frankland	✓	
South	~18 km NW of Darkan	✓	
TKK Engineering	~15 km N of Williams	✓	
White/Beatty	~18 km ENE of Boyup Brook	✓	
Wooldridge/Wright	~13 km NNE of Kojonup	✓	
CALM			
Caldwell P95	~31 km ESE of Boyup Brook	✓	
Charlesworth P95	~41 km ESE of Boyup Brook	✓	
Noonan	~50 km WNW of Brookton	✓	
Owen	Not known	✘	Location not known
Putland	~15 km N of Darkan	✓	
Ritson P95	~12 km SE of Boyup Brook	✘	Ongoing monitoring by DAWA
Wardle	~34 km E of Boyup Brook	✘	Ongoing monitoring by DAWA

^A visited by FPC, CSIRO, and UWA staff

^B visited with CSIRO staff

? not certain if the correct site was located

Hunt

The site could only have been in one of two positions on Gunwarrie Road (Smith *et al*, 1998a), and there were farm trees in good condition established in the vicinity in both of these positions. No monitoring equipment was visible at either site so it is not recommended that monitoring commence at this site.

Noonan

The Noonan tree plantation appeared to be in good condition but no monitoring installations were shown or observed so it is not recommended to commence monitoring at this time.

Popanyinning

By contrast to Dryandra (above) the Popanyinning site was easy to find from the sketch map provided. The site consists of quadrat blocks of different *Eucalyptus* spp. All of which appear to be in very good condition and the neutron probe holes appear to be ready for use. If there are historic data for this site, which the neutron probe sites would suggest, it would be worth considering recommencing monitoring to see how the trial is doing a few years on.

Putland

The alleys at Putland are separated by belts of four rows of *E. globulus* planted on a reasonably steep hill slope. There is some evidence that lateral movement of groundwater is delivering water from the alley bays to the tree belts, this includes the observation that the upslope row of trees in each belt is in the best condition, with down slope row being second best. The two middle rows are the worst and this is where most of the estimated 10% tree mortality has occurred. Evidence that the tree belts are causing drawdown of the groundwater across the alley bays between the tree belts is the strong regrowth and condition improvement of *Corymbia calophylla* (marri) trees growing within the bays, compared to those growing outside the system, which are showing improvement but not to the same extent.

Although there is no monitoring equipment installed it might be worth considering a transect of deep piezometers through the system to see if the hypothesis that the belts of trees are causing groundwater drawdown across the hill slope is true.

South

This site was originally not located, principally because the only key to location is in one corner of the map in Smith *et al* (1998c). At the site which was located (on the east-west road from the junction shown in Smith *et al* (1998c) to the South's farm house the trees in the plantation appeared to be growing well despite the fact that groundwater was strongly seeping at the site and the one piezometer we located had brackish groundwater at ~0.4 m above ground and was overflowing (there was evidence of seepage above this piezometer so the overflow water was not what was causing the appearance of seepage. We were unable to find any other piezometers at the site.

The trees are clearly failing to do what was required of them but the absence of much of the monitoring equipment shown on the map combined with the uncertainty of location and what was actually installed, leads us to recommend not recommencing monitoring at this site.

However, after discussion with Richard George (the second author of Smith *et al* (1998c)) the proper site was located by us on a later field trip for another purpose. Here all the trees are doing very well (except for some *Acacia saligna* which had died, probably due to senescence, and which had been replaced by numerous volunteers) and there was evidence from iron staining in one piezometer that,

either the groundwater is cycling with rainfall or there has been a reduction in water level, probably due to the plantation. Several other piezometers were sighted (but we did not have the plans with us) and in view of the success of the trees, despite early belief that they would not survive because of winter inundation, this would make a worthy site for further research.

TKK Engineering

At this site the trees are in excellent condition with very few fatalities, indeed there is significant volunteering of *Eucalypts*, *Melaleuca* and *Allocasuarina* spp., and there appears to have been a reduction in the saline area. However, none of the piezometers could be found (although we were at the exact site of two of them) nor could the two internal fences shown on the map in Smith *et al*, (1998b), but extensive evidence for sheet flooding across the site probably explains their absence. It would have been interesting to see how this site has progressed, since it seems to have been at least partially successful, but the absence of any monitoring equipment, and the flood induced instability of the site suggests that this is not practical.

