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Plantations, Farm Forestry and Water

**Proceedings of a national
workshop, 20-21 July 2000,
Melbourne**

**Agriculture, Forests and Fisheries-
Australia
Joint Venture Agroforestry Program
CSIRO Forestry and Forest Products**

**Edited by
E.K. Sadanandan Nambiar and
Alan G. Brown**

**A report for the
RIRDC/ LWA/ FWPRDC
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**Water and Salinity Issues in
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Foreword

To explore interactions between afforestation and water, and provide a forum for informed and balanced discussion, CSIRO, Agriculture Forests and Fisheries Australia and the Joint Venture Agroforestry Program jointly organised a national workshop – *Plantations, Farm Forestry and Water*. The workshop was held on the 20-21 of July, 2000 and had the following aims:

- Review the broad scientific principles underlying interactions between communities of trees and hydrological processes at the landscape level;
- Examine the potential positive and negative impacts in the context of land use;
- Explore the current and expected scenarios of selected ecosystems (regions) as case studies; and,
- Based on the above analysis, prepare a discussion paper to provide balanced information for all concerned with land management and development of land use policies.

The Joint Venture Agroforestry Program are publishing both the *Workshop Proceedings* (this volume) and the *Discussion Paper* (forthcoming) developed following the workshop.

This report, a new addition to RIRDC's diverse range of over 600 research publications, forms part of our Joint Venture Agroforestry R&D Program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/reports/Index.htm
- purchases at www.rirdc.gov.au/eshop

Peter Core

Managing Director

Rural Industries Research and Development Corporation

Executive Summary

In recent years there has been a major surge of interest, investment and activity promoting further development of plantations and farm forestry and revegetation in general in Australia. Incentives for this have come from the expectation of both economic and environmental benefits, especially to rural and regional Australia.

The shared commitment of the community, industry and the State and Commonwealth Governments to *Plantations for Australia – The 2020 Vision* gave a much-needed focus for commercial forestry development. This vision, if fulfilled, would treble the present land base under plantation forestry. Reforestation with deep-rooted perennials and reforestation on a large scale are being proposed through a variety of policies and initiatives by a variety of land management agencies as one option for saving the land from increasing salinisation.

The purposes of these schemes include timber production, mitigation of land degradation, enhancing biodiversity, carbon sequestration and bioenergy production. Accordingly the structure, composition and life cycle of planted forests vary widely. The level of these activities in progress and proposed represents a large change in agricultural land use, the rate and intensity of which vary substantially between regions, and are strongly influenced by many factors.

Australia is committed to ecologically sustainable development. Sustainability is a balancing act involving accommodation of and trade-offs between multiple and sometimes conflicting values. The development of plantations and farm forestry, therefore, faces the challenges of achieving economic and ecological balance at farm, landscape, and regional levels. One major challenge, already with us, is the management of interactions between plantations of trees and hydrological processes to achieve sustainability in the broad sense.

As noted, it is widely recognised that well-planned reforestation offers a major opportunity to redress the hydrological imbalance that is the root cause of dryland salinity on farms. However, concerns have arisen that in some situations substantial plantation forestry expansion could have negative hydrological effects leading to threats to water availability or water quality for other users. Experience in other countries has shown that perceived competition for water between plantations and farm forestry and other users would be detrimental to the orderly progress and investment in resource development for the multiple benefits mentioned earlier.

The potential impacts of plantation forestry on water resources are of increasing concern to the community. Balanced discussions, land use policies and communication between stakeholders and land management agencies are required for attracting investment and achieving orderly development. There is no single, universally applicable model of the impact of plantation forestry

on water resources – impacts are likely to be diverse, ecosystem-specific and related to goals of land management and use.

To inform this debate a workshop was convened with the following aims:

- Review the broad scientific principles underlying interactions between communities of trees and hydrological processes at the landscape level;
- Examine the potential positive and negative impacts in the context of land use;
- Explore the current and expected scenarios of selected ecosystems (regions) as case studies; and,
- Based on the above analysis, prepare a discussion paper to provide balanced information for all concerned with land management and development of land use policies.

The scope of the workshop was restricted to regions where industrial and farm activities are advancing rapidly: southern and western Australia, where the extent of development and available information provide a reasonable basis for case study analysis.

The workshop was held over two days (20-21 July 2000) in Melbourne and attended by about 55 participants representing a wide range of stakeholders.

These proceedings are a collection of the papers presented at the workshop and subsequently reviewed and revised. They formed the background to structured discussion. A synthesis of the papers, the views which emerged from discussion, and an executive summary will form the discussion paper which will soon be published separately.

E.K S. Nambiar
CSIRO Forestry and Forest Products

Acknowledgements

The workshop Plantations, Farm Forestry and Water was guided by a Steering Committee consisting of:

Richard Benyon	CSIRO Forestry and Forest Products
Sharon Davis	Joint Venture Agroforestry Program
Brian Myers	CSIRO Forestry and Forest Products
Sadanandan Nambiar	CSIRO Forestry and Forest Products (Chair)
Phil Pritchard	Agriculture, Fisheries and Forestry – Australia
Richard Stanton	Plantations for Australia: The 2020 Vision
Rob Vertessy	CSIRO Land and Water; CRC for Catchment Hydrology

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Rod Keenan	Bureau of Rural Sciences
Phil Pritchard	Agriculture, Fisheries and Forestry – Australia
Hugh Stewart	Treecorp Group
Rob Vertessy	CSIRO Land and Water, CRC for Catchment Hydrology
Don White	CSIRO Forestry and Forest Products

Professor Barry Hart, Monash University, CRC for Freshwater Ecology, gave a presentation at the workshop on ecological risks from timber plantations.

Professor Ian Ferguson, University of Melbourne, chaired the workshop discussion session.

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1

An Overview of Timber Plantation Development in Australia – Drivers, Trends and Prospects

Richard Stanton

National Plantations Co-Ordinator
Plantations for Australia: The 2020 Vision

The growing of tree plantations and the processing and exporting of timber is a significant industry in several regions across Australia. The national plantation strategy, *Plantations for Australia - The 2020 Vision* envisages a major expansion of Australia's timber plantation resources. The last four years have seen an unprecedented increase in interest and activity in the timber plantation sector in Australia. The plantation area continues to expand, production from plantations continues to increase as the plantations mature, and a wider range of investors is seeing the potential of plantation growing and wood processing. This paper summarises recent trends in plantation development in Australia, including the rapid expansion of the resource, the increased emphasis on short-rotation hardwoods and the increasing level of private investment. The major drivers behind the current plantation expansion and the major challenges that are likely to be encountered by the plantation sector in the near future are discussed. Some broad observations are made about the relationship between timber plantations and water in the landscape.

Introduction

The growing of tree plantations and the processing and exporting of timber is a significant industry in several regions across Australia. The industry generates income for State government forestry agencies; corporate, institutional and private

investors; service and support industries, and individual employees. The employment generated by the sector supports the social structure of the towns, cities and regions concerned. Table 1 provides an overview of the extent of Australia's major timber plantation regions, and the employment and income associated with the growing and processing of plantation timber in those regions.

Table 1. Major plantation regions and associated activity

Region	Major towns	Plantation area (ha)	Direct jobs (estimate)	Value of production (\$ million yr ⁻¹)
South-west Western Australia	Albury, Bunbury	212 000	2077	209
Tasmania	Burnie, Launceston	150 000	1619	644
Green Triangle	Mt Gambier, Hamilton	160 000	3029	948
Murray Valley	Wangaratta, Albury, Tumut	165 000	2722	342
Central Gippsland	Morwell, Sale, Yarram	80 000	1172	376
NSW Central Tablelands	Bathurst, Oberon	85 000	1789	242
South-east Queensland	Gympie, Maryborough	150 000	2189	340
Total (selected regions)		1 002 000	14 597	310

Source: Based on ABARE (1999) *Forest plantations on cleared agricultural land in Australia*, Research Report 99.11

Wood grown in plantations in Australia is used for a wide range of purposes, from solid timber for construction to reconstituted fibreboard and paper manufacture. The markets for these products are highly competitive and, with increasing world trade, Australian wood growers and processors are being forced to compete with the most efficient producers in the world.

The national plantation strategy, *Plantations for Australia - The 2020 Vision* envisages a major expansion of Australia's timber plantation resources. The key reason for promoting such expansion is to provide sufficient wood in key regions to support fully integrated, world-scale, cost-competitive processing industries. The existing plantation resource in several regions, such as the Green Triangle and Murray Valley softwood estates, is close to the size required but further expansion, even in these regions, is desirable. The plantation resources in most plantation regions in Australia are significantly smaller than what is required to support world-competitive processing on a sustainable basis.

Definitions

The title of this conference refers to both 'plantations' and 'farm forestry'. There appears to be little benefit from trying to define these terms precisely. I acknowledge, however, that in the future timber and other tree products will be produced in Australia under a range of management strategies.

For the purpose of this paper I will refer only to plantations, being any trees planted with the aim of producing a commercial return through timber production. Thus plantations can include a range of tree species, planting configurations and production systems. The discussion and data must inevitably focus on the larger-scale plantings that account for the vast majority of the land area and timber production concerned.

The statistics provided in this presentation do not include the small but increasing area of small-scale commercial tree plantings. The exclusion of these areas is unlikely to represent a significant inadequacy in the data. Preliminary estimates would suggest that these small-scale plantings currently occupy less than 10% of the area occupied by traditional, large-scale plantations. Production, although it might be significant in certain areas, is likely to be an even smaller proportion of the total because of the broader range of management objectives.

The size, location, species and configuration of plantations may be relevant factors when considering the relationship between trees and catchment hydrology. It is very difficult, however, to generalise about such relationships and it is more appropriate that they be

considered at the regional or local planning and management level.

Recent trends in Australia's plantation resource development

The last four years have seen a significant increase in interest and activity in the timber plantation sector in Australia. The plantation area continues to expand, production from plantations continues to increase as the plantations mature, and a wider range of investors is seeing the potential of plantation growing and wood processing. However, significant issues remain unresolved and new issues continue to arise as the plantations expand and mature.

There has been a dramatic increase in the extent of Australia's timber plantations over the past five years, according to National Plantation Inventory data published by the Bureau of Rural Sciences.

Table 2 indicates an increase in the plantation area of 295 000 ha, or more than 25%, between 1994 and 1999. This would suggest an average annual plantation expansion rate of almost 60 000 ha, although the annual data reveal that the expansion rate has been building gradually over the four-year period. The most dramatic increase in plantation area has occurred in Western Australia, with continued steady increases in all other States, particularly Tasmania and Victoria.

Hardwoods (predominantly eucalypts) now make up nearly 30% of the plantation area, a significant increase from approximately 15% in 1994. Nearly 80% of the new plantation area established over the past five years consists of hardwoods. Most of these hardwood plantations are being grown on short rotations (10-15 yr) for the production of pulpwood for export to paper processing facilities in Japan or possibly elsewhere in Asia.

Table 3 provides a breakdown of the total plantation area in 1999 between hardwood and softwood. Hardwood plantations represent more than half of the resource in Tasmania and Western Australia but the more traditional longer-rotation softwood plantations continue to dominate in the other States and are expanding steadily in several regions.

The level of private plantation ownership has also increased over the past five years from around 30% in 1994 to more than 55% in 1999. This change has occurred as a result of the sale of the plantation assets of the Victorian Government, the joint venture between Forestry Tasmania and GMO Renewable Resources and the significant planting programs undertaken by a range of private-sector investment and industrial companies.

Table 2. Australian plantation area by State 1994–1999

State	1994 (ha)	1999 (ha)	Increase (%)
Tasmania	133 990	177 256	33.29
Western Australia	130 845	247 300	89.00
Victoria	215 376	284 575	32.13
South Australia	102 945	118 383	15.00
New South Wales	270 252	291 385	7.82
Queensland	169 990	196 737	15.73
Aust Capital Territory	14 859	15 463	4.06
Northern Territory	4 225	6 184	46.37
Total	1 042 482	1 337 283	28.28

Source: Based on data from National Forest Inventory (1997), *National Plantation Inventory of Australia*. Bureau of Resource Sciences, Canberra, and National Forest Inventory (2000), *National Plantation Inventory Tabular Report – March 2000*. Bureau of Rural Sciences, Canberra.

Table 3. Australian plantation area 1999 - hardwood and softwood

State	Softwood (ha)	Hardwood (ha)	Total
Tasmania	75 412	101 844	177 256
WA	94 500	152 800	247 300
Victoria	219 197	65 378	284 575
SA	106 153	12 230	118 383
NSW	246 934	44 451	291 385
Queensland	185 555	11 182	196 737
ACT	15 269	194	15 463
NT	5 235	949	6 184
	948 255	389 028	1 337 283

Source: *National Plantation Inventory Tabular Report – March 2000*. Bureau of Rural Sciences, Canberra.

Plantation expansion drivers

There are a number of reasons for the current high level of interest and activity in the timber plantation sector. The relative importance of these factors varies depending on the region, the investor and the market concerned.

Resource for off-shore manufacturers

Australia, and particularly Western Australia, has been highly successful in attracting off-shore pulp and paper manufacturers seeking to secure a proportion of their raw material supplies from plantations. There are currently more than a dozen such plantation projects underway in Australia, which aim to establish a total area of 150 000 – 200 000 ha of plantations over the next ten years. The companies concerned are predominantly Japanese, and they are aiming to produce eucalypt pulpwood on short rotations.

Each project is based on a discrete region and there are projects underway in Western Australia, South Australia, Victoria, Tasmania and Queensland. In most instances a locally-based company is responsible for acquiring land by purchase, lease or joint venture and for establishing and managing the plantations. In some cases the State government forestry agency or a local industrial company may be fulfilling the management role. The relative certainty that there will be a market for the material from these plantations is driving additional plantation establishment activity in the same areas.

Domestic investment opportunity

A significant proportion (probably more than 70%) of the current plantation expansion in Australia is being funded by domestic investors through a range of prospectus-based projects. As a result, there are more than a dozen companies with significant areas of prospectus-funded plantation under management, and several of these companies have successfully listed on the Australian Stock Exchange. Most of the projects are also based on growing hardwood plantations on short rotations to produce export pulpwood. The prospectuses for these projects often rely on a bullish outlook in respect of tree growth rates, wood quality and market demand for plantation-grown hardwoods.

The success these companies have had in raising funds for their projects can be attributed to a number of factors:

- The projects provide taxation deferral benefits for taxpayers on high marginal tax rates;
- The development of the silvicultural knowledge to underpin the short-rotation wood production system has provided an investment product with a time horizon acceptable to potential investors;
- Investments in Australia by offshore manufacturers have provided a degree of market certainty;
- The Product Rulings regime instituted by the Australian Taxation Office has given investors certainty that their expenditure will be deductible against their income at the beginning of the life of the plantation. However, it should be noted that these rulings do not provide any guarantee in relation to the financial success of the projects;
- As a result of promotional efforts, including *Plantations for Australia: The 2020 Vision*, plantation growing is seen as a sound investment with a range of broader benefits including environmental enhancement and the reinvigoration of rural communities; and
- The Australian economy has been growing relatively strongly in recent years, providing significant funds for the investment market.

Agricultural industry decline

One reason why the plantation programs mentioned above have been able to secure significant areas of land is the decline in profitability of alternative broad-acre land uses, particularly sheep and cattle grazing. Many rural landholders are looking for ways to diversify their income or to make a dignified exit from their farming business. Annuity or annual-lease payments and land purchases by plantation investors have provided opportunities for those suffering from the current low beef and wool prices.

Ownership changes

The actual and potential sale of significant areas of mature plantation is creating interest in plantations amongst large institutional investors, both domestic and foreign. The size of the plantations involved and the fact that they are already producing a sustainable cash flow makes them more attractive to an institutional investor than a green-fields plantation establishment project with a long lead-time.

In late 1998 the Victorian Government sold its plantation assets to Hancock Victorian Plantations Pty Ltd (HVP) for \$550 million. HVP is 60% owned by US investment company Hancock Timber Resource Group and 40% by Australian superannuation funds comprising Unisuper, National Australia Asset Management, and superannuation investors managed by Morgan Grenfell. HVP has purchased long-term management rights for 115 000 ha of plantation and the Government has retained ownership of the land.

Prior to the Victorian Plantations Corporation sale there was no significant involvement of institutional investors in the plantation forestry sector in Australia. It is hoped that the sale will help to convince other investors of the long life and steady earnings with low volatility and low cyclicity which make plantations an ideal investment for superannuation funds with long-term liabilities.

CSR has sold its Victorian and South Australian plantations (approximately 20 000 ha) and wood processing operation to the United States-based RII Weyerhaeuser World Timber Fund. Subsequently, CSR's wood processing operations in NSW and Queensland have been sold to New Zealand-based firm Carter Holt Harvey and to Weyerhaeuser.

In 1999 Forestry Tasmania (FT) entered into a joint venture with US investment company, GMO Renewable Resources Ltd. GMO has taken a 50% stake in FT's 38 000 ha of softwood plantation for \$48.8 million. Forestry Tasmania retains ownership of the land and another US company, Rayonier, will provide forest management and international marketing for the joint venture. It is hoped that the venture will result in a further \$120 million in investment over the next decade,

including expansion of the plantation resource by 30 000 ha.

Further privatisation scenarios continue to do the rounds of the rumour mill as State government election cycles wax and wane. Ownership changes in the corporate sector are also likely to continue, with the most recent example being Rio Tinto's takeover bid for North Ltd which includes Australia's largest woodchip exporter and major plantation owner, North Forest Products.

It is hoped that the privatisation of Government plantation assets and the other potential changes in industrial plantation ownership will result in the emergence of new players with the vision and capital required for further plantation expansion and resource development.

Regional forest agreements

In Tasmania the signing of the Regional Forest Agreement and the resultant deregulation of the export market for woodchips and unprocessed wood has increased the overall confidence of the industry and may have contributed to an increase in plantation establishment activity in that State. In Western Australia, the State Government's decision to reduce the level of harvesting in the karri forests will lead to a significant reduction in the volume of pulpwood available for export. However, this reduction will be offset by a dramatic increase in the volume of *Eucalyptus globulus* pulpwood available from the large areas of plantation soon to reach the intended harvest age. Sotico (formerly Bunnings Forest Products) has recently announced its intention to increase blue gum woodchip exports from 50 000 t in 1999 to 750 000 t in 2002 and one million tonnes by 2004. This realisation of a market for the oldest blue gum plantations in Western Australia may further enhance confidence in the sector.

It is more difficult to find a strong relationship between the regional forest agreements and plantation establishment activity in the other States.

Maturing plantation industry

Australia already has a significant plantation estate and associated expertise and experience in all aspects of intensive timber production. In certain regions the softwood plantation estate continues to expand steadily as the plantations established in the 1960s and 70s come on-stream and processing infrastructure develops to create a mature industry. The construction of the Visy Industries pulpmill at Tumut will build on what is already a vibrant softwood growing and processing centre, and will require further expansion of the plantation estate in that region. This maturing of the plantation sector and the creation of critical mass of wood resource in a number of regions is demonstrating

to investors that tree growing is a legitimate commercial activity and not purely the domain of governments.

Greenhouse and carbon trading

The potential to use plantations as a means of storing carbon to meet targets set under the Kyoto Protocol and thus creating a tradable carbon credit has raised the interest of yet another set of potential investors in plantations. At this stage a legal framework for carbon trading either within Australia or internationally is still some way off, and investors are being encouraged to approach this issue with caution. However, a number of essentially trial carbon trades involving new plantations have already taken place, and the NSW Government has taken a very active role in endeavouring to develop a carbon market. Companies likely to incur a significant carbon debt are evaluating the potential of plantations against other means of reducing their liability.

Natural resource management factors

Trees have been identified as having a key role to play in improved natural resource management in Australia. As large, deep-rooted, perennial plants, trees provide a useful tool for soil, crop and animal protection, and the enhancement of biodiversity and aesthetic values. Trees also have a major role in the hydrologic cycle as evidenced by the topic of this conference.

In many instances the natural resource management benefits of trees do not provide sufficient incentive to drive major tree-planting programs. When wood production can be integrated with other objectives, however, the prospects for increased investment in tree planting are enhanced.

The Commonwealth Government has provided significant funding through the Farm Forestry Program and Natural Heritage Trust to facilitate increased integration of commercial tree growing into traditional farming enterprises. This is a long-term strategy and the level of uptake to date has been modest, but there is no doubt that recognition of the multiple roles of trees in natural resource management is contributing to plantation expansion in Australia today.

2020 Vision confidence

Finally the existence of the 2020 Vision with its wide support from governments and industry, and broad, positive and expansionary outlook, has provided confidence and a focus for those considering plantations as an investment.

The future for the Australian plantation sector

The above analysis of drivers of the expansion of plantations in Australia suggests that there are strong prospects that the current expansionary trend will continue. Figure 1 provides a hypothetical evaluation of the likely distribution of the plantation resource among the States if the 2020 Vision target is ultimately achieved. Key points to note are that the proportion of hardwood in the total estate is likely to continue to increase, but the area of hardwood is predicted to stabilise at somewhat less than the total area of softwood in the longer term. The States that will see the major expansion, based primarily on environmental factors (climate, soils, topography, land use), are Western Australia, NSW and to a lesser extent Victoria. South Australia, Tasmania and the ACT are limited by the availability of suitable land and the situation in Queensland and the Northern Territory is more difficult to predict because of lack of experience with commercial timber production in plantations in the Australian tropics.

It should be noted that scenario presented in Figure 1 is highly speculative because plantation area alone will not determine the success of the plantation sector and of the processing and service industries dependent on it. The quality, location, configuration, management and overall competitiveness of the resource are factors just as important as the total land area involved, if not more so.

Commercial and market factors

While there is a broad range of drivers encouraging plantation expansion in Australia, the level of new plantings will ultimately be determined by investors' assessment of the likely financial returns from plantation growing. The plantation resource established in the 1960s and 70s, primarily softwood, is now reaching maturity and there has been a great deal of success in developing markets for this timber. Australia is rapidly reaching a point, however, where the domestic market will be unable to absorb more of the products from these plantations or the new plantations that are currently being established.

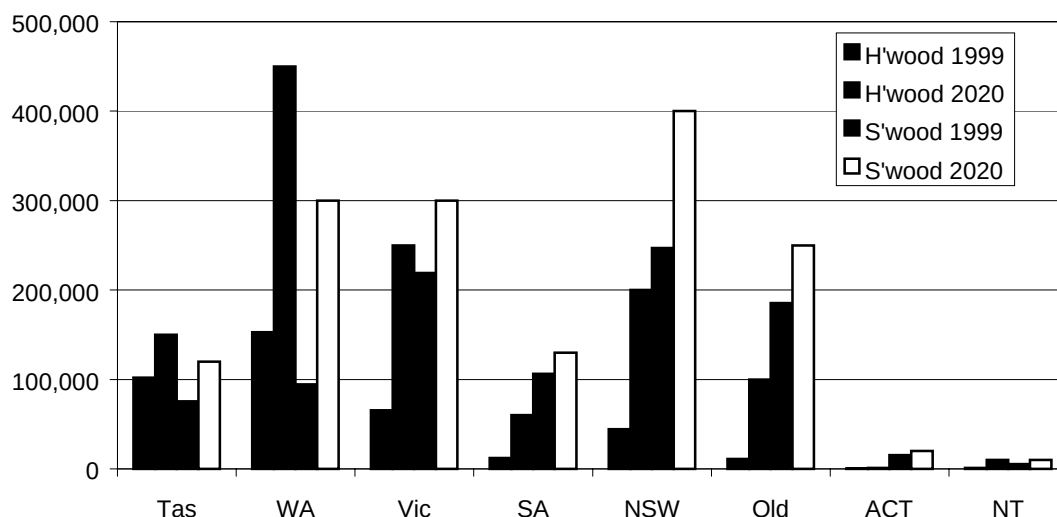


Figure 1. Hypothetical 2020 plantation areas (ha)

It is therefore essential that export markets for the wood or manufactured products from these new plantations are developed, noting that in some instances the wood is already owned by or committed to specific processors.

Cost of production will be a key factor determining Australia's success in selling plantation-grown wood to world markets. In order to minimise cost of production, plantation growers will have to focus on the key cost drivers.

- **Location** – plantations must be grown on sites capable of sustaining adequate growth rates, and in consolidated units, to minimise operational costs though economies of scale. Access to infrastructure, particularly road, rail and port facilities and/or processing plants is vital.
- **Growth rates and wood quality** – plantations must produce the maximum possible volume of wood of the required quality in the minimum time. On-going genetic improvement, state-of-the-art silvicultural practice and pest control are the keys to maximising growth and quality.
- **Regulation** – Commonwealth, State and local governments have the potential to impose significant costs on plantation growing through complex approval mechanisms for planting and harvesting plantations and transporting logs. Plantations should be treated in the same manner

as the other agricultural enterprises with which they compete for land and capital. Whatever the legislative environment for plantation growing, investors need certainty and stability in order to make the long-term investment decisions involved with plantation growing. The plantation industry in every State has demonstrated its commitment to operate in accordance with Codes of Practice.

Significant attention is now being directed towards identifying ways in which funds allocated for environmental protection and repair can be linked with commercial investors' funds to achieve a combination of desirable environmental and commercial outcomes. Such 'incentive' schemes may provide a means of achieving broad-scale tree planting in areas where timber production is not currently economic, primarily due to low productivity or great distances to markets.

Social and environmental issues

The plantation sector is seen by some, particularly at a superficial and broad scale, as an environmental saviour, but this should not be interpreted to mean that the plantation sector is immune from the environmental controversies which impact on many rural and natural-resource-based production systems. The visual impact, corporate ownership and long life cycle of plantations make them an attractive target for unwarranted criticism. The plantation industry in Australia is currently endeavouring to ensure that a number of

potential environmental issues are not used to unjustifiably restrict plantation development. These include:

- Chemical contamination of waterways following pesticide application;
- Poisoning of wildlife with 1080 baits used in vermin control;
- Impact of clearing of native vegetation including isolated remnant trees;
- Soil compaction and erosion caused by harvesting operations;
- Soil nutrient decline and acidification;
- Visual impact following planting or harvesting of plantations; and
- Reduced stream flow and consumption of groundwater.

The industry is addressing these issues by promoting good management practices which minimise environmental impacts, undertaking research and monitoring to identify and quantify any impacts and by informing the community about the relationship between plantations and the environment.

In addition, the rapid expansion of plantations in some regions has been criticised on a number of social grounds. The expansion of plantations is seen by some as a cause of the decline of traditional agricultural enterprises and rural populations. These criticisms are made despite the fact that the demographic decline in rural Australia has little if anything to do with the plantation industry, and there are a number of outstanding examples of the positive social and economic impacts that a plantation resource can have on a region, including increased income and employment.

Plantations and water

This workshop aims to address the relationship between commercial timber plantations and the hydrology of the landscapes in which they grow. This paper provides an overview of developments in the plantation sector and it is not appropriate to provide a detailed analysis of hydrological issues here. However, a number of general observations about the relationship between hydrology and plantation timber production in Australia must be made to provide a background for subsequent papers.

The first point that should be noted is the scale of plantation growing in the Australian landscape. The 2020 Vision envisages a trebling of the plantation area in 20 yr, but even if this massive increase (in plantation industry terms) is achieved, plantations will occupy only 0.4% of the total lands area or 0.7% of the agricultural land area. The plantations will generally be

restricted to the medium- to high-rainfall zone but, if trebled, the area would represent only approximately 10% of the cleared agricultural land receiving more than 600 mm mean annual rainfall.

Plantations may be concentrated at a local scale but will generally take up a relatively small fraction of the land in a region or major river catchment. A trebling of the area of commercial timber plantations should not necessarily be seen as the same as the revegetation that may be required to address dryland salinity in certain areas.

Most of the new plantations in Australia are being established on land that has been used for agriculture, primarily grazing, for an extended period of time. However, prior to being used for grazing these lands carried forests or woodlands with an open understorey. Establishing plantations is restoring deep-rooted perennials to a portion of the landscape and thereby restoring the hydrological balance that existed prior to the arrival of European agriculture.

While plantation expansion may be causing a major land-use change in some areas today, it is not reasonable to assume that prior to this change in land-use the catchment hydrology was in a steady state or that land-use would have continued unchanged without the expansion of plantations. Plantation expansion should not be considered in isolation from other land-use changes and long-term changes in catchment hydrology that may already be underway.

Hydrological systems vary greatly depending on geology, topography and climate. Plantation location, configuration and management can also vary greatly. There is no universal formula for summarising the relationship between trees and catchment hydrology. Simplistic assertions that trees are the saviour or the sinner in relation to hydrological issues are of little practical value.

Given the land-use changes that have occurred over time and the productive pressures which humans are placing on many landscapes it is not possible to merely use a prohibitive approach to addressing perceptions about the impact of plantations on water.

Conclusions

The Australian plantation resource is expanding rapidly in response to a range of economic, social and environmental drivers. This expansion is dominated by short-rotation hardwood plantings and is associated with a significant shift in plantation ownership from one dominated by State forest management agencies to a more diversified ownership with significant involvement of a range of private investors.

As the Australian plantation industry becomes increasingly exposed to international markets for wood products, the need to minimise production costs increases. The location, management and regulation of plantation growing are the major determinants of plantation costs. If the vision of achieving increased rural incomes, employment and environmental benefits through a dramatic expansion of timber plantations is to be achieved, it is essential that all aspects of plantation growing in Australia be competitive with world standards.

The relationship between plantations and water is just one issue that must be managed to ensure the optimum outcome for plantation owners, wood processors and communities. The plantation industry is seeking an outcome in relation to water that acknowledges all the factors influencing water quality and quantity and does not discriminate unjustifiably against plantation growing.

2

Impacts of Plantation Forestry on Catchment Runoff

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The afforestation of agricultural and pastoral areas, if conducted on a sufficiently broad scale, will profoundly influence the hydrology of catchments. Principal amongst the consequences will be reduced water yields and reduced groundwater recharge, though changes in the seasonal distribution of runoff, the timing and magnitude of peak flows, and the persistence of low flows can also be expected. While hydrologic changes may appear within four years of plantation establishment, the full effects may not be felt for ten or more years. In the case of groundwater, the benefits of reduced recharge may take several decades to appear.

Simple but reliable models are available to predict changes in mean annual runoff that might ensue from afforestation. These show that runoff reductions will be greatest in high-rainfall areas and that pine plantations will have a greater impact than eucalypts. For areas with 800 mm mean annual rainfall, mean annual runoff may decline by up to 165 mm under eucalypts and up to 210 mm under pines. For areas with mean annual rainfall of 1200 mm, the mean annual runoff reductions may be 265 and 350 mm. Depending on the plantation productivity, their extent of cover and the management regime, the effects may be less. However, in years wetter than average, annual runoff reductions may exceed these long-term averages.

The recently developed MAYA software has been used for a spatial analysis of possible afforestation-induced runoff reductions for the Murrumbidgee catchment upstream of Wagga Wagga, covering an area of 26 000 km². Similar analyses can be performed for other large basins, provided that rainfall, elevation and land cover maps are available.

Using a small number of catchment afforestation experiments, we have estimated likely changes to peak-flow magnitude and low-flow persistence. We found that peak flows would be halved in afforested catchments for small- and medium-sized storm events, conferring significant flood control benefits. However, reductions in peak flows would probably be much less for severe storm events that cause most damage. Field observations also show that low flows will reduce after afforestation, raising water supply issues for catchments with variable rainfall and/or tightly allocated flows. Streams that have become perennial since post-settlement land clearance are likely to return to intermittent-flow states following afforestation. The consequences of this for flow allocation policy need to be assessed carefully in the afforestation planning process.

Introduction

The Commonwealth and State governments of Australia have promoted a vision of trebling the area of timber plantations by the year 2020 (DPIE 1997). This would raise the plantation area in Australia to over 3 M ha, with much of it in land currently under pasture. All States have responded to this challenge, and the rate of plantation establishment is steadily increasing.

There are several sound drivers for prompt and widespread afforestation in Australia. Chief amongst these is the looming global shortfall in wood and paper products, predicted to occur around 2010. Australia has

the land, technology and expertise to become a major producer of wood and paper products. At the same time, farmers suffering the effects of a depressed agricultural commodities market are eager to diversify their sources of on-farm income. Stimulated by private and public incentive schemes, they are increasingly regarding plantation forestry as a viable alternative to their traditional activities. There are also some significant environmental drivers for plantation expansion. Broad-scale tree planting is regarded as a key strategy in the fight against our biggest environmental problem, dryland salinity. Major catchments within the Murray-Darling Basin are now in the process of setting 'end of valley targets' for salt load reduction, and catchment

managers regard tree planting as a key option in part of an overall strategy for achieving these. Plantation expansion is also seen as a pivotal strategy in our management of greenhouse gas emissions. The carbon sequestration benefits conferred by tree planting are stimulating significant investment from energy providers, who also perceive opportunities in bio-energy production and activated carbon and essential oil manufacture from plantation products. Other oft-mooted benefits of tree planting include the enhancement of aesthetic and bio-diversity values and the provision of windbreaks.

At face value, afforestation seems like a win-win solution for all. However, some of the hydrologic changes caused by tree planting may have adverse consequences if catchment managers do not properly anticipate and plan for them. This paper discusses, and attempts to quantify, the range of hydrologic changes likely to ensue from broad-scale afforestation. Attention is focused on changes in evapotranspiration, groundwater recharge, mean annual runoff, runoff seasonality, peak flows and low flows. These changes are illustrated by examples drawn from Australian, South African and New Zealand field studies.

Evapotranspiration

The water budget for a catchment consists of rainfall (or snow) input, balanced by outputs, including runoff, groundwater recharge and evapotranspiration (ET). ET includes evaporation of ponded water from depressions and plant canopies, evaporation from the soil surface, and water use (transpiration) by plants. Changes in land cover usually result in a change to ET, thus affecting the other water budget output terms of runoff and recharge.

Evapotranspiration rates in native forests and plantations are higher than in pastures and crops (Cornish 1989; Ruprecht and Schofield 1989; Schofield 1996). This is because native forests and plantations have:

- Higher and more persistent leaf area than grasses, leading to greater rainfall interception and transpiration;
- Greater aerodynamic roughness than grasses, leading to greater rainfall interception and transpiration; higher roughness also enhances the likelihood that advected warm, dry air can supplement the radiant energy input;
- Deeper rooting than grasses, enabling better access to soil water, leading to greater transpiration;
- A greater ability to extract moisture from the soil under dry conditions, leading to greater transpiration; and

- Lower albedo (or reflectivity) than grasses, meaning more absorption of radiant energy, leading to greater transpiration.

In southern Australia, mean annual ET is usually less than 650 mm in grasslands, but can exceed 1300 mm in forests (Vertessy 1999; Cornish and Vertessy 2001). Evapotranspiration tends to increase with mean annual rainfall, primarily because of increases in rainfall interception, but also due to increased transpiration promoted by higher productivity. The Holmes and Sinclair (1986) relationship illustrates the combined effects of vegetation cover and mean annual rainfall on mean annual ET. It is based on long-term annual rainfall/runoff relationships for 19 large catchments situated across Victoria, with mean annual rainfalls ranging between 500 and 2500 mm, and varying mixtures of grass and native eucalypt forest cover. Holmes and Sinclair (1986) showed that there were clear differences between ET rates for grassland and eucalypt forest catchments, and illustrated this with a pair of curves that denoted the differences along a rainfall gradient (Fig. 1).

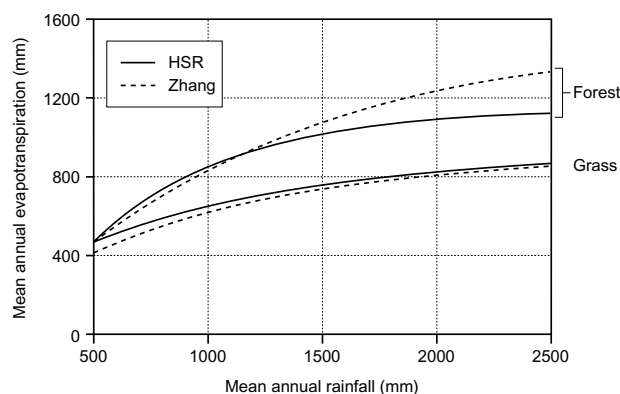


Figure 1. Relationship between land cover, mean annual rainfall and mean annual evapotranspiration, as predicted by the Holmes and Sinclair (1986) relationship and the Zhang et al. (1999a) model.

According to these curves, a fully forested eucalypt catchment would evaporate 40, 90, 215, 240 and 250 mm more per year than a fully grassed catchment with mean annual rainfalls of 600, 800, 1300, 1500 and 1800 mm, respectively. It is important to note that these curves define an ‘envelope’ for ET rates under different land covers and field conditions, implying that the forest curve is an upper estimate and that the grassland curve is a lower estimate.

Zhang *et al.* (1999a) developed a simple process-based model to predict mean annual ET as a function of cover, mean annual rainfall and mean annual potential evapotranspiration. Their model yielded very similar ET curves to those proposed by Holmes and Sinclair (1986), differing only in terms of the ET estimates for

forest cover where mean annual rainfall exceeded 1200 mm (Fig. 1). The Zhang *et al.* (1999a) model predicts that mean annual forest ET should rise to about 1400 mm at wet sites, whereas the Holmes and Sinclair (1986) model predicts an ET peak of about 1150 mm. Zhang *et al.* (1999a) tested their model on over 250 catchments from around the world and obtained a very good fit to field data. Zhang *et al.* (1999a) have shown that their ET curves are very similar to like curves developed by Turner (1991) for 68 Californian catchments of varying land cover. Jointly, these studies demonstrate that land cover and mean annual rainfall are the critical properties controlling mean annual runoff production.

Neither Holmes and Sinclair (1986) nor Zhang *et al.* (1999a) discriminated between different types of forest cover. However, there is significant evidence to indicate that ET rates differ between conifer plantations and eucalypt forests. Most South African studies indicate that eucalypt ET rates exceed those for pines (Bosch 1979; Van Wyk 1987; Smith and Scott 1992; Dye 1996; Scott and Smith 1997). The opposite trend has been observed in Australia, however, where higher ET rates are normally ascribed to pines, primarily because of their higher leaf area index and rainfall interception (Smith *et al.* 1974; Dunin and Mackay 1982; Pilgrim *et al.* 1982; Cornish 1989). It should be noted that in Australia, pine plantations have been compared to native eucalypt forests, rather than to eucalypt plantations, as in South Africa.

Comparing the water balance of pine plantations and native eucalypt forest at Lidsdale, NSW, Pilgrim *et al.* (1982) established that pine plantations had higher ET rates, because of higher rainfall interception (Table 1). Dunin and Mackay (1982) compared the rainfall interception and transpiration rates of *Pinus radiata* plantations and *Eucalyptus maculata* (syn. *Corymbia maculata*) forests in the south-east region of NSW under conditions of abundant soil moisture and similar radiation input. They found that pines transpired at a greater rate than eucalypts during winter, but that the annual transpiration totals for the two forest types were similar. However, they found that the pines intercepted about 10% more of the rainfall than the eucalypts. Similar results were reported by Feller (1981) in a study comparing ET rates of pine plantations with those in *E. regnans* and *E. obliqua* forests.

Table 1. Differences in the mean annual water balance between a pine plantation and a eucalypt forest at Lidsdale, NSW, over the period 1974-1976 (after Pilgrim *et al.* 1982).

Water balance component	Pine plantation	Native eucalypt forest
Gross rainfall (mm)	842	870
Rainfall interception (mm)	183	99
Transpiration and soil evaporation (mm)	472	501
Evapotranspiration (mm)	655	600
Soil moisture change (mm)	-3	1
Streamflow (mm)	190	269

Putuhena and Cordery (2000) provide a detailed account of evapotranspiration changes in a growing *P. radiata* plantation at Lidsdale, relative to that observed in a nearby mature eucalypt forest. They also attributed most of the ET differences in the two forest types to differences in rainfall interception, citing rainfall interception rates of 15% and 27% for a mature eucalypt forest and a 13 – 16-year-old pine plantation, respectively. These values were measured during a period when mean annual rainfall was 733 mm; significantly lower than measured during the period reported by Pilgrim *et al.* (1982). Putuhena and Cordery (2000) also showed that the pine plantation had a greater rate of forest floor interception than the mature eucalypt forest, citing rates of 12% and 7% of gross rainfall, respectively. Hence, total rainfall interception (of the canopy and litter) was 17% greater in the 13 – 16-year-old pine plantation than in the mature eucalypt forest. Contrary to the findings of Pilgrim *et al.* (1982), Putuhena and Cordery (2000) showed that transpiration and soil evaporation rates in the (13 – 16-year-old) pine plantation at Lidsdale was lower than for the mature eucalypt forest. They argued that this was a consequence of the enhanced rainfall interception of the pine plantation that led to drier soils and thus reduced transpiration and soil evaporation.

In summary, pine plantations have higher ET rates than native eucalypt forests. However, insufficient hydrometric data are available to substantiate the hypothesis that pine plantations will have higher ET rates than intensively-managed eucalypt plantations. Data from South Africa indicate that the converse is true in that country, with ET rates from eucalypt plantations almost always exceeding those from pines. However, the environment in South Africa is quite different (particularly in terms of insect predation), so their experience may well not apply in Australia.

Groundwater recharge

Petheram *et al.* (2000) summarised results from several field and modelling studies of recharge rates under a variety of land covers. Mean annual recharge increased with mean annual rainfall, and was highest for annual crops and grasses and lowest for trees, with perennials lying intermediate between these land covers. Significantly, there was virtually no recharge under treed areas with mean annual rainfall up to 1100 mm. Under annual grass with mean annual rainfall less than 700 mm, groundwater recharge generally ranged between 0 and 75 mm. However, mean annual recharge rose to over 250 mm for annual grass sites with mean annual rainfall greater than 700 mm.

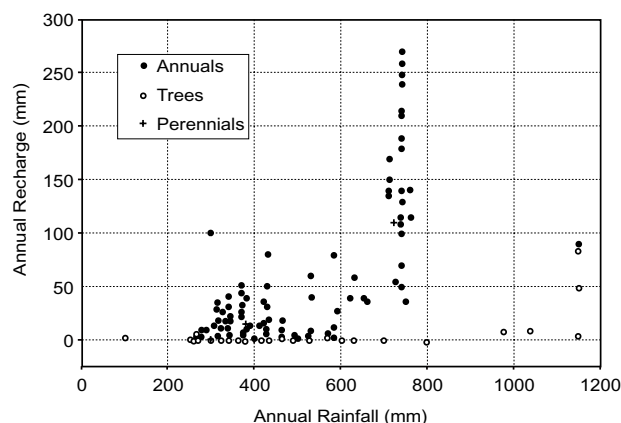


Figure 2. Relationship between mean annual recharge and mean annual rainfall for annuals, perennials and trees, after Petheram *et al.* (2000). All data points are long-term estimates of mean annual recharge, sourced from many field and modelling studies.

There is a growing body of field evidence to show that, in addition to reducing groundwater recharge, trees can use significant quantities of groundwater, depending on the depth and quality of this (Thorburn *et al.* 1985; Benyon *et al.* 1999; Zhang *et al.* 1999b). For these reasons, tree planting is regarded as an effective strategy for salinity abatement. However, there are circumstances where reduced recharge and groundwater abstraction by trees may be undesirable (Hopton *et al.* 2001).

Mean annual runoff

Vertessy and Bessard (1999) developed a simple spatial model to predict the impacts of afforestation on mean annual runoff in the Murrumbidgee Basin. Their analysis was based on the Holmes and Sinclair (1986) ET curves, though extended to account for land covers other than forest and grassland. They developed mean annual runoff curves for grassland, eucalypt woodland, eucalypt forest and pine plantations (Fig. 3) which

explained 82% of the variation in mean annual runoff from 28 sub-catchments of the Murrumbidgee Basin. These catchments were characterised by large variations in catchment size, mean annual rainfall and mixtures of land cover. Such analyses can now be performed using a freely-available PC model called MAYA (an acronym for Mean Annual Yield Analysis). The MAYA model can be applied readily to basins of virtually any size, provided that rainfall, elevation and land cover surfaces are available. It is currently being applied to the Goulburn-Broken catchment in Victoria by researchers in the CRC for Catchment Hydrology.

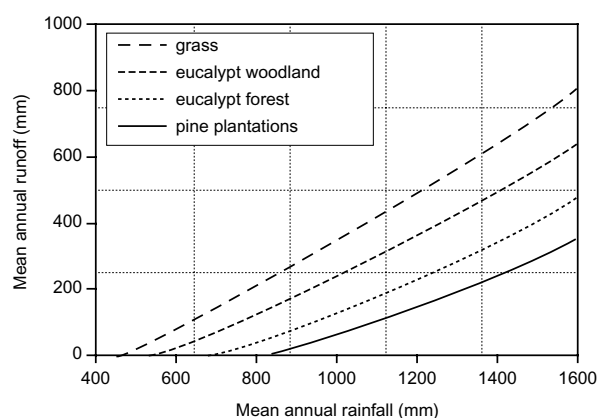


Figure 3. Mean annual runoff curves for different land covers, after Vertessy and Bessard (1999).

By comparing the MAYA curves in Figure 3, it is possible to deduce the reduction in mean annual runoff which would result from pine and eucalypt afforestation of grassland (Fig. 4). Figure 4 shows that reductions in mean annual runoff will be greatest in high-rainfall areas and that pine afforestation will have a greater impact than eucalypt afforestation. For areas with 800 mm mean annual rainfall, grassland catchments are assumed to yield a mean annual runoff of 210 mm yr⁻¹. After complete afforestation of these areas, mean annual runoff may reduce by up to 165 mm under eucalypt forest and up to 210 mm under pine plantations (equating to yield reductions of 79% and 100%, respectively). For areas with mean annual rainfall of 1200 mm, grassland catchments are assumed to yield a mean annual runoff of 493 mm per year. After complete afforestation of these areas, the mean annual runoff reductions may be as great as 265 and 350 mm (equating to yield reductions of 54% and 71%, respectively). We note that the estimated yield reductions are probably maximal ones, because they are derived from the 'ET envelope' of Holmes and Sinclair (1986). Depending on the plantation productivity, the fraction of area afforested and the management regime adopted, the effects may be less. However, in wetter-than-average years, annual runoff reductions may exceed these estimates of mean annual change.

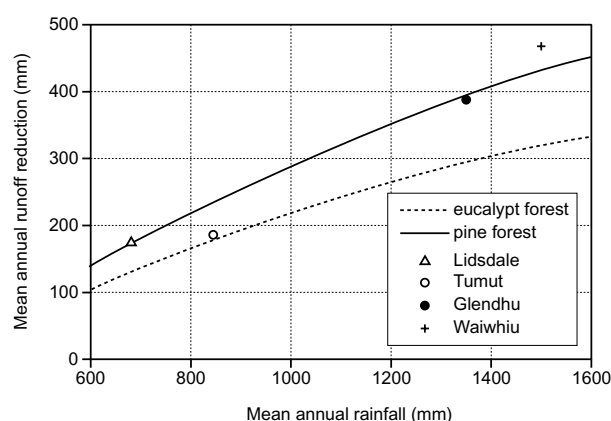


Figure 4. Potential reduction in mean annual runoff estimated to result from afforestation of grasslands with eucalypts and pines. Also shown (as symbols) are field data from four separate field experiments.

Figure 4 also shows field observations of catchment runoff reductions following pine afforestation at two New Zealand sites (Glendhu and Waiwhiu) and two Australian sites (Lidsdale and Tumut). These sites span the wide range of conditions in which commercial plantation forestry is conducted. The Glendhu catchment experiment is located near Dunedin at the southern extreme of the south island (Fahey and Jackson 1997). It comprises two small experimental catchments; a tussock grassland control (218 ha) and a similar catchment later converted to pine plantation (310 ha). The Waiwhiu site is near Warkworth on the North Island (Rowe and Jackson 1997). It consists of a single catchment (803 ha) with mixed land cover, and ultimately afforested with pines over 47% of its area. The Lidsdale catchment is located between Bathurst and Lithgow in the Central Tablelands of NSW. The data referred to here are from the L-6 catchment (9.4 ha) which was covered with mature eucalypt forest until 1978, and then cleared and planted to pines (Putuhena and Cordery 2000). We compared data for two periods in the L-6 record; 1978-80 when the catchment had minimal forest cover (a canopy fraction of less than 5%), and 1990-93 when the plantation was aged 13-16 yr. The Tumut catchment experiment is located near Tumut in southern New South Wales (Major *et al.* 1998). It comprises two catchments; Kileys Run (135 ha), which is an improved pasture control, and a similar catchment, Redhill (195 ha), which has been 78% afforested with pines.

Observed afforestation-induced runoff reductions from these four experimental sites accord reasonably well with the MAYA model estimates. Runoff was reduced by 172 mm in the Lidsdale catchment, compared to the 173 mm drop estimated by MAYA for a site with mean annual rainfall of 680 mm. Runoff reductions at the

Tumut site are lower than predicted by MAYA, presumably because the plantation is still young (data shown are for age 6-10 yr) and yet to reach its maximum ET. The observed runoff reduction for Glendhu is virtually identical to that estimated by MAYA. Reductions at Waiwhiu are slightly greater than estimated by MAYA, supporting the case for adoption of the Zhang *et al.* (1999a) model for wetter forest sites.

A strength of the MAYA model is that it can be used to perform a spatial analysis of afforestation impacts across large catchments. A typical afforestation scenario analysis performed using MAYA is given in Figure 5. Figure 5a shows the Middle and Upper Murrumbidgee catchment segment of a plantation capability assessment, conducted by Booth and Jovanovic (1991) for the southern Murray Darling Basin. It defines 17% of the catchment as having 'high' capability for afforestation, a further 20% as having 'medium' capability, and 1% as having 'low' capability. MAYA was used to predict the consequences of establishing pine plantations in all of the 'high' capability areas, eucalypt forest in all of the 'medium' capability areas, and eucalypt woodland in all of the 'low' capability areas. The MAYA analysis was performed on 250 x 250 m grid cells, the results of which are displayed in Figure 5b. The proposed afforestation scenario would result in mean annual runoff reductions ranging mostly between 30 and 300 mm, with a median reduction of 120 mm. Annual reductions greater than 190 mm would affect 10% of the area planted.

Before closing on annual yield impacts, it is worth considering the details of the Tumut catchment response to pine afforestation. Surprisingly, this experiment is Australia's sole surviving catchment treatment experiment designed to quantify the effects of pine afforestation of grassland in a commercial plantation region. The first analysis of the Tumut data was performed by Major *et al.* (1998). The analysis provided below is based on additional data collected since that report was published.

Although the Tumut experiment has been running for only 11 yr, the catchment has responded in a classic manner, conforming to the general response outlined in Figure 4. Figure 6 shows a 'double-mass' plot comparing cumulative daily runoff from the fully pasture-covered Kileys Run catchment, and the fully pine-afforested Redhill catchment. This shows that the two catchments yielded similar amounts of water for the first two years of the experiment, but that runoff from Redhill began to decline relative to Kileys Run thereafter.