White/Beatty

The western plantation area consists of *A. saligna* and tallow gum planted in a saw log formation, and for people who are hydrogeologists not foresters they look to be in generally good condition. The eastern block is *E. globulus* in wood chip style plantations. None of the piezometers shown in Smith *et al* (1998d) could be found so this site is not recommended for renewed monitoring.

Wooldridge/Wright

At this site most of the trees appear to be in good condition (except *Acacia* spp. Which are in a variable condition from healthy to dead) and many of the piezometers shown on the map in Smith *et al* (1998e) appear to be still viable and there is a rain gauge on site. This map is ambiguous about the arrangement of the trees, but the southern part of the planting is in an alley arrangement and most of the trees (except for those in a 10-20 m wide east west trending belt across the alleys) are in good condition. This would be a very good site to reactivate to see how the groundwater has responded to the treatments six years on.

Sites recommended for reactivation of monitoring

Three sites of those visited are considered to be definitely worthy of reactivating the research programme. These are in order of decreasing importance, South's proper, Wooldridge/Wright and Popanyinning). None of these sites would require significant investment in monitoring equipment to bring them back on line (except possibly South's) and they could provide valuable information on how the trees have developed in the last six years and how the groundwater has responded to these changes.

South's and Wooldridge/Wright's have been visited since these recommendations were made, and groundwater levels taken where possible, these results are contained in Table 6. All the other holes tested were dry (4 at South's and 32 at Wooldridge/Wright's).

Table 6 Water levels at South's and Wooldridge/Wright's in 2005 and compared with 1995 and the groundwater salinities in 1995.

Borehole	Summer w/l 2005	Rough summer w/l 1995	conductivity
	(m)	(m)	(mScm-1)
South's			
RS01D	-3.11	-3.1	0.6
RS01I	-4.12	-3.1	1.2
RS02D	+4.9	-0.7	11.44
RS02I	+0.46	-1	29.6
RS03D	-2.00	-1	15.8
RS04D	-1.75A		
RS04I	-0.47	-2	0.7
RS06I	-0.88A	-1.5	1.7
Wooldridge/Wright's			
WW16D	-2.47	-0.5	28.8
WW71D	-4.58	-3	10.04
WW74D	-3.95	-2.7	13.7
WW82D	-3.85A	-1.8	0.4
WW100D	-3.23		0.6

A not allowing for collar height

Since holes at both these sites were cyclic during their previous monitoring (Smith *et al*, 1998c, e) these data support the case for rekindling the monitoring programme at these sites, but some strategically placed piezometers deeper than those currently available at Wooldridge/Wright's would give a better picture of the groundwater situation since most of the current piezometers did not reach this year's summer water level.

Sites recommended for consideration of commencing research

The Putland site could yield some promising data on the effectiveness of alley farming on sloping land where the trees might be able to access the groundwater in the bays between the tree rows, but there would be some initial expense for installation of piezometers and an unfortunate lack of base line date. The latter could be overcome partially by instrumenting a similar but unvegetated hill slope.

It also could be worth one or two years future monitoring of Cuballing to see if it has reached equilibrium, and if so the nature of that condition (for example is it dynamic or static?).

Other recommendations

If better location evidence could be found for the Dryandra site, if it is not the site we located the proper site could be visited.

It ought to be possible to find location information for the "instrumented catchments established by CALM/FPC [Forest Products Commission] in 2000 in Moora and Wooroloo", and this information should be pursued more vigorously.

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Catchment Scale Evaluation of *Trees, Water and Salt*

RIRDC Publication No. 09/059

Salinity is a major land management issue in Australia and reforestation is often advocated as part of its management. There has been considerable debate about the level of reforestation required to stabilize landscape hydrology, and in particular whether this can be achieved by strategically placed, integrated plantings.

In 2002 the Joint Venture Agroforestry Program (JVAP) published *Trees, Water and Salt* (RIRDC Pub No. 01/086), which summarised knowledge of the use of trees to tackle salinity.

The study reported here followed the establishment of an integrated tree planting, on a farm near Wickepin, Western Australia, with 300 mm annual rainfall. These trees were established using the procedures outlined in *Trees, Water and Salt*. Not only were the

hydrological effects of this planting monitored, but a range of tree species were assessed for biomass production and carbon sequestration.

JVAP is managed by the Rural Industries Research and Development Corporation (RIRDC). RIRDC's business is about developing a more profitable, dynamic and sustainable rural sector.

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