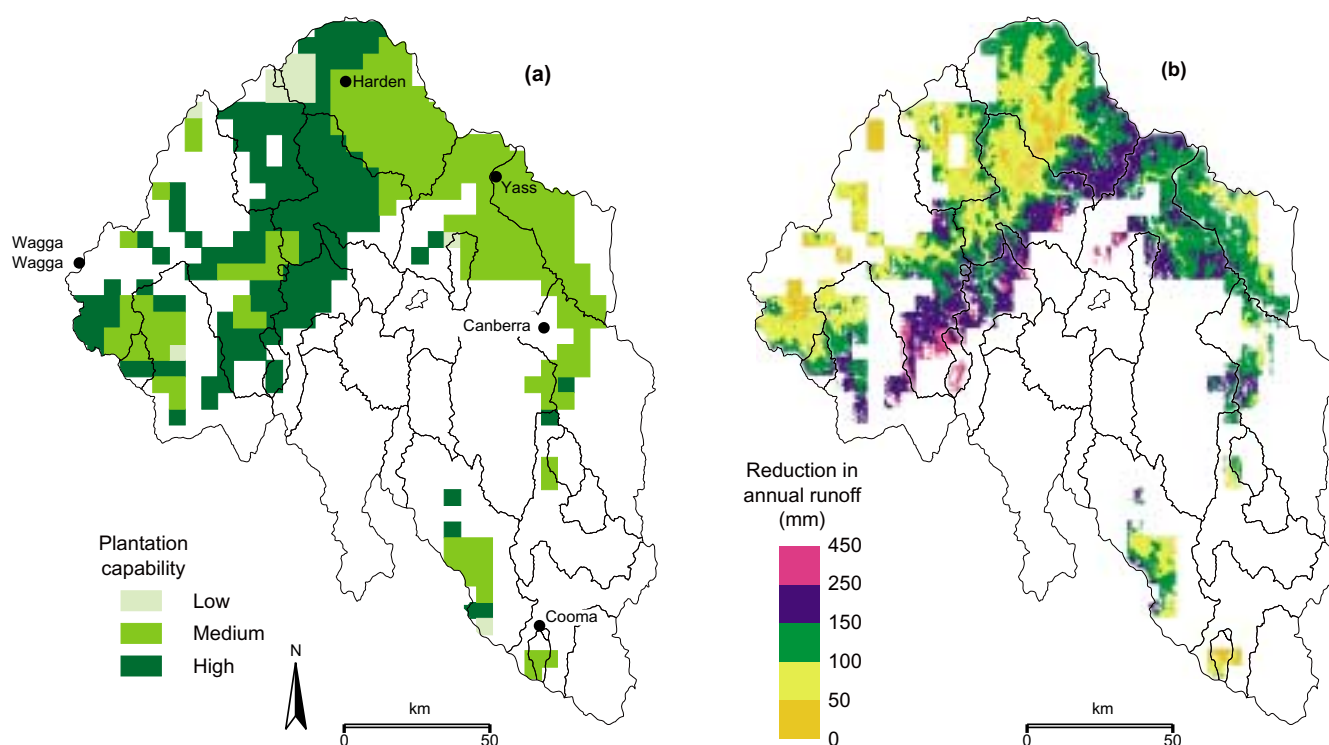


Figure 5. (a) Plantation capability in cleared areas of the Middle and Upper Murrumbidgee catchment, adapted from the analysis of Booth and Jovanovic (1991). (b) MAYA model prediction of mean annual yield reductions after afforestation of areas denoted as 'high', 'medium' and 'low' in (a). Also shown are the boundaries for 28 sub-catchments for which long-term flow gauging records are available.

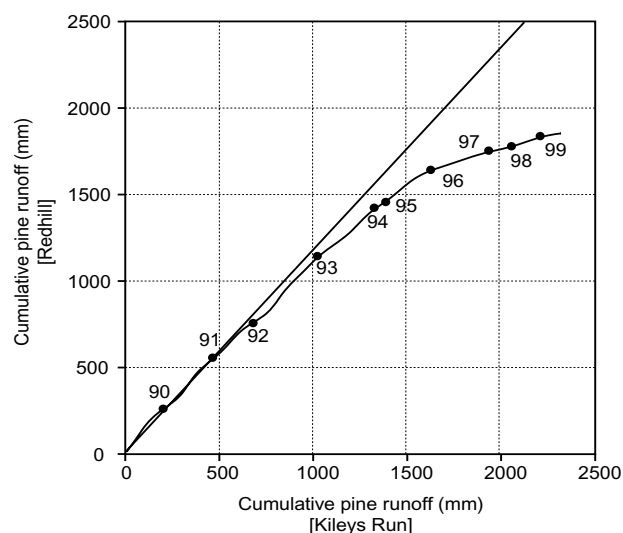


Figure 6. Double-mass plot comparing cumulative runoff from Redhill (afforested with pines) to cumulative runoff from Kileys Run (pasture control). Labels denote beginnings of calendar years.

Figure 7 shows a regression relationship between monthly runoff values from Kileys Run and Redhill for the first 27 months of the catchment experiment. Statistical analysis (not given here) of these data pairs

indicates that the residuals are normally distributed and that there is no serial correlation in the data. These criteria support the use of an ordinary linear least-squares regression to characterise the relationship between monthly flows from these two catchments. This regression relationship was used to estimate the amount of water that might have been yielded from Redhill each year, had it not been afforested. The difference between this estimate and the actual observed runoff from Redhill is shown in Figure 8. This shows annual runoff reductions of 100 mm or more occurring four years after plantation establishment. The average annual runoff reduction for the period 1995-1999 was 182 mm, during which time the mean annual rainfall was 850 mm. It is noteworthy that in 1996 annual rainfall was 1100 mm and the runoff reduction was 345 mm.

As noted earlier in Figure 4, the afforestation-induced annual runoff reductions at Redhill are lower than would be predicted by the MAYA model. It remains to be seen whether the yield reductions will become greater as the plantation ages.

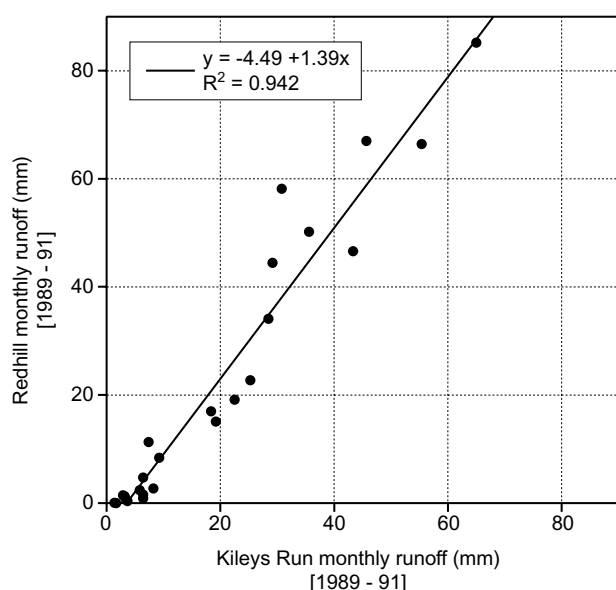


Figure 7. Regression relationship between monthly runoff from Redhill and monthly runoff from Kileys Run, May 1989 – May 1991.

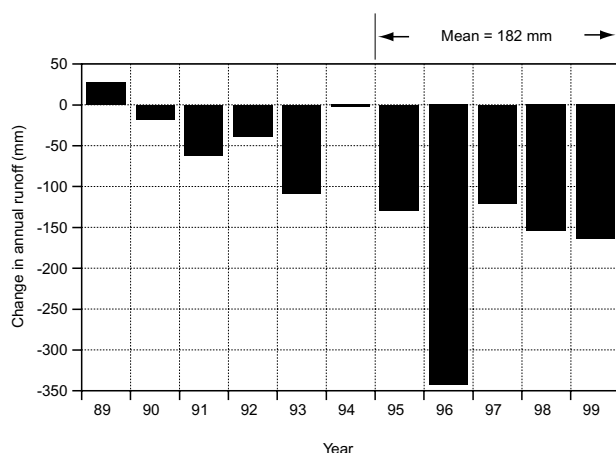


Figure 8. Estimated change in annual runoff from the Redhill catchment for the period 1989-1999. Values have been scaled to assume that 100% of the catchment area had been afforested with pines.

Runoff seasonality

The afforestation-induced reductions in annual runoff discussed above are potentially problematic for catchment managers. Equally important will be contending with altered flow seasonality. Unfortunately, there is very little Australian literature on this topic, presumably because little data has been available until now. However, pertinent data are available from South Africa. Bosch and von Gadow (1990) compared mean monthly yields for the Cathedral Peak catchment in South Africa, before and after afforestation of grasslands with pines (Fig. 9). They demonstrated that absolute reductions in runoff were greatest during the

wet months, but that the reductions were *proportionally* greatest during the drier months. For example, Figure 9 shows the runoff in March (a high-flow month) was reduced by about 30% as a consequence of afforestation, but reduced by over 60% in October (a low-flow month). They attributed this trend to the fact that grasses are dormant during the drier months and thus do not transpire. An interesting feature of Figure 9 is that monthly runoff differences are smallest during the period following peak monthly yields (April-July). Presumably, abundant soil moisture is present in the system during this time, enabling the grasses to transpire at relatively high rates. These reserves are probably depleted from September onwards, resulting in diminishing grass ET and thus larger differences between grass and plantation runoffs.

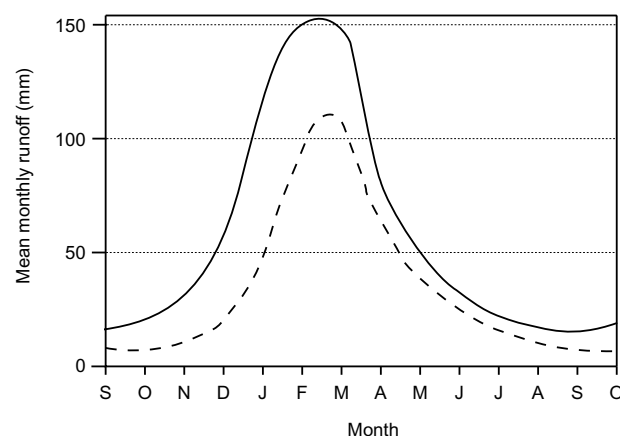


Figure 9. Mean monthly streamflows in the Cathedral Peak catchment, South Africa, before and after afforestation of the grassland with pines (after Bosch and von Gadow 1990). Solid (upper) line is for grassland, dashed (lower) line is for pine plantation.

Low-flow runoff

Probably of greatest concern to catchment managers assessing the hydrologic consequences of afforestation are changes in low-flow magnitude and persistence. Unfortunately, it is difficult to ascribe changes in low flows to afforestation because of variability in rainfall. Runoff from catchments becomes erratic under drier conditions, and this variability obscures controls on low-flow hydrology. Nevertheless, several studies demonstrate afforestation-induced reductions in low-flow magnitudes and persistence, though the statistical bases of these analyses are usually weak. One of the best local examples of altered flow durations has emerged from the Tumut catchment experiment. Figure 10 compares the cumulative frequency distribution of daily flows from the pasture-covered Kileys Run catchment and the pine-afforested Redhill catchment. It reveals significant changes in the duration of daily flows of all magnitudes. Importantly, Figure 10 shows that the

Redhill catchment now ceases to flow for almost 40% of the time, assuming that 0.001 mm per day is a 'no flow' threshold. In comparison, the pasture-covered Kileys Run catchment continues to flow all year round.

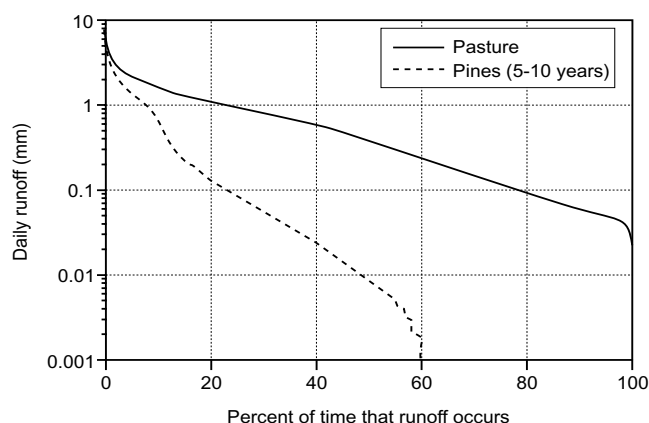


Figure 10. Cumulative frequency distribution of daily flows from the Kileys Run (pasture) and Redhill (pine) catchments near Tumut, NSW, for the period 1995-1999

Smith and Scott (1992) cite monthly low-flow reductions ranging between 63% and 100% following afforestation of seasonally dry grasslands with pines and eucalypts in the Eastern Transvaal Mokobulan catchments, South Africa. Scott and Smith (1997) examined low-flow reductions after afforestation of grassland and scrub sites at various locations in South Africa. They showed that percentage reductions in low flows were significantly greater than for total flows, and that reductions were greatest at high-productivity sites in South Africa. Scott and Smith (1997) developed a series of generalised curves which can be used to estimate percentage reductions in low flows and total flows as a function of plantation species, plantation age, percent area afforested, and site suitability (Fig. 11).

Fahey and Jackson (1997) concluded that pine afforestation of tussock grassland catchments at Glendhu, South Island, New Zealand, reduced low flows by 20%. They acknowledged the difficulties of comparing low-flow hydrology between catchments with differing lithologies and under conditions of variable climate. They concluded, however, that it was certainly possible to detect afforestation-induced reductions in low flows.

Peak flow runoff

Fahey and Jackson (1997) showed that the conversion of tussock grasslands to pine plantations at Glendhu resulted in significant decreases in flood peaks. They plotted the frequency distribution of mean flood peaks for four different size classes of storms, for discrete three-year periods before and after afforestation (Fig. 12). Figure 12 compares the mean flood peak for each storm size class for the control catchment (GH1) and the afforested catchment (GH2), before afforestation and after canopy closure of the plantation. Mean flood peaks for each storm size class were similar in both catchments prior to afforestation. After plantation canopy closure, mean flood peaks were reduced by about 60% in all four storm size classes in the afforested GH2 catchment.

Effects of plantation management

In practice, plantation management exerts a moderating and dynamic influence on the potential hydrologic impacts of afforestation. Factors that would mitigate against the realisation of the maximal hydrologic impacts discussed above include fraction of area planted, variations in stand age, stand thinning regimes and site productivity. These factors are elaborated upon below.

Obviously, the key management factor to consider is the percentage of catchment area planted. In any given catchment, the afforested area would rarely occupy the entire area either because some areas are not suitable or because some land is usually reserved for other uses. There is strong evidence to show that the magnitude of annual runoff change accompanying afforestation is linearly proportional to the fraction of the area planted (Bosch and Hewlett 1982; Stednick 1996). Hence, if only half of a grassland catchment is afforested then the estimated reduction in mean annual runoff would be half of the maximum reduction shown in Figure 4.

Even if a catchment is fully afforested, plantings are usually established over a period of years, leading to a spectrum of stand age classes. The Tumut data presented in this paper, and the data presented by Putuhen and Cordery (2000) both clearly show that the maximal hydrologic impacts of pine plantations may not be felt until the stand has reached about 10-15 yr of age. Hence, any catchment containing a significant proportion of young stands will not exhibit the maximum hydrologic effects of afforestation.

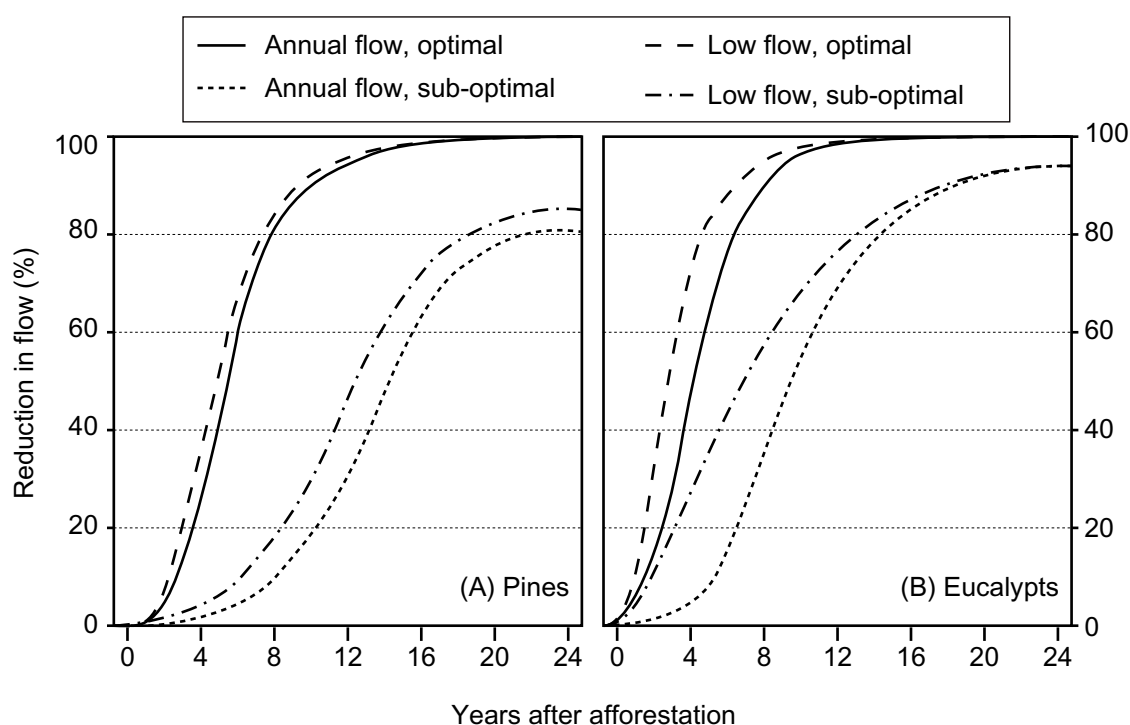


Figure 11. Generalised curves for estimating percentage reductions in total and low flows after 100% pine and eucalypt afforestation of optimal (high productivity) and sub-optimal (lesser productivity) sites, after Scott and Smith (1997)

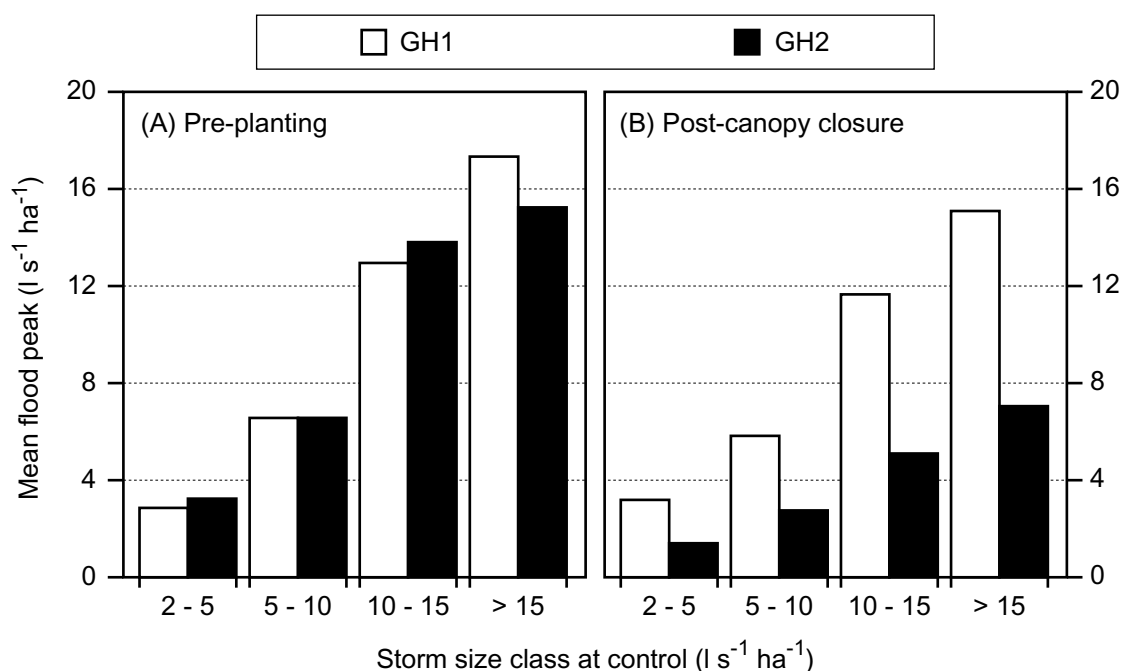


Figure 12. Comparison of mean flood peaks for four size classes of storms in the GH1 (tussock grassland control) and GH2 (pine-afforested treatment) catchments, Glendhu, South Island, New Zealand (after Fahey and Jackson 1997). (a) before the treatment of GH2 when both catchments were covered with tussock grassland, and (b) after canopy closure of the pine plantation established in GH2

There is some evidence to indicate that ET rates in mature pine and eucalypt stands are lower than in vigorously growing ones, with decreases starting to become apparent after 30-35 yr (Van Wyk 1987; Vertessy *et al.* 2001). However, further research is needed to substantiate the timing and magnitude of such ET reductions with age. Such effects are unlikely to be significant in short rotation (<40 yr) plantation systems.

Stand thinning may also reduce the potential hydrologic impacts of afforestation. For example, *Pinus radiata* plantations are sequentially thinned 3-4 times during one crop rotation. Unit reductions in stand leaf area and basal area would confer proportional reductions in ET and hence increases in runoff. However, such effects might only be detectable if thinning is heavy, and it is likely that the effects would be transient.

Finally, variations in site productivity might also affect the magnitude of hydrologic change ensuing from afforestation. If plantation growth rates are poor, ET rates will be lower, leading to lesser reductions in runoff after afforestation. However, if leaf area is increased by application of fertilizer, then ET may also increase, leading to reductions in runoff. With judicious management of soil and stand nutrition, it is possible to direct most growth enhancement to the stems, rather than the leaves (Nambiar 1990, 1991), thereby reducing fertilization-induced increases in ET. Such gains in water use efficiency (unit wood production per unit water transpired) can also be attained by careful genotype selection (Olbrich *et al.* 1993) and may help to reduce the hydrologic impacts of afforestation. In such cases increase in growth *per se* may not affect run-off.

Summary

Afforestation has the capacity to significantly alter catchment water balances, via increases to evapotranspiration, and reductions in groundwater recharge, annual runoff, low flows and peak flows. Some of these changes may be beneficial, whereas others may be problematic for catchment managers. Models and field data are available to estimate the magnitude of most of these changes, though further research on low-flow impacts is needed.

In planning afforestation programs, catchment managers should carefully assess the water use requirements of downstream users and the aquatic environment. The negative hydrologic impacts of afforestation can be minimised by establishing plantations in low-intermediate rainfall zones, by planting parts of catchments only, by having a spectrum of plantation age classes, and by managing the harvesting cycle. Should plantations need to be established in catchments where flows are already highly allocated, afforestation should be preceded by rational water-sharing arrangements.

Acknowledgements

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3

A Physiological Basis for Management of Water Use by Tree Crops

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This paper reviews the tree-environment interactions that determine water use by plantations of *Eucalyptus globulus*, *E. grandis* and *Pinus radiata*. This understanding is used to model the effect of varying leaf area on the components of water use in *E. globulus* plantations. In Australia, if annual rainfall is less than 1000 mm, plantations will use most if not all rainfall and there will be little or no drainage. Under such conditions, mature block plantings of trees will generally carry a leaf area that is in equilibrium with annual rainfall. Where trees have access to stored soil water or groundwater, a greater leaf area will result than for a rainfall-dependent plantation in the same location. This leaf area and associated growth will be maintained only if the additional supply of water can also be maintained.

We present relationships to show that where available water from rainfall, stored soil water and groundwater is non-limiting, *E. globulus* and *E. grandis* plantations will use water at up to the potential rate and that *P. radiata* will use water at the 20%-30% lower equilibrium rate. Where average vapour pressure deficit is high, all our major plantation species will probably use water at the lower equilibrium rate.

The effects of silviculture, especially thinning, on plantation growth and water use, and on plantation-groundwater interactions, and the influence of water quality on these interactions, are poorly understood. Simulations using a model predict that on low-rainfall sites the potential for manipulating plantation water use through varying leaf area is limited. As available water increases through increased rainfall, stored soil water or accessible groundwater the potential to manage water use by manipulating leaf area is greatly enhanced.

Introduction

The tree-environment interactions that influence water balance impinge directly on three land management issues: a) the relationship between water use and tree growth, b) the role of trees in managing groundwater recharge for amelioration and prevention of dryland salinity, and c) the potential of trees to deplete stored soil water and access good quality groundwater that is also in demand by other users of land. If water is free, then the objective of plantation management for wood production or recharge control is to maximise growth. Otherwise the target growth rate may be less than the maximum attainable on a given site. In Australia, where mean annual rainfall is less than 1000 mm, tree plantations will generally use all rainfall. Thus, where trees are planted they will reduce or preclude runoff or groundwater recharge. What is not certain is to what

extent trees will use water in excess of rainfall, either from significant soil water stores or from direct use of groundwater at the capillary fringe or the saturated zone.

Many tree species can access water from considerable depth in soil profiles (e.g. Crombie 1992). If rainfall is less than potential plantation water use, and there is no barrier to root development, *Eucalyptus globulus* plantations will eventually use all stored soil water from even 20-m deep soil profiles (Smettam *et al.* 1999). In addition, *Eucalyptus* spp., as well as other woody perennials, whether in plantations or agroforestry systems, can take up fresh and moderately saline groundwater at rates of up to 3 mm day⁻¹ (e.g. Cohen *et al.* 1997; Thorburn and Walker 1993). However, while it is confirmed that some tree species use groundwater, others will not use even fresh, accessible groundwater (White *et al.* 2000b; White *et al.* 2001).

The potential of tree plantations to compete for limited water resources has received specific attention in South Africa and southern India (Dye 1987; Roberts and Rosier 1993). There is also extensive evidence in southern Australia that reforestation with either pines or eucalypts can reduce stream flow (e.g. Vertessy and Bessard 1999; Zhang *et al.* 2000), an outcome that is mediated by the capacity of tree-planting to influence

Potential evaporation, crop factors and equilibrium leaf area

In order to assess the impact of changes in land use on water use, we need some basis for comparing patterns of water use for different types and amounts of ground cover. The crop factor or relative evapotranspiration (k), a ratio of actual water use to potential evaporation¹

(Priestley and Taylor 1972), provides a means for making this comparison. When k is related to the relative soil water store in the rooting zone, there are two phases to the resultant relationship. The first phase, at high values of relative soil water, is a plateau where k is unrelated to the level of the water store. In the second phase, which starts below a threshold relative soil water store, k declines in a linear fashion as the water store in the root zone is depleted (Fig. 2). These relationships define the well-watered upper bound to water use, the (threshold) soil water content at which plants exert stomatal control over transpiration, and the rate of decline in water use as the soil dries. They have been described for *E. globulus* and *E. nitens* plantations (Beadle *et al.* 1995; Battaglia and Sands 1997), a contour-planted tree-belt comprised of

four *Eucalyptus* species (White *et al.* 2001), a dry sclerophyll forest dominated by *E. maculata* (Dunin and MacKay 1982) and mallee (Dunin *et al.* 1999) (Fig. 2).

As annual rainfall increases from environments supporting mallee to those supporting *E. globulus* plantations, the value of k that defines the plateau increases and the relative soil water store at the threshold decreases. These changes are also associated with an increase in leaf area index. Specht (1972) observed that for a range of native forests in southern Australia, leaf area index increased as a linear function of available water. This observation underpins the view that in order to survive, trees must arrive at a leaf area that is in equilibrium with long-term rainfall (Eagleson 1982; Hatton *et al.* 1998). Higher leaf areas and growth are possible where the trees may access water sources other than current rainfall. However, these will be maintained only where the supply of additional water can be also be maintained.

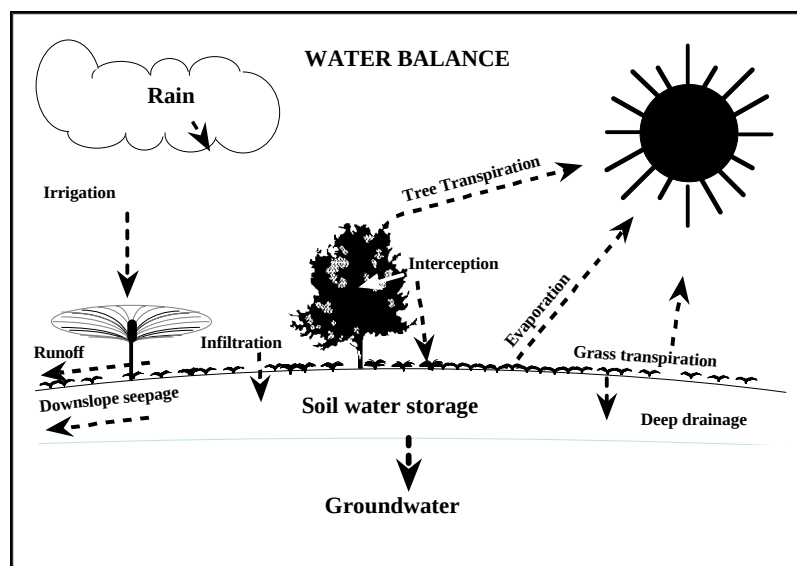


Figure 1. Water balance for an agroforestry system. Irrigation is included as an input although irrigated agroforestry is rare.

all processes in the hydrologic cycle. The focus here will be on evapotranspiration, the sum of soil evaporation, interception and transpiration (Fig. 1). Of these processes, transpiration, the direct use of water by trees, is the most important and will receive most attention.

The total water use of plantations or farm forests will depend on the climatic factors affecting evaporative demand, the amount and seasonal distribution of rain, the hydrologic factors influencing supply (discussed elsewhere in this volume) and the response of trees to climate and hydrology. This paper presents our current understanding of the key tree-environment interactions that influence water use and considers the influence of plantation management on these interactions. As discussed, where supply is seasonally limiting, stand water use will match annual rainfall. Thus the focus of this review is the behaviour of major plantation species when the supply of water is non-limiting. If we can use plant physiological information to generalize about the upper bound of tree water use, then we can define the maximum potential of trees to affect groundwater recharge or use water in competition with other users.

¹ Potential evaporation is the maximum rate of plantation water use. The value is ultimately constrained by the amount of energy available to evaporate water.

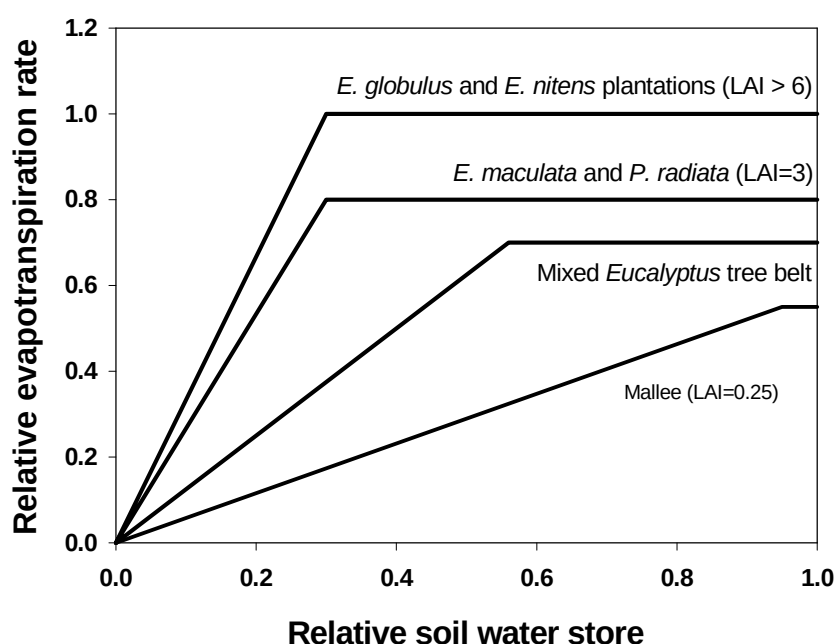


Figure 2. Evapotranspiration characteristics of different stands of trees – relative evapotranspiration rate (crop factor, k) as a function of relative plant-available soil water store in the root zone. Adapted from Dunin (2001).

Transpiration

Transpiration is the dominant process contributing to plantation water use and is the mechanism through which trees interact directly with soil water stores and groundwater. The Penman-Monteith equation (Monteith 1965) remains the best available model of transpiration and calculates transpiration as a function of: stomatal conductance, boundary layer conductance, leaf area index, net radiation and vapour pressure deficit. This model has two components, a net radiation component and an aerodynamic component that is a function of leaf conductance and vapour pressure deficit. The relative importance of these two components depends on the ratio of boundary layer to stomatal conductance. Because tree canopies are aerodynamically rough this ratio is generally high and transpiration by tree crops has been modelled successfully using a simplified Penman-Monteith equation that requires only stomatal conductance and vapour pressure deficit (Tan *et al.* 1978). Thus, under well-watered conditions (the plateau phase in Fig. 2) the value of k will be determined by leaf area, maximum stomatal conductance and the response of stomatal conductance to vapour pressure deficit.

Earlier we observed that the maximum value of k was 1.0 in *E. globulus* and 0.8 in *P. radiata*. The value for *E. globulus* was for an irrigated plantation in southern Tasmania (Battaglia and Sands 1997) while the *P. radiata* plantation measured was in NSW. The observed difference between *E. globulus* and *P. radiata* in the maximum value of k is potentially important. To assess

how generally it applies the stomatal response of these species to vapour pressure deficit must be considered.

Maximum stomatal conductance and response to vapour pressure deficit

In field studies of stomatal responses to environmental factors, maximum stomatal conductance was $387 \text{ mmol m}^{-2} \text{ s}^{-1}$ in *E. globulus* (White *et al.* 1999) and $340 \text{ mmol m}^{-2} \text{ s}^{-1}$ in *E. grandis* (Dye and Olbrich 1993). In both studies the response of stomatal conductance to vapour pressure deficit was described using an exponential decay function with slope -0.63 for *E. globulus* and -0.62 and

-0.299 for *E. grandis* in summer and winter respectively (Fig. 3). Whitehead *et al.* (1994) observed a maximum value of $150 \text{ mmol m}^{-2} \text{ s}^{-1}$ which we have combined with a function by Sheriff and Mattay (1995). The generality of inferences regarding patterns of water use is clearly contingent on the generality of these stomatal responses to vapour pressure deficit (D). At least for *E. globulus* the curve in Figure 3 does seem to apply to a wide range of conditions. In a recent study in south-western Australia an exponential decay function with identical slope to that observed in Tasmania was fitted to data for *E. globulus* (Macfarlane, unpublished data).

Maximum values for stomatal conductance are generally lower for conifers than eucalypts or deciduous hardwoods (Jarvis *et al.* 1976). The lower maximum value of stomatal conductance (g_s) for *P. radiata* than either *E. globulus* or *E. grandis* is consistent with the observation of Dunin and MacKay (1982) that the upper limit of evapotranspiration of *P. radiata* plantations was defined by equilibrium evaporation². It also supports the observation of Beadle *et al.* (1995) and Battaglia and Sands (1997) that evapotranspiration of well-watered *E. globulus* closely approximated potential evaporation.

² Equilibrium evaporation is approximately 75% of potential evaporation.

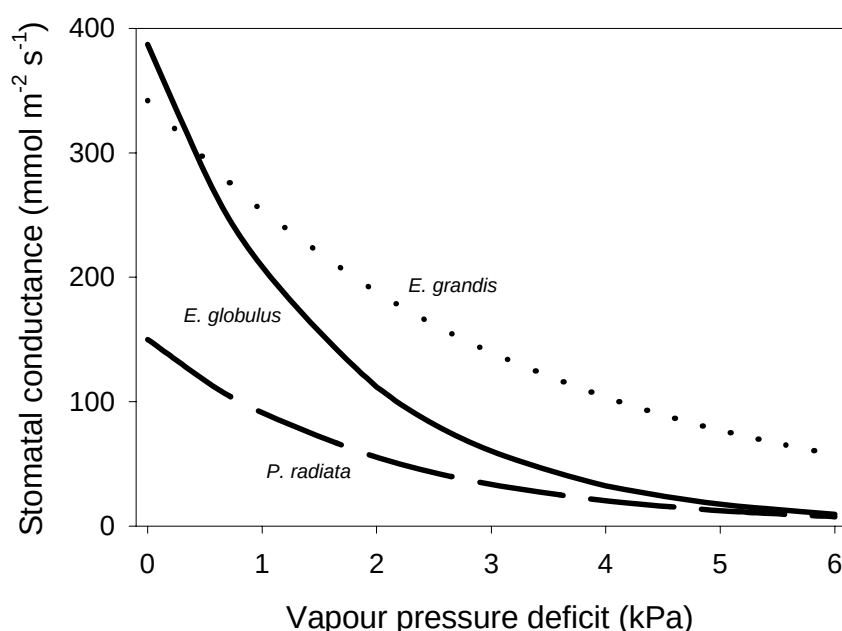


Figure 3. Stomatal conductance as a function of vapour pressure deficit for *E. globulus*, *E. grandis* and *P. radiata*

Thus the plant physiological data suggest that the ramp functions described in Figure 6 might be quite robust. Combining the water balance (Fig. 2) and plant physiological information (Fig. 3), we conclude that when vapour pressure deficit is low (<1.5 kPa) and water is in plentiful supply, *E. globulus* (and probably *E. grandis*) can use more water than *P. radiata*. These limited data also suggest that, at high vapour pressure deficit, water use will approach the equilibrium rate in all our tree species (see Dunin and Greenwood 1986) for a biophysical explanation of these conclusions).

Options for managing water use

The key plant variables determining tree water use are leaf area index and stomatal conductance. While stomatal conductance cannot be easily manipulated, leaf area is amenable to management practice and may be adjusted through nutrition, stand density at establishment, pruning or thinning. Changes in tree leaf area will affect overstorey transpiration, understorey transpiration, soil evaporation, and interception (Fig. 1). To provide a framework for considering the potential of silviculture to influence evapotranspiration we have applied a new model of plantation growth and water use (Battaglia, unpublished). Key features of the model as we applied it include: i) calculation of water use by trees and a shallow-rooted understorey (nominally grass), soil evaporation and interception; ii) grass roots are restricted to the first metre of soil while tree can access that part of the soil in which they have roots; iii) tree water use is constrained by the amount and density of fine roots available to take up water; iv) evaporation of all components is calculated using the Penman-Monteith

equation; and v) for the tree component canopy conductance is calculated after White *et al.* (1999) and White *et al.* (2000a). The model uses an optimization routine to allocate biomass. We fixed leaf area index and applied the model to 690 mm and 1250 mm rainfall sites in south-western Australia.

At both sites, as leaf area index was reduced below 3, the decrease in transpiration and interception was partially offset by increases in soil evaporation and grass transpiration. At the low-rainfall site the net effect of reducing leaf area to less than 1 was to decrease total plantation evapotranspiration to 80% of the annual rainfall of 690 mm (Fig. 4a). Tree transpiration did not increase above a leaf area index of 3 because no additional water was available for the trees due to parallel increases in interception. At the high-rainfall site, the effect of reducing leaf area index to less than 3 was to reduce total water use to about half of rainfall (Fig. 4b).

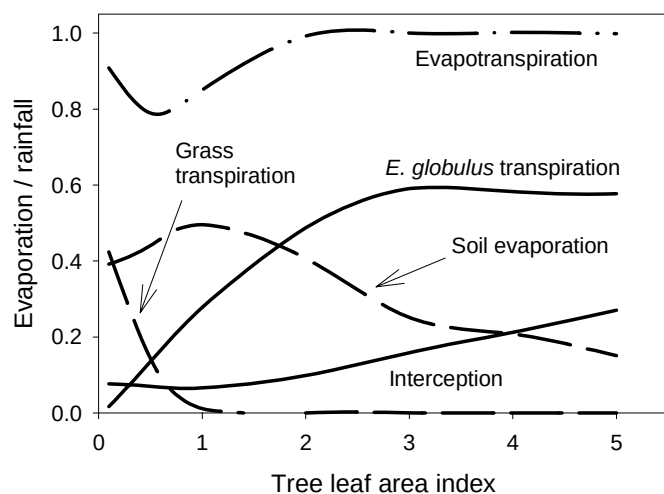
Battaglia *et al.* (1998) modelled the leaf area index that maximised net primary productivity as a function of available soil water and temperature and found that under well-watered conditions it was 6 for *E. globulus*. This leaf area is associated with near-maximum rates of transpiration. If a watertable was present at the low-rainfall site described by Figure 4a, then total evapotranspiration would increase with leaf area up to leaf area index 6. This overall analysis shows that there are options for managing water use by manipulating leaf area through site and stand management.

Thinning, spacing and pruning

Thinning converts the stand from a closed to an open canopy. Individual trees in a stand that has just been thinned and trees that are spaced so that their crowns do not touch have greater access to site resources than trees in a closed canopy.

A larger proportion of the crown is exposed to greater levels of available energy and competition for available water and nutrients decreases as the projected crown area per unit of land area decreases. In principle, therefore, thinning will lead to higher transpiration rates in individual trees.

a) Rainfall 690 mm, potential evaporation 1390 mm



b) Rainfall 1250 mm, potential evaporation 1300 mm

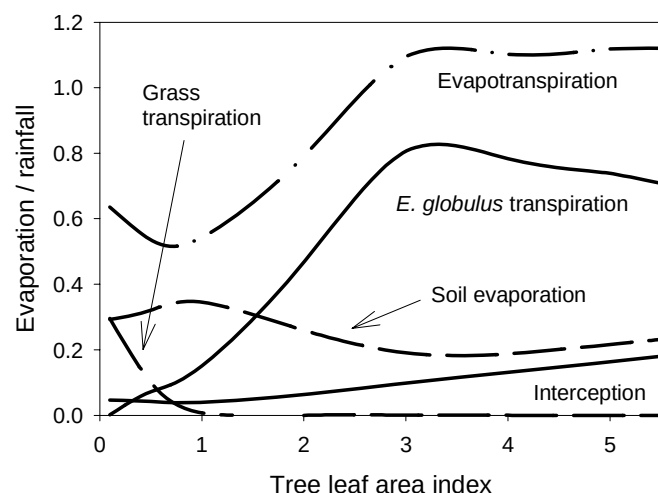


Figure 4. The influence of *E. globulus* leaf area index on total evapotranspiration, *E. globulus* transpiration, grass transpiration, interception by the trees and soil evaporation for a) a medium rainfall site and b) a high-rainfall site.

For a given initial stand density and if the trees are not supply-limited, transpiration will be greater at the individual tree level after thinning, primarily because of greater crown exposure and an increase in tree canopy conductance. Even if the supply of water is limiting, transpiration will still be greater because fewer trees are extracting water (e.g. Bréda *et al.* 1995) and there is increased throughfall (Aussenac and Granier 1988). Silvicultural pruning removes live branches from below and will reduce transpiration. For a given removal of crown length, this reduction will be less in closed stands than open stands because the proportional contribution to total transpiration of the lower crown will be greater in the open stands. Thus the transpirational response to the manipulation of leaf area by thinning, spacing and

pruning is determined by a range of factors that are related to stand structure and environment.

Medhurst (unpublished data) measured mean daily plot transpiration in a stand of *E. nitens* four months after thinning the stand from an initial density of 1250 trees ha⁻¹ to densities of 600, 250 and 100 trees ha⁻¹. On a ground area basis, mean transpiration of the 600, 250 and 100 tree ha⁻¹ stands was 55%, 36% and 23% of the unthinned stand (Fig. 5). Thinning reduced transpiration and this effect increased with intensity of thinning and was proportional to changes in leaf area.

While thinning can reduce transpiration, the effectiveness of spacing and thinning as a tool for managing water use in stands will depend on the planting density and thinning intensity. In pruned or thinned stands, it will also depend on the rate of recovery of leaf area, and the extent to which understorey transpiration and soil evaporation replace the overstorey transpiration (Black *et al.* 1980; Fig. 4). Thinning may have a greater impact on evapotranspiration where levels of available water limit transpiration, and where the understorey vegetation can access water from only the upper part of the soil water store. In climates with marked seasonal patterns of rainfall, such as in south-western Australia, the effect of thinning may be reduced if it simply extends the availability of the total water store in any given annual cycle.

Planting arrangement

Stirzaker *et al.* (1999) modelled optimal tree densities and arrangements for control of rising watertables. Contour-planted tree-belts emerged as a design that achieved the hydrologic objective while minimising tree-crop competition. Contour-planted tree belts can take advantage of lateral movement of groundwater over relatively short distances and therefore maximise the effective area occupied by trees (Lefroy and Stirzaker 1999; Stirzaker *et al.* 1999). Tree belts are also more closely coupled to the atmosphere than larger blocks (Smith *et al.* 1997). Maximising the ratio of edge to planted area will maximize the effect of trees on groundwater recharge. If high water use by trees is considered undesirable, then edge effects should be minimised. In this context avoiding areas with accessible groundwater will be important.

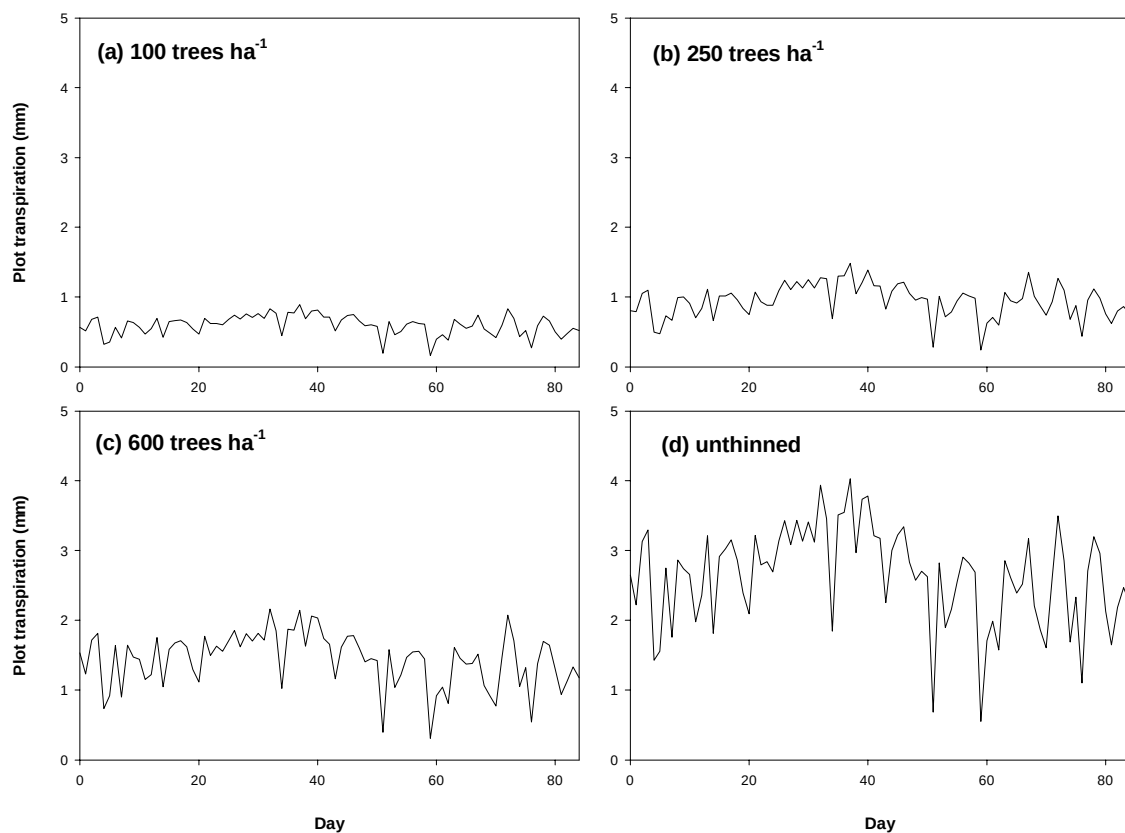


Figure 5. Transpiration expressed on a ground area basis for the thinned and unthinned treatments

Choice of species

Species that have evolved in lower-rainfall environments might have a lower optimum leaf area index and defer some winter and spring water use in order to ensure their persistence. There is also much variation among species in maximum stomatal conductance and stomatal and leaf area responses to drying soil. The high plateau values of k for major plantation species reflect high values of optimum leaf area and maximum stomatal conductance. These traits confer rapid growth under well-watered conditions but also increase the risk of death during drought. Where maintenance of stream flows is important, species with lower inherent productivity and water use may be a suitable option.

Water use rates may also differ between species due to differences in root architecture. A recent study near Deniliquin, NSW, determined groundwater use rates of plantations. *Corymbia maculata* produced a much greater root-length density in the capillary fringe above a shallow, fresh watertable than did *E. grandis* at the same site, and hence was able to transpire at close to potential evaporation. With far fewer roots in the capillary fringe, *E. grandis* had less access to

groundwater and transpired 400 mm yr⁻¹ below potential evaporation (Theiveyanathan *et al.* 2000). Despite this, *E. grandis* had a greater stem volume per hectare at age 4 yr (unpublished data).

Summary and conclusion

In regions where mean annual rainfall is less than mean annual potential evaporation, block plantings of trees will eventually attain a leaf area index in equilibrium with rainfall. If the root zone water-holding capacity of these plantations is greater than the volume needed to store excess water during seasons when rainfall exceeds evapotranspiration, plantations will use all the rain they receive. Under these conditions there will be little or no runoff to surface waters, or recharge of subsurface waters, from forested areas.

If plantations are established at sites where they can obtain water from sources additional to rainfall, they may be able to sustain a higher equilibrium leaf area index, resulting in greater productivity, but also greater water use. The greater leaf area index will not be sustainable if such plantations are depleting stored soil water, if flows of groundwater to the plantation are

lower than the excess of evapotranspiration over rainfall, or if groundwater use results in a continuing rise in salinity in the root zone. There are some regions in southern Australia where commercial tree species are being planted over large areas with widely available supplies of fresh groundwater. The Greater Green Triangle Region is one example, where new plantation areas are expanding currently at the rate of tens of thousands of hectares per year (mainly *E. globulus* but also some *P. radiata*) and much of the new plantation is being established over highly transmissive, freshwater aquifers within 5 m of the ground surface. Some of the irrigated regions of the country are also underlain by rising shallow water tables. In these areas, new tree plantations established in the right locations may have the dual benefits of high productivity and arresting the watertable rise.

Few studies have been undertaken to determine rates of groundwater use by the tree species discussed in this paper. We have presented evidence suggesting that eucalypts such as *E. globulus* will use water at the potential evaporation rate, whereas conifers such as *P. radiata* may use water only at the equilibrium rate of evaporation. Since equilibrium evaporation may be 30% less than potential evaporation, it is likely that pines planted over shallow fresh watertables will use less water than eucalypts. Water use rates may also differ between species due to differences in root architecture.

Plantation management techniques such as planting density and layout, pruning and thinning can be used to manipulate leaf area index and reduce or increase edge effects, to optimise plantation productivity in relation to growth and water use. With tree plantations increasingly competing with alternative land uses for water resources, further research is needed on the effects of silviculture on plantation growth and water use and on plantation-groundwater interactions. Comparative studies of rates of water use for alternative land uses on the same sites are also needed.

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4

The Role of Afforestation in Managing Dryland Salinity

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Fifteen million hectares of Australia are likely to develop shallow watertables and face the risk of dryland salinity. Marginal changes to existing farming systems are unlikely to reverse or even significantly slow its development over most of that area.

In most of the catchments at risk, adequate recharge control (should that be the management strategy) will be achieved only through planting deep-rooted perennial plants. Broad groups of perennials are (1) herbaceous forage or grasses and (2) trees (including woody shrubs). This paper focuses on the impacts of afforestation using trees.

Design guidelines for afforestation aimed at salinity management must first recognise the type of catchment-climate combination under consideration. Based on knowledge of the type of local groundwater flow system, generalities regarding the interaction between trees, soil and climate can be used to recommend the type and scale of revegetation appropriate for controlling dryland salinity.

Recent analyses of the hydrological impacts of current commercially-planted species (*Eucalyptus globulus*, *Pinus radiata*) suggest that as a result of soil and climate constraints, market forces and forecasted trends in planting, afforestation based on these species will make little regional impact on river basin salinity trends and only local impacts (i.e., within the immediate vicinity of the plantation) on dryland salinity. Indeed, if trees are planted in areas where relatively fresh runoff is generated, analyses suggest that down-basin water quality decline may occur.

On a more positive note, there are clearly other combinations of catchment type and climate in which there is the potential for effective salinity control with trees. In some cases, implementation awaits the development of a commercially attractive tree crop, other incentives to tree planting, or both.

Introduction

The hydrological response of Australian catchments to tree planting varies enormously, and it is very difficult to provide specific advice on optimal strategies for tree planting to achieve a particular hydrological outcome. In some catchments previously cleared for agriculture, local strategic tree plantings can have significant and almost immediate benefits in terms of reductions in waterlogging and groundwater discharge. In other catchments, afforestation of most (>50%) of the catchment is probably required to significantly limit salinisation, and the time scale for realising these benefits may be very long. There is little direct or indirect evidence that salinisation is entirely reversible with tree planting in all cases. George *et al.* (1999) evaluated the hydrologic performance of tree plantings

across a diverse range of catchment types in Western Australia, and found that in virtually all cases the extent of impact on lowering watertables did not (yet) extend more than 30 m downslope of the plantation. This work provides a good guide to expectations regarding tree planting options and salinity control.

A few generalities about the hydrological influence of trees in the landscape are useful in developing advice, however. The foremost of these is the fact that fully stocked stands of trees (natural or planted) will use more water from that unit of land than any other kind of vegetation. The rates of evaporation at sites where water is not limiting tend to approach equilibrium evaporation rates; this is equivalent to 1000 - 1400 mm yr⁻¹ in southern Australia. An important corollary to this observation is that many landscapes receiving less than about 900 mm of annual rainfall accumulated salt

in the subsoil because the original woody vegetation essentially prevented groundwater throughflow which would otherwise have purged this salt from the catchment. Thus, after clearing for agriculture, catchments with higher rainfall tend to yield more fresh water, while drier catchments tend to salinise. The principal hydrological issue associated with tree planting in wetter catchments is reduction in fresh streamflow (a potential social-economic disbenefit with respect to salinity) or fresh groundwater recharge (at the potential cost to other groundwater users), while the issues in drier catchments relate to salinity control and environmental sustainability (social-economic benefits). The extent of the area at risk of salinisation in Australia is indicated in Figure 1.



Figure 1. Regions of Australia at risk of salinisation. Source: Land and Water resources Research and Development Corporation, Canberra

The second generality about trees and hydrology is a close relationship between rainfall (as modified by potential evaporation) and the leaf area index (LAI) of stands of woody perennial vegetation. In essence, the LAI of a site comes into a predictable, dynamic equilibrium with the amount of water available (including any advected groundwater). This relationship seems to be independent of vegetation type, at least among Australian sclerophyllous vegetation types (Fig. 2).

The rate of annual recharge in relation to rainfall and the nature of the vegetation is illustrated in Figure 3. If we know the equilibrium tree LAI of a site in an area with less than 900 mm of annual rainfall, we can assume that little or no recharge reaches local groundwater systems at this value. The degree to which a catchment is cleared of trees (as expressed in the remnant LAI) is a good indicator of the enhancement of

groundwater recharge resulting from clearing (Fig. 3).

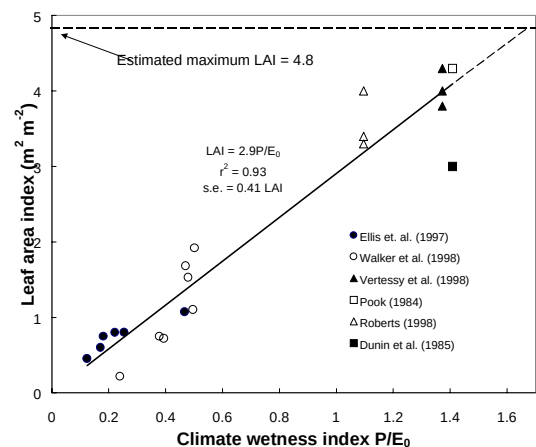


Figure 2. LAI of natural eucalypt forest in southern Australia versus a climate wetness index; average annual rainfall P divided by average annual pan evaporation E_0 . From Ellis et al. (1999)

An important interpretation from the LAI-rainfall relationship is that where landscapes generate lateral water flow, either as surface or subsurface discharge (as a result of clearing upslope or natural discharge processes), tree stands located downslope of the clearing may develop a higher LAI which reflects the total supply of water from local rainfall and the additional water supply from upslope. Circumstances in which water moves to the trees are explored below, and the identification for this potential is crucial in designing tree plantings for hydrological control.

The third generality is that the magnitude of the impact of land use change caused by clearing on salinisation is large in many Australian landscapes, with some evidence suggesting that it may be quite difficult to reverse. We propose that the popular (often implicit) expectation that afforestation will lead a reversal in salinity at a rate consistent with its advance may be a unrealistic for much of the land at risk, especially when the area planted is relatively small (<50% catchment area). The hysteretic nature of the processes needs quantification.

Given the scales of intervention likely to be required, salinity control with afforestation is dependent on commercially attractive options involving trees. In areas where plantation forestry has developed in some States, for example Western Australia, plantations have failed to achieve the requisite yields in areas previously considered to be commercially suitable, at least under the present economic environment.

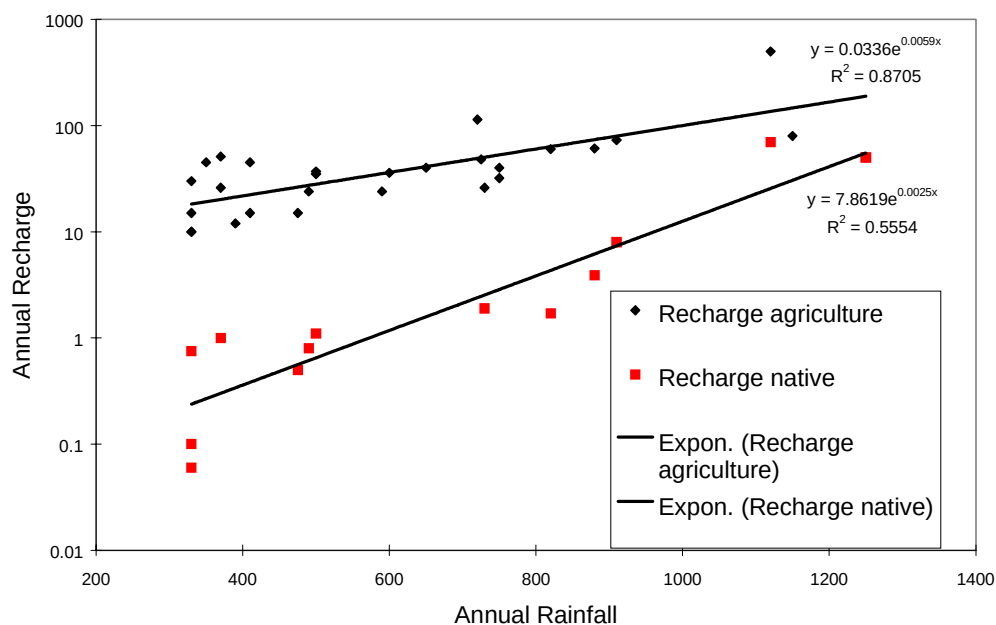


Figure 3. Summary of 60 case studies documenting the magnitude of recharge change due to clearing in Western Australia

Harper *et al.* (this volume) define critical conditions for tree growth and discuss planting systems to maximise salinity benefits. What emerges from this and other studies is that plantations are unlikely to cover large areas of the landscape at risk to salinity, as they require specific site conditions (quite restricted in extent) to meet present commercial expectations. Given this constraint, adequate LAI, recharge control and impact are not assured with the present plantation systems without additional economic incentives.

Farm forestry design guidelines for the basic catchment types of southern Australia

The application of the above generalities is complicated by a huge diversity of catchment types across Australia. This diversity in hydrological response is due to differences in soil and aquifer properties, catchment size, gradients, salt storage and ultimately the controls on groundwater discharge. Afforestation guidelines must be applied in the context of critical catchment attributes, but their specification from catchment to catchment is difficult. Therefore, this paper builds on a catchment classification scheme by Coram (1998) and specifies guidelines by catchment type. To make these guidelines more immediately useful, these types are related to particular regions in southern Australia. These guidelines are available at

<http://www.rirde.gov.au/pub/cat/contents.html#Research>

The following treatment of sets of catchment and climate combinations that may respond similarly to tree planting is derived from the above classification.

High-rainfall catchments

Catchments receiving more than 900 mm of annual rainfall do not generally salinise to any significant degree upon clearing, and the main hydrological concern related to tree planting is the reduction of overall water yield and to the flow regime (Vertessy, this volume). Catchments of this type are located in the south-west of Western Australia, the highlands of Victoria and New South Wales, and small areas of the Mount Lofty Ranges in South Australia. An empirical relationship developed by Holmes and Sinclair (1986) is useful in assessing the reduction in streamflow following afforestation. This reduction in (relatively fresh) streamflow should be factored in to the overall flow and quality regime throughout the catchment.

For catchments in which stream salinity is of particular concern (e.g. water supply catchments), tree plantings potentially offer a means to curtail the delivery of salt to the streams through minimising the wash-off of salt accumulated at the soil surface and the direct discharge of salty groundwater to the streams. However, regional-scale planting of large areas to trees in such catchments may be counterproductive and needs caution. Trees located in the highest rainfall areas may reduce the flow

from zones that usually produce the highest volumes of fresh water that in turn dilutes the saltier water arising from further down in the catchment.

Again, depending on catchment type, the relationship between water yield and salt loads may differ. Afforestation in the upper slopes and watershed divides in some kinds of catchments may not result in expected significant reductions in streamflow, but may not reduce salt load and concentration.

There is less agreement regarding the value of planting trees in the saline discharge areas (and the partial contributing areas if the seepages are not saline) immediately contributing to stream salinity. Strategic plantings of trees near stream courses *potentially* can result in relatively quick and short-term reductions in stream salinity. However, the long-term effectiveness and sustainability of such plantings depend on the local salt balance under the trees. Ultimately, the long-term discharge of salt from the catchment is dependent only on the groundwater processes that deliver salt to the discharge areas. If this volume does not change, then the effects of trees within the catchment will be diminished and changes will only delay the delivery of salt rather than reduce the volume delivered.

These comments on the effectiveness on stream salinity of tree planting in saline discharge areas do not preclude the inclusion of such plantings in catchment water supply remediation. First, while the trees do not enhance the discharge of the aquifer systems causing stream salinisation, they do locally lower watertables and thus offer the potential to facilitate improved grazing of the discharge areas as well as the potential to produce tree products for whatever duration such plantations may have in the context of salt accumulation in the root zone. More importantly, the short-term benefits to salt discharge (as well as nutrient and sediment control) can be of immense value to water resource protection, particularly if combined with tree planting upslope that reduces the net discharge of the saline aquifers by controlling catchment-scale recharge over the longer term.

Low-rainfall (<900 mm) catchments

Afforestation in catchments prone to salinisation upon clearing must be addressed in terms of groundwater management, either through recharge control or (in limited cases) interception of groundwater by vegetation. The degree to which recharge must be controlled to limit the area of (saline) discharge depends on the discharge capacity of the aquifer(s) and the geometry of the discharge zone, and perhaps on the spatial arrangement of the afforestation. The time it may take to achieve a reduction in discharge and the area of salinisation is a function of the gradient, transmissivity, salinity and length of the groundwater flow paths of a catchment. All of these properties vary enormously from

catchment to catchment. While Coram (1998) serves as a useful classification of catchment types and especially the controls on discharge, it is largely qualitative in the description of these properties. Moreover, the classification does not indicate those catchments in which localised (as opposed to diffuse) recharge plays a significant role, where more than one type of aquifer or discharge control may exist and interact with another, and the nature of these interactions.

The key diagnostic properties of a catchment with respect to hydrologic impacts of tree planting are:

- The discharge capacity of the aquifer;
- The nature of the recharge processes;
- Diffuse vs. localised recharge (does water leak into the aquifer everywhere or only in local areas of surface water concentration?);
- The spatial distribution of recharge;
- The size of the groundwater systems (local vs. intermediate vs. regional scale catchments); and
- The salinity of the groundwater.

Generalisations that relate these catchment diagnostics to the agroforestry design criteria identified above include:

- The more local the groundwater system in a catchment, the faster will be the response to revegetation with respect to discharge control;
- The fresher the groundwater system and the shallower the watertable, the more the opportunity to intercept groundwater recharged from upslope with tree belts;
- The thinner the regolith (<5-10 m) the greater the potential for interception of lateral flow and reduction in discharge;
- The more transmissive or steeper the groundwater system is, the faster will be its response to revegetation and the more likely it will be relatively fresh;
- The low discharge capacity of most intermediate and regional groundwater systems limits the benefits of revegetation strategies to extensive recharge control. In such cases, the area of plantation required to significantly limit saline discharge is likely to involve most of the landscape, and the reclamation of land already salinised could be very slow;
- For recharge control strategies, those landscape units in which groundwater recharge upon clearing is the highest should be revegetated first; and
- Where groundwater systems are recharged primarily by localised phenomena, these processes

must be understood to evaluate the effectiveness of any revegetation in the catchment.

Below, we have aggregated these catchment types to a set among which we can reasonably provide distinct agroforestry advice.

Local-flow system catchments

Catchments in which groundwater systems are on an order of 1-3 km in horizontal scale occur in higher-relief landscapes on the edges of plateaus and ranges, or as perched groundwater systems operating independently of deeper regional systems. They may arise from fractured metamorphic and igneous rocks, colluvial sediments or aeolian sediments. The structures that influence the flow of groundwater include subsurface features like dykes and bedrock highs or the termination of the aquifer at an erosional surface.

Local-flow system catchments with high discharge capacity

Some local groundwater flow systems have a characteristically high capacity to transmit water through an aquifer; this property generally translates to lower long-term salinity risk and greater responsiveness to tree planting. The flow systems with high discharge capacities are as follows.

- The most common catchment of this type is one in which discharge occurs as seeps from flow systems above relatively impermeable bedrock. These catchments are characterised by hillside seeps. The seeps tend to be of fresher water and smaller than discharge sites in other kinds of catchments, although this will be dependent of climate and regional geology. These local systems may be more responsive to revegetation if the sites under investigation have relatively low salinity groundwater, high transmissivities and groundwater gradients.
- A second type of local catchment with high discharge capacity is one in which groundwater flows through colluvial sediments with high hydraulic conductivity and subsequently discharges as a result of changes in aquifer thickness or aquifer material. These systems are characteristic of colluvial/alluvial fans at the base of ranges.
- Other local-flow systems with high discharge capacities include those in which groundwater discharges from local aquifers where layers with high hydraulic conductivity terminate at erosional surfaces or faulted/unconformable contacts.
- An additional high discharge system is characterised by discharge from perched unconfined aquifers where they thin or terminate, particularly in unconsolidated sediments. The regolith below these systems may be unsaturated.

These systems tend to be transmissive and relatively fresh. Trees planted to intercept lateral flow may be effective at reducing salinity within 3-5 yr. Effectiveness is a function of aquifer geometry, tree characteristics, plantation design, and in particular, the permeability of the perching horizon.

Revegetation Strategy: *Alley farming, targeted blocks of trees or even widely-scattered trees can often sufficiently control groundwater recharge at levels of stand tree LAI substantially below that of the original vegetation. Indeed, in some of these small upland systems, there may be little (area) salinisation or waterlogging associated with clearing. Discharge-area plantings for amenity or biodiversity purposes have less risk of tree mortality (due to lower levels of salt accumulation), and potentially can give quick, short-term control of stream salinisation. Longer-term (>5 yr) impacts may be limited if the delivery of salt (driven by heads in the aquifer) is unaltered by revegetation.*

Local-flow system catchments with low discharge capacity

Several local groundwater systems have characteristically low flows, including:

- Systems in which discharge is controlled by changes in the topographic gradient ('break of slope' catchments).
- Systems characterised by the coincidence of a change in topographic gradient at a location where unweathered fractured rock aquifers meet weathered material of lower conductivity.
- Systems in which discharge occurs where groundwater movement is impeded by a linear feature of lower conductivity perpendicular to flow, often as a result of the presence of lineaments or dykes associated with faulting or intrusion. An additional feature of these systems may be higher recharge (and transmission) along the contact zone between the aquifer and the linear feature.
- Systems characterised by groundwater discharge from low conductivity sediments or saprolite at local topographic lows where the surface falls below the unconfined water table. Thus, these systems develop in undulating landscapes with shallow groundwater.

In general, low discharge capacity is usually equated with high salt stores in the regolith, very saline groundwater, slow response times to revegetation, and a relatively larger proportion of the catchment salinised at equilibrium.

In Western Australia, revegetation in local-flow systems have been shown to result in small reductions in watertables (George *et al.* 1999) and some reductions of

streamflow if large proportions of the catchment are reforested (Bari 1998). In one catchment typical of the local-flow systems and land use patterns of the region (Batalling Creek), trees now cover most (>70%) of the catchment. In this catchment, remnant forest covers 51% of the upper catchment and 38% of lower slopes have been revegetated. To date, 15 yr later, while a reduction of streamflow has resulted, stream salt concentrations have continued to increase.

Revegetation Strategy: Extensive recharge control is required to limit waterlogging and salinisation in such catchments, indicating the need to approach the equilibrium LAI with tree planting. Thus, alleys may have to be closely spaced (<50m) and/or phase-farmed with perennial and high-water-use crops or pasture, or plantations adopted over most of the catchment. Plantings in discharge areas for amenity or biodiversity purposes should recognise the risk of tree mortality due to salt accumulation, even with salinity-tolerant genotypes. Reductions in stream salt load may not occur unless very large areas are replanted.

Intermediate-flow system catchments

Some catchments have flow systems on a horizontal scale of 5-10 km, usually with alluvial (or lacustrine) fill in foothills and valleys. The aquifers of these systems arise either in fractured rock or in shallow (<50 m) sediments. The controls on groundwater discharge arise from (a) reductions in hydraulic conductivity down-gradient, (b) reduction of gradient or transmissivity with aquifer thinning, or (c) subsurface features like bedrock highs or dykes. Groundwater discharge and associated salinity usually occur in low-lying areas of the catchment. Four types of flow systems characterise groundwater systems of this scale:

- Flow systems that discharge into low-lying areas as a result of reductions in transmissivity, for instance in broad valley systems. In WA, these systems are widespread and cause saline areas of hundreds or thousands of hectares with very saline water (>35 000 mg L⁻¹) (e.g. the Belka Valley, the Yilgarn Salt River Catchment). In SA, examples include the Upper South East, MacGilvray Plains on Kangaroo Island, Jamestown Flats in the Mid-North, Agery-Weetulta catchment on the Yorke Peninsula, and the Driver River Catchment on the Upper Eyre Peninsula. The Ovens Valley in Victoria is another example. In NSW, these catchments are restricted to Permian-recent sediments such as Yarraman Creek and Lake Goran. In Queensland, an example is the Lockyer Valley. It is worth noting that even road construction across a valley system can reduce aquifer transmissivity.

- A second intermediate-flow system type occurs where groundwater systems discharge from confined or semi-confined aquifers as a result of downstream reductions in conductivity; discharge occurs in low points in the landscape. These catchments are characteristic of paleodrainage systems buried within broad alluvial plains. Local systems may overly these systems.
- A third intermediate system is characterised by groundwater discharge from unweathered fractured rock aquifers where the gradient lessens downslope. In this sense they are similar to local-flow systems with similar discharge controls, but extend over at greater scale (10 – 20 km).
- A final intermediate system that is not commonly recognised occurs where a linear zone of high conductivity cuts across a number of surface catchments. In WA, we believe that these (groundwater) catchments discharge highly saline water (20 000 mg L⁻¹) at large springs in hilly terrain and via evaporation-driven seepage in flatter country. In a sense, these systems are recharged chiefly by localised recharge and require special consideration in revegetation planning.

Revegetation Strategy: Extensive afforestation, at levels approaching the original tree cover, is required to control watertables in these catchments. Where watertables are still deep (e.g. the eastern wheatbelt in Western Australia), less afforestation will buy time but ultimately may not avert widespread salinisation. Alley farming with closely-spaced trees (<50 m), when combined with perennial pasture in the alleys, may achieve sufficient recharge control to contain the spread of salinity in such catchments. Discharge area plantings are of questionable worth and potential, given the high salinities in the groundwater, but may for a time allow some production for grazing among the trees through their (perhaps temporary) effects on local-flow systems and shallow watertables. Deep surface drains or groundwater pumping and saline disposal may have to be considered in managing discharge areas.

Regional-flow systems

Some catchments consist of broad riverine plains on depositional basins of large horizontal scale (>50 km), with deep interbedded marine, alluvial and aeolian sedimentary sequences often hundreds of metres deep. Controls on groundwater discharge arise from reductions in flow due to structural deformation or aquifer thinning.

Such catchments occur throughout the Perth Basin, Bremmer and the North Stirling Basins of Western Australia, where groundwater discharge occurs from the

deeper aquifer into surficial aquifers that evaporate at the soil surface. The degree of salinisation of these catchments varies widely, with the North Stirlings already extensively saline. In eastern Australia, the regional catchments (e.g. the Loddon and Campaspe) of the Riverine Plains and the eastern margins of the Murray-Darling Basin discharge as a result of reduced conductivity of the confined ('deep lead') aquifer. Similar catchments exist in the western margins of the Riverine plains and the Murray Basin in New South Wales.

In South Australia (e.g. Cooke plains) and Victoria (e.g. Lake Tyrrell, East Manangatang, Lough Calvert area), regional systems discharge where topography falls below the regional unconfined water table.

It should be noted that some of these systems recharge in areas with higher rainfall, and with very sandy soils permit substantial recharge to systems that are largely fresh and constitute important urban and agricultural groundwater supplies. As a result, in places (such as the Gnangara Mound north of Perth) there are controls on afforestation. In South Australia and Western Victoria, afforestation of regional limestone aquifers has already sparked controversy over allocation and land use regulation.

Revegetation Strategy: *In these regional systems, there is little opportunity to intercept groundwater once it reaches the regional aquifer. Recharge control may be exerted on overlying local and intermediate systems without influence of the regional systems of interest. Recharge control requires levels of afforestation of recharge areas approaching the original LAI. Discharge plantings are not recommended. Where deeper groundwaters are relatively fresh, pumping to control water levels and provide irrigation to the trees may be an option.*

Summary

The key to designing forestry systems for catchments in need of salinity control is recognising (a) the discharge capacity of the aquifer, and what constrains this capacity; (b) the salinity of the groundwater; (c) the scale of the groundwater flow systems; and (d) the desired outcomes in terms of stream salinity or land salinity.

The scale and discharge capacity of the flow systems can be assessed in approximate terms through application of the catchment classification of Coram (1998), in conjunction with local knowledge of hydrology. We emphasize the importance of adequately understanding how water moves through a particular catchment, as well as the relative salinity of the groundwater. This information provides a basis planning for the afforestation effort required to achieve a

particular outcome, and also for assessing what can be achieved with a particular agroforestry design and how soon we might see the benefits.

Some local-flow systems affected by salinity can be largely restored through judicious and targeted tree planting, particularly where the discharge capacities are high and the groundwater is relatively fresh. Where flow systems are longer and of lower discharge capacity, the challenge is much greater; indeed, some of these systems may have progressed sufficiently toward the new equilibrium that their reversal with trees may not be feasible. Furthermore, the relationships between area planted, streamflow and concentration are not likely to be straightforward. Revegetation above critical thresholds related to the groundwater flow system and climate may be required to reduce load and concentrations. Furthermore, reforestation in areas that yield fresh water may increase concentration down-basin.

Thus, the catchment-scale guidelines can be used for two separate but related purposes. First, they can be used to select appropriate forestry approaches and revegetation targets for controlling salinity in specific catchment types. Alternatively, the information in this paper can guide and prioritise revegetation efforts to those catchments most likely to respond to treatment, and to look for alternative remediation strategies elsewhere.

This paper provides an assessment of the prospects and problems of afforestation in relation to dryland salinity remediation. The central point is that any remediation strategy must recognise the underlying hydrological features of the landscape in question, given the enormous diversity of catchment types and associated environments in Australia. While some local groundwater flow systems have aquifer characteristics and climates that make them amenable to salinity control through modest degrees of afforestation, much of the area at risk to salinisation in Australia will likely require quite extensive levels of afforestation to achieve a significant degree of salinity control. Where the latter is the case, success may depend upon fostering adoption through new commercial tree crops, economic incentives to tree planting, or both.

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5

Forestry, Land use Change and Water Management: A Green Triangle Perspective

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The water resources of the Glenelg Hopkins Catchment Management Authority and the South East Catchment Water Management Board are predominantly surface water and groundwater respectively. The quality and quantity of the water resources are highly dependent on land use and land management practices.

Rapid and large-scale change of land use from rain-fed agriculture to plantation forestry is revealing inadequacies in the water allocation and management policies and legislation. At risk are water-using enterprises, certainty for future water-based and forestry investment, the well-being of the region's water resources and the associated ecosystems.

There is a strong and growing need for information and predictive analysis to underpin the management of water resources and the effect of land use change on those resources. On the basis of open and constructive debate, water resources management needs to rapidly become more sophisticated, transparent and responsive so that all parts of the water cycle can be managed more effectively.

Introduction

The Green Triangle region includes the South East of South Australia and the South West of Victoria. For the purposes of this paper, it includes the combined areas of the South East Catchment Water Management Board and the Glenelg Hopkins Catchment Management Authority, together exceeding 5.5 M ha.

The area is experiencing an unprecedented expansion in plantation forestry, in addition to the significant integrated industry already thriving in the area. This land-use change is revealing inadequacies in planning systems and water allocation and management systems. There is significant potential for conflict between the forestry sector, current and aspiring water users, and advocates for the environment.

This paper outlines the background to water resources management in the region and examines the emerging issues in detail.

Description of the area

Land use

The area has been substantially cleared of native vegetation, with 7% remaining in South Australia and 16% in Victoria. The bulk of remnant native vegetation is in parks and reserves and is unevenly distributed. In South Australia, native vegetation covers 14% of the Upper South East.

Forest plantations account for almost 3% of the area, amounting to nearly 150 000 ha. In South Australia, they are concentrated in the southern part of the catchment, and consist predominantly of *Pinus radiata*.

A further 83 000 ha is irrigated for agriculture, with water allocation licence holders reporting irrigation on 73 000 ha in South Australia in 1998/99, the bulk of which was for pasture (Binks 2000). In Victoria, 10 700 ha are reported to be irrigated (Glenelg CaLP Board, 1997).

Most (83%) of the land of both catchments is used for rain-fed agriculture.

Geology and soils

The South East is a flat to undulating region with low hills in the north-east and a succession of north-west to south-east ranges formed from stranded coastlines proceeding westwards towards the current coastline. Most of the South East is underlain by a complex sequence of terrestrial and marine sediments, deposition of which commenced about 150 M yr ago.

The dominant geomorphological feature of the South West is the extensive volcanic plain that covers the southern and eastern part of the region. Dune complexes occur along the coast, extending inland several kilometres. The southern part of the Grampians mountain range extends into the northern part of the region.

Climate

The climate of the area is Mediterranean, with cool wet winters and warm to hot dry summers. Rainfall ranges from more than 800 mm in the south and 910 mm near Heywood, to less than 420 mm in the north near Keith and 500 mm in the east near Lake Bolac. Annual pan evaporation ranges from 1350 mm in the south to 1717 mm in the north.

Ecosystems of the area

The South West of Victoria contains 44% of Victoria's wetlands, with 90% of them on private land. Few stream and river sections remain in their natural state. For example, 83% of the Hopkins Basin streams were found to be in poor to very poor environmental condition, as were 65% of those in the Glenelg Basin.

Clearing, predominantly for agriculture, has resulted in only 18% of the original native vegetation remaining in the Portland Coast Basin, 5% in the Hopkins Basin and 28% in the Glenelg Basin. The area is home to a range of endangered, rare and vulnerable flora and fauna species.

Native vegetation in the South East is closely related to soils and landform, especially the pattern of about thirty parallel north-westerly trending dune ridges and ranges, and the periodically-inundated interdunal flats and plains. Only 7% of the catchment still carries native vegetation. It is considered to be under threat from grazing, continued clearing of scattered trees for agriculture, irrigation, forestry, drainage, fragmentation, weed invasion and salinity.

Water resources

The hydrogeology of the region is unusual when compared to that of the rest of the country.

Surface water

The geology, high soil permeability and low relief of the South East mean that most of the region's water resources are underground. There are only three permanently flowing streams in the South East. A number of ephemeral creeks flow west across the Victorian border into South Australia. Prior to European settlement, the interdunal flats in the west remained inundated for extended periods each year. Surface water flow is now predominantly controlled through the 6000 km of drains serving the region.

In Victoria, the water resources are predominantly surface, occurring in three major basins: Glenelg, Portland Coast and the Hopkins. The annual average surface flow is estimated to be 1 370 000 megalitres (ML), with 28% divertible, but only 7% currently being diverted.

Groundwater

In the South East, and across the State border into the adjacent part of Victoria, two aquifers hold vast quantities of water. The rain-fed unconfined limestone aquifer accounts for the bulk of the region's water resources. It is from this aquifer that most of the water licensed for extraction and use is drawn. Water quality ranges from very good at a salinity of 500 milligrams per litre (mg L^{-1}) in the south, increasing to more than 50 000 mg L^{-1} in the north west. Depth to water ranges from 2 m in lower-lying areas to more than 35 m in elevated areas.

The unconfined aquifer is recharged by rainfall at a rate of 10-15 mm yr^{-1} in the north to >150 mm in the south, depending on rainfall, vegetation and soils. Most recharge occurs in the months of May to November. The aquifer has a hydraulic gradient towards the coast with a watertable elevation of more than 80 m AHD east of Naracoorte to less than 5 m AHD near the coast. The depth to groundwater ranges from over 20 m around Mt Gambier to 2 m over much of the central area.

The lateral groundwater flow is very slow, ranging from 1 - 100 m yr^{-1} . Despite the karstic landscape, most water moves through pores in the rock, not through underground channels. This has consequences for salt flushing.

The deeper tertiary confined sands aquifer (TCSA) contains water that is more than 25 000 yr old. Its salinity ranges from about 600 to 3000 mg L^{-1} . Of the minimal recharge of this aquifer, most occurs in Victoria on the eastern edge of the aquifer. The TCSA is separated from the unconfined aquifer by an overlying plastic layer of clay and marls. Relative head pressures between the two aquifers changes mid-catchment, resulting in artesian flows from the confined aquifer to the west of the catchment.

The groundwater resources in the South West of Victoria have not been well quantified.

The economy of the area

The area is in dynamic economic transition. The economy in the recent past was dominated by extensive agriculture of rain-fed grazing of sheep and cattle, cropping, softwood forestry and timber processing, and fisheries.

In 1995-96, the South East regional economy generated a gross regional product of \$1523 M or 5% of gross State product. The wood and paper products manufacturing sector provided 19% of the gross output of the region, with most derived from processing. The relative contribution of intensive industries such as wine grape production was expected to grow. In contrast, grazing enterprises occupied 95% of the region and yielded 45% of the region's product, while wine grapes occupied 0.7% of the region and yielded 10% of the product. The farm gate value of irrigation product in 1999 was \$234 M (Binks 2000).

The economy of the Glenelg Hopkins Catchment Management Authority area is also agriculturally based, with 22% of the workforce employed in agriculture, forestry or fisheries. The value of agricultural commodities was \$77 M for cropping and \$293 for livestock production in December 1995 (GHCaLP 1997). Industry expansion from 1990-91 to 2000-01 is expected as follows: cropping (62 000 to 205 000 ha), dairy (30 000 to 39 000 ha) and blue gum plantations (0 to >40 000 ha). The area used for wool production is expected to reduce from 35% to 28% of the area, and prime lamb from 530 000 ha to 390 000 ha in the same time (GRCaLP 2000).

Irrigated agriculture in SA has expanded significantly from predominantly flood irrigation for lucerne hay and seed in the mid 1980s to centre pivot irrigation for broad-acre applications for a wide range of crops, and dripper technology for viticulture and horticulture. Flood irrigation continues in many areas. Aquaculture (terrestrial and marine) is a sunrise industry.

More than 160 000 people are reported to be resident in the area (Econsearch 1998; GHCaLP 1997), with 62 000 in the South East.

Currently, the effect of the changes in agriculture on water budgets is assumed to be negligible. However, sophistication in agricultural production is also related to water use efficiency. As with sizable changes in land use from agriculture to forestry, the hydrological effects of significant change within the agricultural sector need to be quantified.

Management of extraction and use of water

The legislative framework

Water resources legislation in both States sets the framework for water resources management. In South Australia, the Water Resources Act 1997 is based on the principles of ecologically sustainable development. The objectives of the Act require that water resources management ensures the physical, economic and social well-being of the people of the State, while ensuring that the needs of ecosystems and future generations can be met. The Victorian Act is prime legislation emphasising the equitable and efficient use of water, conservation and community involvement in decision-making. It also links with and specifies a cascade of other legislation, plans and policies, including Council of Australian Governments, State Water Plan, Catchment Water Management Plans, Water Allocation Plans, the Groundwater (Border Agreement) Act 1985, the South Eastern Water Conservation and Drainage Act 1992, the Environment Protection Act 1993 and the Development Act 1993.

South Australia and Victoria have established a groundwater management zone extending 20 km into each state under the Groundwater (Border Agreement) Act 1985. Groundwater resources in the 40 km strip are required to be jointly managed in a way agreed to by both States.

Regional management

The South East Catchment Water Management Board, as required by the Water Resources Act 1997, is developing a catchment water management plan for its catchment. It is also in the process of developing Water Allocation Plans for the five Prescribed Wells Areas (PWAs). The groundwaters in these zones are prescribed under provisions of the Water Resources Act 1997. Within each of these areas are smaller management zones.

Permissible annual volumes (PAVs) for allocation and extraction for each management zone and Prescribed Wells Area have been developed on the basis of hydrogeological assessment. In essence, the volume available for extraction from the unconfined aquifer is equivalent to the long-term average annual recharge. The PAVs are under continual monitoring and review.

At present only the extraction of water from the saturated zone is regulated. Licences are required for the extraction of water for uses such as irrigation and industrial uses, but stock and domestic use is not required to be licensed. The use of water through the interception of rainfall or by extraction from the unsaturated zone is not currently regulated.

The Glenelg Hopkins Catchment Management Authority is responsible for natural resources management of its area. Excluded from this is the management of groundwater resources, which are the responsibility of Rural Water Authorities and the State Government.

Patterns of change

There has been incremental change in the character of land use of the region. In the last 20 yr, the following trends have been observed:

- Clearance of native vegetation virtually halted;
- Property rights in land and water separated;
- Declining terms of trade in the agricultural sector;
- Intensification of agriculture, improved per hectare biomass production including pastures, and claying of non-wetting soils;
- Decrease in sole reliance on sheep and cattle;
- Increase in the area cropped;
- Increase in the diversity of crops;
- Failure of lucerne in the Upper South East resulting in water table rise;
- Technological advances in forest management, harvesting and timber processing;
- Forestry moving from State government control to commercialised / private management.

Changes in water resources management have included:

- Groundwater in some areas has been found to be under threat from over-exploitation;
- Prescription of much of the groundwater of the South East;
- Licensing of extractive water users (2300 in the South East);
- The introduction of water allocation trading, within hydrogeological constraints;
- Water tables rising in the Upper South East, with associated dryland salinity;
- Water tables declining in the Lower South East;
- General trends in increasing groundwater salinity in some area;
- Significant capital investment in sophisticated irrigation technology.

The SA Water Resources Act 1997 provides a framework for regular review of catchment and water allocation plans to enable the water management environment to keep pace with such changes, and to set direction for future management.

Water availability

In total, almost one million ML of groundwater are available for annual extraction and use in the South East. Limits for the extraction of groundwater in South Australia have been calculated using assessments of the long-term average annual vertical recharge to the unconfined aquifer in each management zone. The rate of vertical recharge is very much affected by climate, and changes to land use and land management. Dramatic or incremental changes to land use or land management affecting vertical recharge rates, such as forestry, will therefore have a significant effect on the permissible annual extraction for each zone.

The water budget comprises inputs of rainfall, surface flow, lateral groundwater flow, and upward and downward leakage between aquifers. The outputs include evaporation, transpiration, surface flows, extractions, lateral groundwater flow, and upward and downward leakage between aquifers.

Lateral groundwater movement is very slow, estimated to be 1 - 100 m yr⁻¹. Most of the movement is through the pore spaces of the substrate, and not through karstic features. However, very rapid groundwater movement can occur through some of these features.

Water levels and salinity of the waters of the South East continue to be monitored through a network of 1100 wells which are sampled quarterly. With more than 25 yr of data in some areas, trends in quality and water level are well defined. There are more than 400 such wells in the Glenelg-Hopkins CMA area.

Water allocation

An area-based water allocation system is currently used in the South East of South Australia. This is based on the water needed in excess of rainfall to maintain one hectare of a reference crop, which is fully-irrigated pasture, and is known as an Irrigation Equivalent. Crop Area Ratios are used to determine the areas of other crops which can be irrigated with one Irrigation Equivalent, based on the water use of these other crops relative to that of the reference crop.

For example, the irrigated water needs of the reference crop may be 446 mm per annum and that of vines 127 mm, so that the Crop Area Ratio for vines is 3.5, meaning that 3.5 ha of vines can be grown for each Irrigation Equivalent.

In the southern part of the catchment, the reference crop's water requirement has been estimated at 446 mm, in addition to rainfall. Recharge in the same area is deemed to be 100 mm. This means that for every hectare of irrigated pasture, there needs to be another 4.46 hectares of recharge (Desmier 1990). Vines by way of contrast have been estimated to need 173 mm.

Because of this, the sustainability of the South East's water resources and irrigated enterprises is reliant on the majority of the catchment continuing to remain as rainfed agriculture, and not deep-rooted perennials such as forests or lucerne.

The extraction of water for irrigation generally occurs in summer, while most unconfined aquifer recharge occurs in winter-spring.

In 29 of the SE's 70 management zones, the entire PAV has been allocated. Usage of the allocations varies from near full to very low. Change of land use will affect the character and volume of recharge in a management zone. To protect the water resource, PAVs may need to be reduced. Under current rules, the licensed water users must then share the reduction, usually with each having their licensed volume reduced by the same percentage.

Land use change and water management

For zones that are not fully allocated, land use change holds little threat to users of water for stock and domestic purposes, irrigation, or other uses, except where the zone becomes substantially used for zero-recharge land uses such as forestry. In fully-allocated zones, the situation is very different, and is causing community consternation. The concerns have been made very clear in the Parliamentary Select Committee report into Water Allocations in the South East (1999), and during the extensive community consultation for water allocation plan preparation (SECWMB 2000).

The South Australian Parliament, at the time of writing, was considering an opposition, Upper House amendment to the Water Resources Act 1997 which would require new forest owners to hold an unused water allocation. The allocation would need to be equivalent to the deemed recharge intercepted by the plantation. The concept was to activate this requirement in management zones where plantation forest expansion is likely to result in a need to reduce PAVs to protect groundwater quality or level. Any PAV reduction would otherwise be required to be shared by existing licensees.

It appeared that the amendment also provided that there should be no hindrance to new forestry or revegetation in management zones where forestry could intervene in rising trends in groundwater and salinity levels that were causing natural resources degradation.

Those proposing the amendment considered that the continued expansion of forests would result in groundwater licensees experiencing regular cuts to their allocated volume. It was expected that this in turn would cause uncertainty for current and future investors, because some licensees who are fully using their volume would need to purchase extra volume from other licensees, thus increasing the price of water allocations and possibly leading to collapse of some businesses.

The proposal is a significant departure from the underlying principles of the Water Resources Act 1997 in South Australia. The Act focuses on the taking of water from surface or underground resources, but not the management of the hydrological cycle, recharge or replenishment of those water resources. As some have stated in the South East, it seems to be a question of who owns the rain. The SA law is silent on this point.

Rate of land use change

Significant areas of rain-fed farmland are now being converted to *Eucalyptus globulus* (blue gum) plantations. It is expected that 20 000 – 40 000 ha will be established in the Green Triangle Region in the year 2000, compared to an estimated underlying expansion rate (mainly pine) of 1500 - 2000 ha yr⁻¹ for the area. At this rate, in 3 - 6 yr, the blue gum estate will exceed the pine estate gradually established since the 1880s.

It will also mean that the PAVs in the southern part of the South East catchment may need to be reduced by the amount of recharge intercepted, which could potentially exceed 100 000 ML over the same time. This equates to 10% of the PAV of the entire catchment, and a significantly higher proportion in some management zones in the southern part of the catchment.

The value of water

In the South East, water remains available from the Crown in nearly 40 management zones at the cost of an application fee of \$130 in SA or \$58 in Victoria. In June 1999, the equivalent of more than 5000 ML of licence was handed back to the Crown by water allocation licence holders who believed they would be unable to meet the conditions on their licences, by those who wished to avoid paying the catchment levy, and by those who could find no market for their licence. This means water has no real price in these areas.

In other parts, prices exceeding \$1000 ML⁻¹ for licences in management zones that are fully allocated have been reported. The operations of the South East Catchment Water Management Board are funded by a levy of \$1.50 ML⁻¹. In SW Victoria, the annual charge is \$1.40 ML⁻¹. This means that the cost of holding water is low in comparison to some sale prices.

Forests and water use

CSIRO work in the South East has found that on *Pinus radiata* trial sites all the potential aquifer recharge is intercepted, and that on these sites the plantations do not use water from the aquifer (pers. comm. P. Benyon, CSIRO FFP 2000).

A significant gap in the information surrounds the likelihood of and circumstances when plantation forests would use water from the aquifer. Large areas of new blue gum plantations are being established in localities where direct access of the aquifer by the trees can be expected, with potentially significant impact on local and regional water budgets. A key question is whether the long-term reduction in recharge is a more significant water balance issue than some possibly short-term opportunistic use of shallow fresh groundwater at some sites.

It is likely that site, depth to water, water quality, species and season will influence the quantity of groundwater used, if any. If plantations are found to use aquifer water, there will be a need to consider the water resource management implications, equity in relation to licenced water users, and the need for regulatory measures.

The recent dramatic expansion of forestry activity in the Green Triangle Region has revealed the need for holistic management of the entire water cycle and budget. This must be based on quantitative data collected over a range of seasons, sites and climates, and modelled for the longer-term and larger-scale impacts.

The benefits of accelerated afforestation

The significant benefits from the rapid expansion of the forest estate include:

- The regional contribution to meeting the 2020 Vision target;
- Out-of-region investment in the region;
- Land prices have increased by a factor of two to three times, enabling farmers to exit their enterprise with liquidity, or to acquire two to three times the carrying capacity elsewhere;
- Protection of water resources from diffuse point pollution associated with annual or cyclical agricultural practices;
- Changed habitat opportunities for fauna, and farming pressures on ecosystems reduced;
- Interception of recharge and intervention in dryland salinity processes;

- Development of the potential basis for future timber industry, including value-adding.

Concerns from accelerated afforestation

The concerns about the current rate of afforestation cover social, economic and environmental issues, including:

- Interception of recharge, requiring reduction of permissible annual volumes and licensee volumes;
- Interception of rainfall and reduced stream flows, and threats to riverine and estuarine ecosystems;
- Lower chance of local or regional inundation, threatening the survival of ephemeral swamps and semi-permanent to permanent wetlands;
- Lowering of regional water tables, affecting aquatic ecosystems and requiring re-equipping of bores;
- Weed invasion of local native vegetation communities;
- Loss of local communities, employment and services;
- Loss of the commerce and businesses surrounding agriculture;
- Limited prospects of attracting value-adding for timber products to the region;
- The potential to buy land, sell the water licence associated with it, and then plant forests (double dipping);
- Impacts of large volumes of traffic on the local road network;
- Loss of rate revenue, leading to rates increases; and
- Potential for extensive wild fire.

Accounting for forestry in the water budget

Until now the small but steady increase in the area of the forest estate has been accounted for in the setting or revision of permissible annual volumes for the management zones of the South East. The amount of water made available for distribution among water allocation licensees has been adjusted down to account for the very small or nil recharge beneath plantation forests.

Accommodating the expansion in forestry in groundwater zones

A range of options has been suggested through the community consultation on Water Allocation Plans recently conducted by the South East Catchment Water Management Board (2000). The options and their effects can be summarised in the table below.

requirement on the forestry sector to take account of its effect on the water balance until these flow are harnessed;

- A hierarchy of land uses should exist, with forestry high on the list. If forest expansion causes reductions in PAVs, then licensees should take cuts to their allocations as they are opportunistic exploiters of a natural resource;

Effect of option on:	Option 1. Forestry remains independent of the water management framework	Option 2. Forestry restricted by zoning to plant in groundwater areas not already fully allocated	Option 3. New forestry plantings required to retire a water allocation volume equivalent to the recharge intercepted
Forest investors	Nil	Restricted land available, potentially higher land prices	Some restriction in land available for acquisition, and requirement to own an unused water allocation.
Existing forest owners	Nil	Nil. Accounted for in setting the PAV	Nil. Accounted for in setting the PAV
Existing groundwater licensees in partially allocated zones	Nil	Nil	Nil
Existing groundwater licensees in fully allocated zones	Reductions in licence volumes, continued uncertainty	Nil	Nil

The reaction of the forestry sector

The forestry sector has responded to the issue in two ways. Firstly it has taken a responsible approach in sponsoring and joint funding of investigations to quantify the effects of forests on the groundwater budget of the South East. It has also been an active participant in water allocation planning.

Secondly, to some extent the sector has advanced defensive arguments that can be summarised as follows:

- The region was originally covered in deep-rooted perennial vegetation, so forest expansion should not be hindered in any way in causing a partial return to this land use;
- The forestry sector should not be singled out in the land use change debate, as there is considerable change within the agricultural sector which also has an effect on the groundwater balance;
- The South East's drainage system carries significant volumes of water out to sea, so there should be no

- The science describing the effects of forestry is too incomplete, so no restraint on forest expansion should be applied until there is more substantial evidence that forests do intercept recharge or use water from an aquifer; and
- If land use change is not addressed within the agricultural sector, then the forestry sector should not be required to adjust for it.

There is a growing urgency for the forestry sector, the water planning bodies, the regulation agencies, and the water using industry sectors to collaboratively devise a framework for balanced water management in which all interests can be accommodated.

Recommendations

The salient issues emerging from the foregoing discussion of forestry, land use change and water management prompt the following key recommendations:

- That gaps in information on the effect of conversion of agriculture to plantation forestry on the surface water and groundwater resources of the study area be addressed;
- That the probability, extent and effect of groundwater use by plantations, particularly blue gums, be assessed and the hydrological effects modelled;
- That the water resource management implications of changes within agriculture away from traditional enterprises be quantified and modelled;
- That the social and economic effects of land use change be modelled at the conclusion of the SW Victorian study; and
- That there be a well-designed process to enable productive and non-divisive discussion to develop a practical and fair water regulatory framework to provide certainty to both water-using industries and the plantation forestry sector.

Conclusion

Dramatic expansion of forest plantations in the South East of South Australia and the South West of Victoria is a new phenomenon. It holds significant opportunity through regional investment and the potential for value adding. It also has a significant role in the natural resource management in large areas of the two catchments, particularly in addressing waterlogging, dryland salinity and ecosystem decline.

The impact on the surface and groundwater resources of the area of plantation expansion at such a rate and scale is unquantified. Also unresolved is the framework in which the following can be achieved: continued investment in forestry, reasonable certainty for the

water-using industry sectors, sustainable water resources management, and positive ecological outcomes.

The challenge for all players is to expeditiously find the right mechanisms or face regulation or ruin. The challenge for water resource managers is to develop management systems that take account of all parts of the water cycle, not just extractive uses.

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6

Manipulating Catchment Water Balance Using Plantation and Farm Forestry: Case Studies from South-Western Australia

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Three case studies are presented that describe the use of plantations and farm forestry in south-western Australia to tackle the problems of maintaining water supply and overcoming dryland salinity. The approaches we describe have both geographic and temporal components. The case studies are (1) the revegetation of partially cleared catchments with rainfall $>600 \text{ mm yr}^{-1}$ to protect surface water supplies from salinisation; (2) the recent widespread establishment of *Eucalyptus globulus* (Tasmanian blue gum) plantations on mostly cleared farmland with rainfall $>600 \text{ mm yr}^{-1}$; and (3) the extension of farm forestry into lower (300–600 mm yr^{-1}) rainfall areas.

Dryland salinity results from an increase in infiltration and drainage to groundwater systems following replacement of natural vegetation with shallow-rooted annual agricultural plants. Revegetation can restore the hydrological balance, but given the current scale of and increase in salinity in this area, with 6 M ha eventually likely to be affected, this will have to be extensive. Several issues need to be confronted before such revegetation. These include (a) social and economic considerations; (b) integrating the trees with agriculture; (c) resolving technical issues associated with establishing trees on farmland; and (d) the development of economically viable tree crop industries to promote adoption.

Some of these issues have been resolved for Tasmanian blue gums, but in many cases these have been established as broad-scale plantations and the problems associated with integration have been avoided. Potential constraints on the long-term sustainability of the Tasmanian blue gum industry include (a) a reduction in yield with declining rainfall; (b) the ever-present risk of drought in a Mediterranean climate; and (c) the depletion of stored soil water in the first rotation with likely consequences on second-rotation yields. In low-rainfall areas commercial farm forestry options do not yet exist but are required at a scale of 2–3 M ha. Here the challenges are to develop tree-based industries that deliver both profits and environmental benefits.

Introduction

Two of the major issues confronting Western Australian natural resource managers are the provision of water for an expanding economy and the relentless salinisation of water resources, agricultural soils and remnant natural eco-systems. In south-western Australia potable water is derived from two sources: groundwater from aquifers on the Perth Basin and surface water from forested reservoirs on the granitic Darling Plateau. This surface water flows in relatively short streams that originate in catchments with almost complete forest cover and generally with rainfall $>900 \text{ mm yr}^{-1}$. Catchments that extend into areas with $<900 \text{ mm yr}^{-1}$ or have any substantial area of cleared agricultural land are invariably affected by salinity. The

link between land clearing and salinity is well established (Wood 1924; Schofield 1992).

As well as threatening the quality of water from key catchments, dryland salinity currently affects 1.8 M ha of Western Australian farmland, a figure projected to increase to 6 M ha in the absence of intervention (Ferdowsian *et al.* 1996). Moreover, salinity threatens remnant natural ecosystems and rural infrastructure and increases the risk of flooding. It is estimated that 480 species might become extinct in the south-west of WA as a result of salinity (pers. comm., G. Keighery, CALM).

Plantations and farm forestry have the potential to restore the hydrological balance, to ensure sustainable supplies of fresh water and minimise the extent of

dryland salinity (Schofield 1992). We define plantations in this context as broad-scale revegetation irrespective of previous land-use. Farm-forestry is where an attempt has been made to integrate the revegetation with agriculture. While it is clear that revegetation is needed for sustainable land management (Shea and Bartle 1988) the investment needed is massive. Although the task is daunting, a range of approaches has encouraged investment in farmland revegetation (Shea and Hewett 1997).

In this paper we use three case studies to review the use of plantations and farm forestry in south-western Australia to tackle the problems of maintaining water supply and managing dryland salinity. These are:

- (a) The revegetation of specific, partially cleared catchments with rainfall $>600 \text{ mm yr}^{-1}$ to protect surface water supplies from salinisation.
- (b) The recent, more widespread revegetation of agricultural land in areas with rainfall $>600 \text{ mm yr}^{-1}$. In particular, we describe the rapid expansion of *E. globulus* plantations on farmland, review the soil and climatic factors controlling growth, and outline several future challenges that may confront this industry.
- (c) The current developments in extending farm forestry into areas with rainfall $<600 \text{ mm yr}^{-1}$. Here, salinity is most extensive and the major challenge is to develop new, profitable tree-based industries and encourage integration of trees into agricultural systems over large areas.

We do not consider cases where plantations have been managed to maintain recharge over groundwater supply areas, as this has been well described elsewhere (see for example Butcher 1979). Although the paper has a Western Australian focus many of the themes are relevant to issues elsewhere in Australia.

Physical environment of south western Australia

Land use and climate

South-western Australia has a Mediterranean environment, characterised by a predominance of winter rainfall and an annual summer drought. The annual rainfall ranges from 1400 mm in the south-western corner to around 250 mm at the limit of agriculture. Similarly, annual pan evaporation varies from 1200 mm on the south coast at Albany to 2600 mm at Geraldton, near the northern extent of agriculture (Luke *et al.* 1987).

The area developed for agriculture comprises 18 M ha of the total land area of 24 M ha. The remainder comprises natural vegetation systems, managed either for wood production or as conservation reserves. Much of the farming of this area is reliant on annual rainfall, with dryland farming systems comprising rotations of

wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) or grain-legume (*Lupinus angustifolius*) crops and annual subterranean clover (*Trifolium subterraneum*) or blue-lupin (*Lupinus consentinii*) pastures.

Geology and geomorphology

The geology and geomorphology of south-western Australia has been reviewed (Geological Survey of Western Australia 1990). For the purposes of this paper, we consider two major types of terrain each characterised by distinct hydro-geological systems:

Granitic terrain: The region is dominated by the Archaean Yilgarn Craton, and adjacent Proterozoic zones, which extend approximately 400 km north-south and over 600 km east-west, and are mainly comprised of granitic basement rocks. Dolerite dykes have often intruded the Archaean granites, but these are of limited total area.

Sedimentary terrain: The Yilgarn Craton is bounded to the west by the sedimentary Perth Basin. The surface expression of Perth Basin is the 20-30 km wide and 300 km long Swan Coastal Plain, which is comprised of a series of remnant quartzose beach ridges, alluvia associated with rivers, and the Victoria Plateau, which lies between the coastal plain and the Yilgarn Craton. The Plantagenet Beds comprise a range of Tertiary sediments that occur as a thin veneer over the southern margin of the Archaean and Proterozoic basement, extending from Northcliffe to Esperance, and up to 50 km inland.

Both granitic and sedimentary rocks have been strongly weathered, possibly under a previous tropical climate, resulting in deep weathering (laterite) profiles often 30-50 m deep and a surface cover of sands and ferricrete gravels (Mulcahy 1973). Together this material is described as regolith. Along the western and southern margins of the Yilgarn Craton, drainage lines are prominent and the regolith has been variably stripped, the extent depending on the local drainage patterns. In some river valleys, the regolith has been completely removed and basement rock exposed, whereas in other valleys only partial removal of the regolith has occurred. In inland lower-rainfall areas the drainage lines are less competent and landscape stripping is less complete than at the western margins. Here the gently undulating landscapes comprise deeply-weathered materials and their weathering products (Mulcahy 1973).

Hydrogeology and salinity

The regolith encompasses several interacting aquifers often including a shallow, seasonally perched system, a local semi-confined aquifer and a deeper confined regional system (George *et al.* 1997). The regolith also contains a store of salts derived from rainfall (Hingston and Gailitis 1976). These salt stores tend to increase from 100 t ha^{-1} (to bedrock) on the western edge of the

Yilgarn Craton to $\sim 1000\text{--}10\,000\text{ t ha}^{-1}$ in inland areas (Schofield and Ruprecht 1989).

Under natural vegetation, where most annual rainfall is utilized by the vegetation, the level of permanent groundwater in the profile is low and the salt store is relatively immobile. Conversion to shallow-rooted, annual agricultural plants has profoundly changed the water balance of the landscape. Annual water use by vegetation has decreased as growth and water use are confined to the low evaporative conditions of winter to spring, resulting in leakage beyond the shallow root-zone of annual plants. Furthermore, the annual plants do not utilise irregular summer rainfall. Estimates of leakage of water from the agricultural systems range up to 200 mm yr^{-1} (Johnston 1987), with a value of around 25 mm yr^{-1} regarded as average (George *et al.* 1997). Increased groundwater recharge and rising groundwater tables result in the mobilisation of stored salt and its redistribution towards the soil surface.

Case Study 1: revegetation of surface water catchments

The Helena Catchment

The Helena Catchment (in the Darling Plateau 30 km east of Perth) was dammed with the Mundaring Weir in 1903 as part of a scheme to provide water to Kalgoorlie, 550 km inland. The catchment occupies an area of 1490 km^2 and has an average annual rainfall ranging between 600 and 1100 mm. Consecutive dry years in 1902 and 1903 reduced catchment yield and in an attempt to maintain the water supply from the reservoir, trees were ringbarked. Although stream-flow increased, turbidity increased and reservoir salinity rose to 550 mg L^{-1} . To remedy the situation, regrowth forest was allowed to develop and *Pinus radiata* plantations were established; turbidity and salinity levels in the reservoir slowly decreased (Stokes and Batini 1985).

Agricultural clearing commenced in 1948 in the 5% of the catchment in private ownership, with half this area cleared by 1978. State-owned forest was also cut extensively to supply charcoal from 1960 onwards. In the latter half of the 1960s, stream salinity in the main tributary draining the northern half of the catchment started to increase, reaching annual average values of 1000 to 2000 mg L^{-1} by the mid 1970s. Further clearing was controlled by legislation in 1978. The Government purchased mostly forested, private land and the cleared parts were revegetated. Since 1978 30% of the cleared area has been revegetated. Hydrological analysis indicates that reductions in stream salinity following revegetation occur 10–12 yr after the revegetation. Salinity is currently $\sim 1200\text{ mg L}^{-1}$ but the current rate of decrease of $15\text{ mg L}^{-1}\text{ yr}^{-1}$ may not be sustainable without further revegetation.

The Collie Catchment

The Collie Catchment occupies 2830 km^2 and annual rainfall ranges from 600 in the east to 1300 mm in the west. Half of the 100 000 ha of freehold land in the catchment was cleared of native vegetation before the Government legislated to control the release of Crown Land (1961) and to control native forest clearing (1976). As a result, salinity of the Collie River upstream of Wellington Reservoir was increasing at a rate of $42\text{ mg L}^{-1}\text{ yr}^{-1}$ (Schofield *et al.* 1988). It was estimated that if no further action were taken, salinity would rise to a flow-weighted mean value of 1500 mg L^{-1} . Large-scale acquisition of private land and revegetation of the catchment commenced in 1979. To date, the Government has planted 6740 ha and private owners have replanted additional areas.

In the mid-1970s, a series of five experimental catchments was established within the Collie Basin to determine the processes causing salinity (Williamson *et al.* 1987). Treatments included the clearing of native forest in catchments in contrasting rainfall zones with 1200 mm yr^{-1} and 800 mm yr^{-1} , and comparing groundwater responses in these areas with uncleared controls. Groundwater and stream-flow of the planted areas were monitored in addition to stream-flow and salinity of the major tributaries. This work (Holmes and Talsma 1981; Peck and Williamson 1987) demonstrated the strong association between land clearing and salinity and provided details of the local influences of vegetation type, preferred pathways and soil properties on catchment hydrology. It has led to an improved understanding of salinity processes and provided data to underpin rehabilitation strategy.

Reforestation Trials

During the late 1970s and early 1980s, experimental trials in both catchments were established to quantify the effect of revegetation strategies on groundwater levels and stream salinity (Bari and Boyd 1992). The sites in the Helena catchment (Flynn's Farm), the Collie catchment (Stenes) and Maringee Farms can be categorised into four groups; lower slope and discharge plantings (35% of cleared area revegetated), wide-spaced plantations (54%–57% revegetated), strips and small blocks strategically placed near streamlines and seeps (8% and 14% revegetated) and dense plantations (54%–70% revegetated). Measurement of groundwater levels, stream-flow and salinity indicate that the reduction in groundwater levels depends primarily on the area of trees planted and crown cover rather than the particular revegetation strategy (Bell *et al.* 1990).

The studies have demonstrated the difficulties associated with optimising the relationship between water yield and water quality. In low-rainfall areas, clearing releases salt from the regolith to streams. Revegetation may not halt the mobilisation of salt but does reduce the rate at which salt is discharged into downstream waterbodies. In contrast, in high-rainfall

areas the regolith is less saline and revegetation can decrease the yields of non-saline water. Understanding the catchment processes, and in particular the sources of salinity (both in terms of salt concentration and load), has allowed catchment remediation to be targeted to where it will be most effective, rather than using a generic approach across the whole catchment.

Case Study 2: revegetation of farmland in the >600 mm rainfall zone with Tasmanian blue gums (*Eucalyptus globulus*)

Clearing is extensive in the >600 mm yr⁻¹ rainfall zone and salinity more widespread. Despite an expectation that tree planting could restore an appropriate hydrologic balance, tree planting was limited (Shea and Hewett 1997). Impediments to tree planting included (a) the need to use trees without displacing agricultural enterprises and associated rural communities; (b) incomplete knowledge of the extent of tree planting necessary to restore water balances; (c) uncertainty about whether recharge or discharge area plantings were more effective; (d) an array of technical issues, associated with the move onto farmland (such as insect and weed control, establishment techniques, site selection and nutrition); and (e) obtaining investment to plant trees at the required scale.

Initially agroforestry was advocated with the expectation that the trees would reduce salinity and provide an income in their own right (Shea and Bartle 1988). Marketable commercial species capable of producing a return in a short rotation (10–12 yr) were sought; rotation length was crucial due to the high interest rates prevalent in the late 1980s. *E. globulus* had performed well in experimental plantings, was already planted over large areas on the Iberian Peninsula and was thus promoted as a profitable means of restoring the hydrologic balance (Shea and Hewett 1997). Based on overseas and local investment, *E. globulus* plantations on farmland have become a major industry in south-western Australia with about 153 000 ha established in the last 10 yr; this represents a dramatic acceleration of plantation establishment in Western Australia.

As available water is the principal determinant of *E. globulus* productivity, managing for maximum sustainable growth will also maximise the hydrologic impact of these plantations (Edwards and Harper 1996). There will always be a trade-off between productivity and risk in a climate where drought is an annual event. Faster growth will increase the risk of drought deaths and *E. globulus* must therefore be managed to ensure survival. The effect of drought on tree mortality is largely a function of total stored water, which can be estimated from soil volume. Strong relationships have been established between soil volume and drought deaths in *Pinus radiata* (McGrath

et al. 1991) and *E. globulus* (Harper *et al.* 1998). Where soil water storage capacity is limited, tree deaths often occur during autumn, for example, deaths of *P. pinaster* occurred in the late 1940s and 1980s, of *P. radiata* in the 1960s, 1970s and 1980s and of *E. globulus* in the mid-1990s. Such events have prompted revision of site selection and silvicultural prescriptions.

There are strong climatic effects on growth, with a marked increase with increasing rainfall and decreasing evaporation. Estimated mean yields at 10 yr across the 600–800 mm yr⁻¹ rainfall zone are 160 m³ ha⁻¹, with low pan evaporation (<1500 mm yr⁻¹), and 130 m³ ha⁻¹ with high evaporation (>1500 mm yr⁻¹), whereas in higher rainfall (>800 mm) areas with low evaporation likely yields are around 250 m³ ha⁻¹ (Harper *et al.* 2000a). Other factors that affect the growth of *E. globulus* plantations include soil volume, soil fertility and stocking (Harper *et al.* 2000a). This analysis also suggests that both the location of trees in the landscape (slope position) and planting conformation (strips integrated with farming) will become more important in areas with decreasing rainfall and increasing evaporation. The sensitivity of *E. globulus* to salinity has also been demonstrated (Bennett and George 1995) and the species cannot be planted on discharge areas.

The rapid growth of *E. globulus* in the first rotation is at least partially attributable to water and nutrients accumulated under agriculture. The efficiency with which *E. globulus* has depleted the stored water built up under agriculture has been demonstrated by deep drilling beneath 8-yr-old *E. globulus* that showed water has been depleted to depths of up to 9 m (Crombie and Harper, unpublished; Smettem *et al.* 1999). The implications of this depletion of stored water are likely to be a greater risk of drought death and a depression of yield in the second rotation. The strong linkage of tree growth and survival to annual rainfall indicates the efficiency of trees in both depleting the stored water reserves in the profile and capturing all incoming rainfall; this demonstrates the key role trees can have in reducing recharge to groundwater.

Case Study 3: revegetation of farmland in the <600 mm rainfall zone

Revegetation of the <600 mm yr⁻¹ rainfall zone of south-western Australia poses major challenges. Although this is the region where the most rapid and extensive deployment of trees is required to combat dryland salinity (State Salinity Council 2000), a range of technical and socio-economic issues has impeded adoption of trees. These include uncertainty about productivity and financial returns, poorly-developed markets for products, poor understanding about where to plant trees for best hydrological impact and perceived conflicts with agricultural activities. It is

worth reflecting that similar concerns prevailed at the onset of the *E. globulus* industry.

The development of commercially-viable revegetation systems that provide hydrological benefits is necessary for widespread adoption by land-holders. Economic analysis of these systems should also account for off-farm benefits such as reduction of land degradation, rather than simply comparing the on-farm returns from trees with standard agricultural practice.

To this end CALM is involved in developing new tree-based industries in this region. It has entered partnerships to plant *P. pinaster* in the 400–600 mm yr⁻¹ rainfall zone, both for timber and carbon sequestration (Shea 1998) and is developing mallee eucalypts (<600 mm yr⁻¹) for industrial oil, activated carbon, carbon sequestration and bioenergy (Bartle 1999). Cumulative areas planted to date are 11 800 ha and 9 000 ha, respectively.

While a number of options exist for the integration of trees into the agricultural areas of southern Australia, here we consider three of the most prospective options for broadscale revegetation (strategic placement of trees within catchments, integrated tree belts or alley farming, and phase farming with trees).

Strategic placement of trees

Where vegetation is seasonally water-limited, such as in the <600 mm rainfall zone, it will arrive at a leaf area index that is independent of species and in equilibrium with available water (Specht 1972; Hatton *et al.* 1998). Although complete revegetation will prevent further recharge, it is a costly solution. The challenge is to maximise the hydrologic impact of trees and generate the greatest return from tree planting.

There is some debate over the interaction between landscape positioning of trees and the proportion of catchments that need to be replanted with perennials to control recharge. The use of strategic plantations to intercept lateral flow appears limited to a few highly specific situations where trees can intercept relatively fresh groundwater (George 1990). Where trees can only prevent recharge, their lateral influence on water tables is quite limited. Indeed, after reviewing groundwater measurements at 80 sites, George *et al.* (1999) concluded that trees might need to occupy up to 80% of the landscape to prevent further drainage to groundwater. The view that trees have only a local effect on hydrology is consistent with measurement of groundwater levels under trees and adjacent farmland (e.g. Lefroy and Stirzaker 1999). The issue of the extent of lateral influence of trees, in the undulating terrain that comprises 60% of this region, has not been conclusively resolved for all areas of the wheatbelt (Bartle 1999).

Hatton and Dawes (2000) used the ecohydrological model WAVES and long-term rainfall records for Merredin (320 mm yr⁻¹ rainfall), and predicted a strong

influence of soil texture on recharge under crops. Predicted recharge ranged from 1 mm yr⁻¹ for clayey profiles to 100 mm yr⁻¹ for deep sandy profiles. This suggests that tree planting should target particular areas of farms for maximum recharge control.

Another debate has centred on the relative benefits of recharge compared with discharge plantings. Morris and Thomson (1983) demonstrated that trees planted in recharge areas were more effective in controlling salinity. The limited long-term impact of discharge plantings was demonstrated in multi-species eucalypt plantations on salt seeps after 15 yr (Greenwood *et al.* 1994). A tree plantation established on lower hill-slopes in and adjacent to a discharge area at Boundain showed initial decreases in watertable levels in the first five years, but increasing groundwater salinity under trees suggests future problems for their long-term survival (Stolte *et al.* 1997). Despite this increasing salinity these trees are now 20 yr old, and so the extent and time involved in root zone salinisation needs to be further investigated. It is important to understand the local hydrology prior to planting trees.

Although current practice suggests planting on recharge areas that often comprise the best agricultural land, the resultant trade-offs between using productive agricultural land for trees to save land down-slope has to be considered. Again, as demonstrated for *E. globulus*, direct returns from trees will offset the loss of land for cropping.

Trees planted on recharge areas must be integrated with agriculture. In south-western Australia, where cropping is the major economic activity, there are two principal options:

1. Permanent tree belts or 'alleys' (Lefroy and Stirzaker 1999), or
2. Trees in any planting design (blocks, strips) that are rotated across the landscape (Harper *et al.* 2000b).

Integrated tree belts or alley farming

Challenges with the placement of belts include determining whether they will intercept water either by lateral extension of roots, or through interception of down-slope flow. Developing this understanding will allow issues such as the spacing between belts to be optimized for different conditions, and help to resolve the number of tree belts necessary to account for the recharge under annual crops. This approach may also require the characterization of site attributes such as hydrology, and soil hydraulic gradient and conductivity. Alley width in any case will be constrained by a minimum width to allow the passage of machinery. In this region, where annual crops are sown as soon as possible following 'opening' autumn rains, using large machinery, there is an absolute minimum alley width of 40–60 m.

Water-use measurements on tagasaste (*Chamaecytisus proliferus*) integrated in 30 m rows with lupins and oats on profiles with 10 m of sand overlying clay indicate that soil water extraction was confined to 4 m either side of the tree rows (Lefroy and Stirzaker 1999). Calculations based on crop and tree water use, without any interaction between the root zones of the two, indicate that 24% of the catchment needed tree cover to prevent further water table rise, assuming all trees had access to the perched fresh watertable. This however was a species with a low leaf area index due to grazing. There are few field measurements of water use and productivity of alley farming systems, particularly in the valley floor soils, where subsoils are clayey and highly likely to be saline.

The lateral extension of tree roots from the belts increases water use, but this is at the expense of crop production. Management of integrated tree and crop systems requires a balance between productivity and water balance objectives. This will be difficult to achieve in the lower-rainfall areas where competition for soil water between trees and crops will be greatest. The development of tree species that provide a commercial return in their own right, such as mallee eucalypts, is necessary to offset direct and indirect reductions in crop or livestock production.

Phase farming with trees

An alternative approach is to rotate short-rotation tree crops with agriculture in 'phase farming with trees' (PFT), designed to grow trees at high planting densities in very short rotations (3-5 yr) (Harper *et al.* 2000b). These would rapidly deplete water in farmed catchments at risk of salinity, by utilising soil water while producing useable products such as wood fibre and biomass. The tree phase is followed by an agricultural phase of a length defined by the persistence of the hydrological buffer to recharge created by the trees drying out the soil profile to depth. Other potential benefits of this approach include improved soil structure and provision of a break in disease cycles and disruption in weed cycles. Production of large amounts of biomass suitable for electricity could decrease Australia's emissions of Greenhouse gases.

The biophysical feasibility of the system has been modelled using WAVES (Hatton and Dawes 2000). This analysis suggests that the premise of the PFT system (*viz.* depletion of sub-soil moisture reserves under trees and subsequent recharge under agriculture) is realistic. In areas with deep, root-penetratable regolith, PFT may reduce overall recharge and provide storage for out-of-growing-season rainfall while allowing the continuation of farming. This analysis also suggests different tree-planting strategies are needed according to broad differences in soil and hydrological conditions. For example, although sites with deep soil profiles could be treated with PFT, other sites may be less suitable. Deep sandy soils and soils with an accessible fresh groundwater table may require

permanent revegetation, whereas sites with low recharge rates may not need revegetation at all.

Conclusions

The capacity of tree plantings to slow or reverse salinisation of land and streams, by restoring the water balance to something approaching the situation prior to clearing, has been demonstrated for a number of catchments in southern WA. Two major challenges to broadscale planting of trees are the capacity to locate and arrange the tree planting to achieve the required hydrologic benefit, and to develop the economic drivers to facilitate the extensive replanting that appears necessary to achieve a reduction in salinity. An enormous investment in tree planting will be necessary to manage salinity over the Western Australian agricultural area of 18 M ha, 2.1 M ha of which are already salt affected. Revegetation of 20% of the landscape over a 10-yr period would require an annual planting program of 360 000 ha. Perspective is brought to the scale of this undertaking by considering that the annual rate of *E. globulus* planting is around 30 000 ha in an environment where economic returns are demonstrable. Thus any tree-based solutions to salinity will clearly require products that fit into mass rather than niche markets.

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7

Revegetation for Salinity Management in the Macquarie Valley: A Case Study in the Murray-Darling Basin

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The Murray-Darling Basin Commission (MDBC) Basin Salinity Audit released in October 1999 predicted that Macquarie end-of-valley salinity would exceed the desirable limit for drinking water of 800 EC within 20 yr, and the 1500 EC threshold for healthy wetland ecosystems within 50 yr. Major community values and assets are at risk of serious damage from salinity, especially in the mid-to-lower catchment. Preliminary end-of-valley salinity targets have been proposed to protect the values and assets. Revegetation appears to be an attractive option for meeting targets, but it needs to be well designed and strategically targeted to minimise unintended impacts on surface water flow and river salinity. The net effect of large-scale plantation forestry in the high-rainfall upper catchment could be negative in the short term because of the loss of dilution flows. Revegetation in medium-rainfall mid-catchment areas appears to be a better option.

Introduction

The Macquarie River is the largest river in Central Western New South Wales, flowing north-west from Oberon (34°S) to the Darling River (30°S). Average annual rainfall ranges from more than 900 mm in the upper catchment at Oberon, to 600 mm in the mid-catchment at Dubbo, to less than 350 mm in the lower catchment. Topography ranges from hilly in the upper catchment on the western side of the Great Dividing Range, to the gentle slopes of the mid-catchment, to the flat plains of the lower catchment. Soils are mainly yellow/red duplexes and sands, with some loams.

There are two major water storages in the Macquarie Valley, Lake Burrendong and Lake Windemere, which provide domestic and irrigation supplies. The Macquarie River is regulated downstream of Lake Burrendong until it enters the Macquarie Marshes. The Macquarie meets the Castlereagh River north-west of the Marshes before flowing into the Darling River.

The Macquarie Valley is home to around 204 000 people. There are about 75 630 jobs in agriculture, forestry, mining and tourism. The Valley produces 11% of New South Wales' agricultural output, with the gross value of irrigated crops such as cotton and wine grapes totalling more than \$800 M in 1996 (pers. comm. J. McAloon, NSW Department of Land and Water Conservation, Sydney 2000).

Revegetation for salinity management

Salinity impacts

Salinity has been a problem in the Macquarie Valley for many years, and there has been increasing community and government effort to address it. The then Central West Catchment Management Committee completed a Salinity Risk Assessment of the Macquarie, Bogan and Castlereagh Valleys in March 2000 (Humphries 2000). A large proportion of the Macquarie Valley was assessed as having high to very high salinity hazard, based on seven biophysical data layers.

The Macquarie was also studied in the Murray-Darling Basin Salinity Audit (Murray-Darling Basin Ministerial Council 1999), which predicted that in a 'business as usual' scenario:

- End-of-valley salt loads would double by 2020 and treble by 2100;
- End-of-valley salinity would exceed 800 EC by 2020 and 1500 EC by 2050;
- Water supplies for twelve urban centres with a combined population of 65 000 people are at risk; and
- Salinity in the Macquarie River as it enters the Ramsar-listed Macquarie Marshes would rise to 2110 EC by 2100, which would cause significant impacts including loss of species diversity.

A recent Basin-wide study into the costs of salinity (Ivey ATP 2000; pers. comm. A. Wilson, Central Tablelands Farm Forestry Project, Bathurst, 2000) estimated that in the Macquarie Valley current salinity impact costs on urban households and businesses, agricultural landholders and local government total about \$30 M yr⁻¹.

Capacity to address salinity

A general overview of the social and economic constraints to salinity management was undertaken as part of the Central West Catchment Management Committee's Salinity Risk Assessment. The primary issues of concern to respondents were profitability of enterprises and shifts in commodity markets. Significant constraints to action to address salinity were identified as a lack of economic incentives, a lack of environmental awareness amongst landholders, and a lack of confidence to change land management practices. From a catchment perspective, overwhelming support was given for government incentives to assist landholders to adopt new management styles.

The above findings are consistent with other socio-economic studies in salinised catchments of the Murray-Darling Basin which suggest that in less-favoured areas (in terms of soils, climate, rainfall etc.), there is little capacity for landholders to invest in long-term sustainability. Established broadacre industries tend to return low profits, landholders are aging, and even with off-farm employment total household income is low. In some localities, up to 30% of the population is reliant on welfare, and up to 48% of children under the age of 15 are living in chronically poor families (Anon. 1999).

Government salinity responses

The New South Wales Government convened a Salinity Summit in March 2000, which recommended that a coordinated State-wide strategy be developed urgently and pursued vigorously. The Strategy was released in August 2000 and it includes setting targets; market-based solutions and strategic investment; salinity-related business opportunities; regulation; government advice; information; scientific knowledge; and planning systems.

The Murray-Darling Basin Ministerial Council (representing the six governments of the Basin working in partnership) has decided to develop a Basin Salinity Management Strategy to coordinate salinity management across the Basin States for Basin outcomes. A draft Basin Salinity Management Strategy was released for public comment by the Ministerial Council in September 2000. It is a strategic Basin-wide response comprising:

- A framework for State salinity strategies, catchment management strategies, and Land and

Water Management Plans to work together for common objectives;

- Adoption of water quality targets to drive catchment management focussed on key values and assets at risk;
- A program of landscape change and engineering works to give greater certainty of outcome; and
- Clear responsibilities and accountabilities for partner governments.

A final Basin Salinity Management Strategy is expected to be considered by the Ministerial Council in March 2001.

Macquarie Valley revegetation activities

Revegetation activities in the Macquarie Valley include an initiative between Macquarie River Food and Fibre (MRFF, which represents 600 irrigators), New South Wales State Forests (NSWSF), the Central Tablelands Farm Forestry Project, and the Australian Bureau of Agricultural and Resource Economics (ABARE) to model the salinity outcomes of converting grazing land to plantation forestry. These activities are discussed below.

Under a Memorandum of Understanding with NSWSF, MRFF intends to purchase salinity control credits based on the quantity of water transpired from 100 ha of newly-planted forest. Irrigators in MRFF expect to benefit from their investment by securing irrigation water quality, and those benefits are expected to flow on to the whole water-using community of the Macquarie Valley. The New South Wales Department of Land and Water Conservation (DLWC) is working with NSWSF and MRFF to identify suitable plantation forestry sites (Anon. 2000).

The Central Tablelands Farm Forestry Project is being managed by the Central West Regional Development Board in collaboration with the Central West Regional Plantation Committee, DLWC, and CSIRO Forestry and Forest Products (pers. comm. A. Wilson, Central Tablelands Farm Forestry Project, Bathurst, 2000). The Project is:

- Investigating recharge plantings in 400-650 mm yr⁻¹ rainfall areas in the Macquarie Valley;
- Investigating management options for privately-owned cypress pine/hardwood native forest;
- Exploring the potential for 30 000 ha of timber and biomass energy plantations;
- Considering pooling investment funds to establish and manage the new plantations; and
- Developing regional planning for optimal outcomes, from both regional economic development and salinity management perspectives.

The Murray-Darling Basin Commission is involved in a joint project with ABARE to develop a Basin-scale

modelling framework to assess the economic and salinity outcomes of plantation forestry. As part of this Basin project, ABARE, in collaboration with the Cooperative Research Centre for Catchment Hydrology, has carried out developmental model runs in the Macquarie Valley (Beare and Heaney 2000). Using the best available understanding of hydrogeology, preliminary results from the model runs indicate that if 417 000 ha of grazing land in the upper catchment is converted to plantation forestry, then after 100 yr of 30-yr rotations:

- The area of land affected by high watertables would be largely unchanged from the grazing scenario;
- Despite reductions in salt loads, lower surface water yields would cause higher instream salinities relative to the grazing scenario;
- The cost of the plantation forestry option would be almost \$50 M (Net Present Value) greater than the grazing scenario; and
- Catchment surface water yields would reduce by 200 ggalitres.

Discussion

The preliminary ABARE results need to be interpreted with caution, as they are based on establishing plantation forests over a large proportion of the high-rainfall (up to 900 mm) upper catchment area, which is separate from the medium-rainfall (around 600 mm) mid-catchment area most affected by and at risk of future salinity. In addition, the results are based on a relatively coarse-scale understanding of hydrogeology, and limited knowledge about how plantation forests would perform in the upper Macquarie, particularly in terms of survival and growth.

Local knowledge of hydrogeology in the Macquarie Valley, the development of improved grazing systems, and emerging prospects for timber and biomass energy plantations in medium-rainfall areas, suggest that revegetation is feasible as an option for protecting high-value community assets in the mid-Macquarie and for contributing to end-of-valley salinity targets. Furthermore, there are indications that carefully planned revegetation will not necessarily compromise catchment water yield, dilution flows and river water quality. This balancing act will require locality-scale modelling and careful planting design and siting to ensure that revegetation has maximum effect on groundwater recharge with minimal loss of surface water yield.

Priority locations for revegetation are likely to be recharge areas in localities where salinity poses a serious threat to rivers or other high-value community assets; large amounts of salt are being mobilised by rising watertables; groundwater salinities are high; there is a high level of confidence that revegetation will deliver the salinity outcomes required within

satisfactory timeframes and without compromising catchment water yield and river flows; revegetation is considered to be the most cost-effective option available; and the social effects of revegetation are acceptable to communities.

Where to from here?

We have a good appreciation of the potential salinity impacts on key community values and assets if nothing is done to manage salinity in the Macquarie Valley. ‘Business as usual’ is not an option. While broadscale revegetation appears attractive as a salinity management option, and a range of revegetation initiatives are under consideration in the Macquarie Valley, the results of revegetation-related investigations and modelling to-date are equivocal about its net effects. Revegetation needs to be strategically positioned in catchments to avoid possible adverse effects on river water quality and flow. The salinity strategies developed by the New South Wales Government and the Murray-Darling Basin Commission will assist Macquarie Valley stakeholders to work through these issues. The strategies provide support for:

- **Developing decision support systems for revegetation**, utilising knowledge and understanding from geophysical investigations to map salt stores in the landscape; hydrogeological investigations into water-driven salt mobilisation processes; forest hydrology investigations into groundwater recharge and surface water yield; forest management and market development; and socio-economic and socio-demographic data;
- **Institutional change and integrated catchment modelling frameworks** to give stakeholders the capacity to assess the level of intervention required to achieve within-valley and end-of-valley salinity targets; balance the need to meet salinity targets against other natural resource management targets (e.g. environmental flows) and social and economic needs; and to plan and implement salinity management in the context of regional development; and
- **Instruments and schemes to support revegetation** as part of planned structural adjustment and regional development, including financial investment vehicles, auctions, tax concessions, grants and possibly levies.

Conclusions

The Macquarie Valley, like many other tributaries in the Murray-Darling Basin, is facing serious salinity impacts within 20 yr if concerted action is not taken to manage it. Key community values and assets, including water for the city of Dubbo, water for high-value irrigation industries, and environmental values of the Ramsar-listed Macquarie Marshes, are threatened.

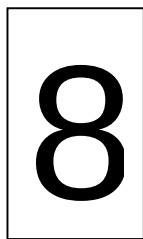
Revegetation appears feasible as a salinity management option, particularly in the mid-catchment which is more at risk of salinity than the upper catchment. A number of innovative forestry initiatives are underway, including consideration of timber and biomass energy plantations. However, preliminary results of sub-regional-scale modelling suggest that large-scale revegetation for salinity management may have unintended negative effects on river salinity and flow unless it is carefully targeted to strategic locations in the landscape.

The New South Wales Government and the Murray-Darling Basin Commission are working together to develop strategies to manage salinity and protect key community values and assets within the Basin's tributaries and the shared water resources of the Murray and Darling Rivers. Salinity targets are an important element of the strategies. The strategies also include comprehensive knowledge support initiatives, which will generate information and modelling tools for salinity management. These tools will assist Macquarie Valley stakeholders to clarify the potential for revegetation to assist in meeting salinity targets, and to carefully position revegetation in the landscape so that it delivers the desired outcomes.

On-ground implementation of revegetation works will be supported by innovative market-based schemes which provide for investment sharing in proportion to the public and private benefits generated by the works.

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Potential Water Issues Associated with Farm Forestry Expansion in High-Rainfall Areas of the Southern Murray Darling Basin

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The Murray Darling Basin Commission Cap is an important initial step to provide for the sustainability of the Murray-Darling Basin river system by limiting the extraction of water. Dryland salinity as a result of past tree clearing is also a major threat to the Basin. Farm forestry with commercial species and revegetation with non-commercial species have been proposed as an important land use option. This expanding forest plantation base requires identification and analysis of the environmental and socio-economic tradeoffs such as a decrease in water yield and a possible decrease in salinity.

While increased tree plantings may provide benefits in the management of dryland salinity and water quality, there are potential negative effects associated with reduced water yields and river flows. A cost/benefit analysis is required to consider these positive and negative impacts. Development of farm forestry supported by appropriate incentive is an important option for the economic and environmental well being of the North East Catchment areas of Victoria.

Introduction

The Murray Darling Basin Commission has adopted a Cap (which stipulates that the amount of water extracted for commercial use not exceed that used in 1993/94) as an initial step to provide for the sustainability of the basin river system. Concurrently there is an increasing threat of dryland salinity as a result of past tree clearing.

As large-scale tree planting through farm forestry is being considered as an option for land use, there is a requirement to identify the environmental and socio-economic tradeoffs of an expanding plantation base against decreased water yield and possible increases or decreases in salinity.

In the North East catchments of Victoria (covering 2 M ha including the townships of Wangaratta, Wodonga and Corryong), a substantial forestry plantation base sustains a viable and expanding timber industry. Increases in this plantation base, targeted to identified recharge areas, could potentially lead to beneficial impacts on stream and dryland salinity. However, unless they are carefully sited, new plantations could also reduce water yield and increase stream salinity.

Current extent of plantations

Major conversions from native forest to radiata pine plantation occurred in the 1960s and 1970s as a

consequence of government policy. Since that time there has been a small but steady increase in the establishment of plantations on pasture in farmland.

The current area consists of 38 500 ha of radiata pine mostly owned by Hancock Victoria and about 600 ha of farm forestry planting, mostly eucalypt.

Generic land capability mapping indicates 400 000 – 450 000 ha of cleared private land (of a total 600 000 – 750 000 ha of cleared land in the North East) is suitable in terms of soils and annual rainfall (>650mm) for the establishment of commercial plantations (Borschmann 1998).

Likelihood of plantation expansion in the near future

Distance from ports, and other factors such as farm size and land costs, make it unlikely that blue gum plantations grown on short rotations will expand to the same degree in the North East as they have done in the Green Triangle (South Australia and Victoria) and the south-west of Western Australia.

The most likely plantation expansion possibilities are:

- Radiata pine for sawlog/veneer production, as this is a proven model in the North East (Vic.) and South West slopes (NSW), and the manufacturing infrastructure is well developed. New investment would be required to kick-start this opportunity, but the timber industry is currently showing little interest.
- Hardwood for sawlog/veneer production; this is conditional upon availability of government or private investment. As with radiata pine, the timber industry is showing little interest at the present time.
- Hardwood or pine for timber production providing for salinity control in a well-controlled and planned program, with finance provided to farmers on an annuity basis. Opportunities may arise from:
 - a. Industry, based on realistic estimates for commercial timber yield, and
 - b. Support from other sources (salinity and Greenhouse mitigation) to assist establishment, maintenance and management costs. Funding needs to reach an incentive level for attracting change in land use.

The model shown in Figure 1 is currently being trialed in the North East of Victoria. Government grants from salinity and Greenhouse programs are being used to support farmers who are establishing hardwood plantations. The level of incentives depends on the degree of environmental benefit. The incentive levels vary between 50% and 70% of the establishment costs. Industry is being asked to provide an annuity to the landholder to provide some commercial reality to the venture. These annuity payments typically cover the commercial life of the plantation (nominally 20 yr).

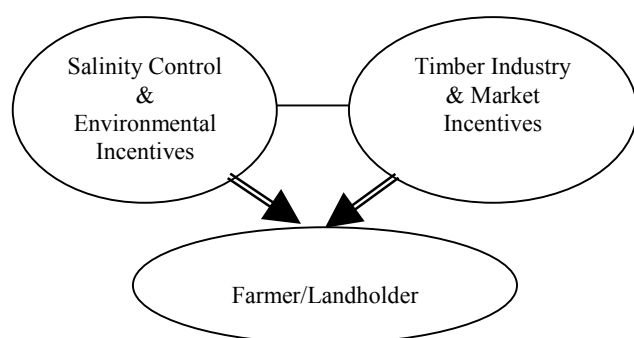


Figure 1. Combining incentives for plantation establishment

Impact on the Cap

An emerging equity issue raised in submissions to the Review of the Operation of the Cap (MDBC 2000) is

the trend towards increased plantations. Increases in tree plantations will reduce catchment water yield and also reduce re-charge to groundwater. While the reduction in accessions to groundwater could be seen as beneficial for the control of dryland salinity, the reduction in river flows will have an impact on downstream users. The Salinity Management Strategy developed for the Murray-Darling Basin encourages large-scale reforestation to combat salinity. As reforestation programs develop, the significance of this equity can be expected to increase over the coming years (MDBC 2000).

The North East river basins contribute 38% of the total water of the Murray Darling Basin system (MWEC 1997), despite its relatively small geographic area of 20 000 km². Consequently the North East forms a strategic and very important water resource for the Basin. A significant increase in the forest plantation base will impact on the overall water yield.

It has been recommended by the Project Board reporting on the review of the Cap that:

- The extent of proposed planting in the Basin be ascertained as soon as practicable;
- Water use by new plantations, and other changes in land use, be investigated to determine the yield; and
- The eventual form of this water use be included under the Cap.

‘The Project Board strongly supports the integration of the outcomes of the Salinity Management Strategy, including those relating to tree plantations, into Cap implementation procedures to ensure an integrated approach to the management of the Basin’s resources’ (MDBC 2000). Payment of water allocation through normal trading systems for establishment of plantations would obviously be a significant disincentive. In my opinion any water allocation regulations associated with water use by plantations should be dealt with through special consideration or other incentives designed to offset the allocation.

Policy implications

Commonwealth and State governments are committed to developing a commercial timber plantation estate in Australia of 3 M ha by 2020. If this target is achieved and depending on where the plantations are established, there could be significant impacts on water yield over the next 30 - 50 yr. This needs to be weighed against the positive environmental benefits associated with such an expansion.

Issues that need to be considered include:

- Up to 10 000 ha of hardwood plantations and native revegetation establishment is planned under a component of the Rural Land Stewardship Program (a program to match land use with land capability, stimulate rural communities, encourage

landholders to manage their land for environmental outcomes, and provide incentives to sustain agriculture, the environment and rural communities) in North East Victoria.

- Assuming water use by plantations of 2 ML ha⁻¹ yr⁻¹ (pers. comm. Rob Vertessy, CSIRO) the annual estimated future loss of water associated with the development of an estate of 10 000 ha is 20 000 ML. At the current trading price of \$850 ML⁻¹ this water is valued at \$17 M.
- There are positive environmental benefits, in terms of salinity and water quality, of an expanding plantation base, and especially of farm forestry at strategic locations at farm and catchment level.
- The estimated rate of spread of saline discharge areas for North East Victoria is 5.8% yr⁻¹ without intervention. This means over 117 000 ha of land will be affected by salinity over the next 30 yr (NECMA 1999).
- If salinity intervention programs are not implemented, the North East region is expected to contribute an increase in salt load to the Murray River of 1% (compound) over the next 30 yr. This corresponds to a 35% increase in salt loads if nothing is carried out to the year 2027 (NECMA 1999). Table 1 shows current salt loads of the three major river basins in the North East, and resulting impacts on the Murray River.

Table 1. Current salt loads in the North East Region

Catchment	Average annual salt load (t yr ⁻¹)	Impact on Murray River (EC at Morgan)
Upper Murray	104 668	15.5
Kiewa	21 078	4.4
Ovens	55 942	10.8
Total	181 688	30.7

The implementation of the North East Salinity Strategy (through the planting of deep-rooted perennials (trees) on targeted recharge areas) will help to reverse these salinity trends.

Conclusion

There are many positive aspects of increased tree planting on dryland salinity and water quality. The potential benefits should be weighted against the potential for reduced flows in the Murray Darling Basin and in the region by a cost/benefit analysis. The value of the water used by plantations should not be accounted for through traditional water trading mechanisms, but through special 'offsets' or alternative market systems such as salinity or water quality credits.

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9

Sustainable Rivers and Reforestation: Policy Issues for their Co-Existence in the Murray Darling Basin

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States facing major salinity damage to water resources and other natural and built assets, along with the Murray-Darling Basin Commission, are committed to reforestation as a key component of their salinity strategies. However, some recent studies indicate that reforestation for control of dryland salinity will result in significant reductions in surface water yield, so simple 'win-win' solutions may be unrealistic.

In the 600-800 mm rainfall zone of the Murray-Darling Basin, where much of the salinity problem arises and threatens the tributary rivers, many current forestry options are not financially attractive to investors and early modelling indicates that, if implemented, the projected reduction in salinity lags behind the loss of surface water. In the higher-rainfall zones where forestry is profitable and will expand, the water yield trade-offs are greater, requiring consideration of planning controls and potential purchase of water rights.

The logical conclusion is that the prospect of an optimum outcome depends on our strategies for 'getting it right' spatially. That is, there are good prospects for forestry properly located on farms, where reduction in recharge has the greatest impact on saline water-tables and salt stores, and where the trade-offs with other profitable farm enterprises and with surface water yield are minimised. The challenge is to acquire the level of knowledge, policy intervention, and industry and community participation necessary to bring about long-term changes.

Introduction

For the past two decades plantation forestry and farm forestry have been promoted and supported as preferred land uses in higher-rainfall zones of southern Australia, for economic and environmental benefits. As recently as 1999, the Murray-Darling Basin Commission, in response to its Basin Salinity Audit (Murray-Darling Basin Ministerial Council 1999) predicting loss of consumptive use and environmental damage in key tributary rivers, released a review (Walker *et al.* 1999) concluding that current farming systems can't deal with the scale of the salinity problem and that deep-rooted woody perennials are currently the only available options.

Over the last five years there has been a dramatic increase in forestry on private land, particularly in south-west Western Australia, southern South Australia and western Victoria. Considerable research effort has gone into developing appropriate new farm forestry systems for these regions. For example, in Western Australia maritime pine, oil mallee and blue gums have been developed for a range of annual rainfall environments from around 450 mm to around 1400 mm. Much of this expansion has occurred on

medium-rainfall zones in the 600-800 mm range. In contrast, the adoption of forestry on farms in the Murray-Darling Basin has been comparatively slow. This is due in part to the much greater distance to the coast, driving up transport costs and making the planting of short-rotation tree crops for pulp uneconomic. Consequently, generous annuity payments from prospectus companies have not generally been available to provide farmers with immediate financial benefits for planting trees.

There is also the trade-off issue that is the topic of this workshop – the potential reduction in surface water yield and its cost to industries as a consequence of reforestation. For example, Vertessy and Bressard (1999) suggested that plantation expansion in the mid-Murrumbidgee catchment might significantly reduce surface water flows. This modelling study was based on what the authors described as 'rather crude assumptions' and they indicated that work was needed to validate the relationships they proposed. Nevertheless, this workshop is recognition of the need to explore its possible implications.

The Murray-Darling Basin in particular, faces trade-offs from three policy initiatives:

- Water is a scarce resource and under water reform policies it is priced at its scarcity value.
- Forestry is a beneficial land use and under a national vision statement its area is to treble to offset a trade deficit and boost regional economies.
- There are limited options for long-term control of salinity, and re-establishment of deep-rooted woody perennials is a key option.

The question for this paper is – How can we develop an effective policy that optimises commercial forestry, sustainable farming and the water resources of the Basin's rivers?

Water as a scarce resource

In the Murray-Darling Basin, more than any other region in Australia, the surface water resources have been over-allocated with consequent detrimental impacts on river ecosystem health and reliability of water supplies. However, under water reform policies of the last decade, consumptive use of water has a higher marginal price. Any change in land use that impacts on surface water resources becomes an economic and environmental issue.

The River Murray now flows to the sea at 19% of its former median natural flow and 38% of its average natural flow. This is a reflection of the heavy allocation of Murray-Darling rivers to consumptive use; about 96% for irrigation worth about \$4.5 billion in gross value of agricultural product, and 4% for secondary industry and urban/metropolitan use. Under current policies, water entitlements are trading at \$500-\$1000 ML⁻¹, and annual water sales at \$50-90 ML⁻¹. This interstate economy around water is made possible by:

- The Cap on diversions from rivers, instituted in 1995, that put the scarcity value on water, and arrested the decline in river condition;
- The progressive liberalisation of water trading, including interstate trading; and
- The high degree of regulation of the rivers, allowing the delivery of traded water according to demand.

However, the growth in diversions of water prior to 1995 and the associated regulation of river flow has come at a high environmental cost. The combination of reduced flow, removal of flow variability and running rivers at capacity in the summer irrigation seasons has upset the natural wetting and drying of floodplain wetlands and riparian vegetation. Cold-water pollution from large dams and the myriad of structures impeding fish passage has dramatically reduced in-stream values and threatened some fish species. Other human interventions such as levee banks, drainage and de-snagging have aggravated the decline in river and wetland environmental values.

Consequently, the value of water is not limited to its market price under current supply and demand conditions. Its 'environmental price' will be determined by a number of policy interventions under way:

- The decision to restore the Snowy headwater to 28% of its former natural flow (currently 1%), with this water sourced from savings in the Murray-Darling system;
- An active program to determine environmental flow rules for the tributary rivers of the Murray, including a current project to review environmental flow and water quality management for the River Murray itself;
- Refurbishment of current structures to allow fish passage, and revised operations to improve environmental flow; and
- The prospect of providing further dilution flows for salinity mitigation purposes.

Earlier this year the Murray-Darling Basin Commission reviewed the operations of the Cap on diversions and concluded that while this intervention brought the threat of further development to the river environment under control, it was not necessarily at the right level to maintain or restore river sustainability. Significantly, it identified two threats to the integrity of the Cap: the growth in on-farm dams, and the projected expansion in commercial forestry (Murray-Darling Basin Ministerial Council 2000).

Murray-Darling Basin surface water now has a scarcity value in economic and environmental terms, and planning for forestry will need to account for impacts on reliability of water supply.

Forestry as a beneficial land use

Plantation forestry, farm forestry, re-vegetation and vegetation management are all part of our vision for sustainable land uses. The projected benefits range from:

- Growing more timber as a resource for value-adding;
- Eliminating the net trade deficit in timber products; and
- Generating regional economic benefits, particularly in regions traditionally dependent on grazing livestock incomes; to
- Salinity control and management of land degradation generally.

On the other hand, if we are going to effectively manage salinity, there is a priority need for new land use options that better mimic the capacity of native vegetation to reduce recharge to levels close to discharge capacity of catchments, thus limiting groundwater rise and salinity. Scientific evidence suggests that only deeper-rooted, perennial woody and

herbaceous plants can do this, either in stands or in combination with commercial annual crops.

Recent salt load studies for the Basin Salinity Audit (Murray-Darling Basin Ministerial Council 1999) have identified the 600-800 mm rainfall zone on the inland slopes of the Great Dividing Range as the area mobilising most salt to the rivers. The dominant land use in this zone is wool and meat production on introduced annual pastures. Under current market conditions and farm management, this is not a sustainable land use. Many farms have been running at a financial loss and current farm practices cannot meet necessary water use targets, and rates of farm transfer are below average. This is potentially a target area for reforestation, for socio-economic and salinity control reasons.

There are several reasons why large-scale reforestation may occur. The plantation forestry '2020 Vision' is to treble the current area established, to 3 M ha nationally. Catchment hydrology research in different parts of Australia is indicating that from 30% to more than 70% of catchments will have to be revegetated to get an effective salinity outcome. The identified area in the Murray-Darling Basin most at risk of salinisation, and most likely to threaten water quality in rivers, is about 5-6 M ha. If this scale of reforestation was to occur, the trade-off with surface water resources could be very significant.

Gross estimation of the forestry area that can deliver benefits is one thing; the placement of those forests is quite another. Commercial forestry will tend to go to locations that are most profitable, where yields are favoured by rainfall and soil types, and where there is appropriate regional infrastructure and access to ports. Typically, these are areas of greatest surface water resources and highest water quality. However, high-rainfall land with access to ports is now expensive and short-rotation farm forestry plantations for pulp production are now common in medium-rainfall zones (650-800 mm yr⁻¹) in both Western Australia and South Australia. Commercial reforestation for salinity control in the Murray Darling Basin also needs to be targeted at moderate-rainfall zones, but many of these areas could not compete for private investment for pulp production.

There is a need to develop new products, appropriate financial 'vehicles' and silvicultural systems for commercial forestry in the Basin, in the same way innovative tree crops have been developed in Western Australia. For example, State Forests of New South Wales is exploring the potential for biomass energy and charcoal production for regional use as well as providing carbon and salinity credit payments to subsidise farm forest plantations. In another initiative sponsored by CSIRO and the Murray-Darling Basin Commission – the Heartlands project – reforestation on a significant scale will be carried out in four catchments of the southern Basin, to fully test this potential new approach.

Prospects for salinity control

The draft Basin Salinity Management Strategy (Murray-Darling Basin Ministerial Council 2000) is focused on 'capping' the rise in salinity of the Murray and Darling tributaries while holding the salinity in the lower River Murray at its current level. These end-of-valley river salinity targets are to be met by 2015 and the Basin governments are agreeing to be held accountable for the actions necessary to achieve them. To do so will require an expanded program of salt interception schemes on the mid-lower Murray in the shorter term, while bringing in the land use changes over the longer term.

While the Strategy is targeted on protecting water quality for 15 yr, this is a means to achieving other important objectives – protecting river and wetland ecosystems, terrestrial biodiversity, regional and urban infrastructure, and productive agricultural land. With future salinity threats to rivers shifting from irrigation areas to dryland catchment sources, 'in-stream' targets limit the total salt loads delivered to the shared Murray and Darling rivers, while giving a signal to upstream catchments to change land management sufficiently to protect their significant natural and built resources.

The land management options under consideration for catchment-scale adoption are the development of high-water-use farming systems, expansion of forestry on farms, building new industries around woody perennial plants, and revegetation and vegetation management. A CSIRO report (Stirzaker *et al.* 2000), prepared specifically to accompany the Salinity Strategy, assessed the prospects of a suite of farming and forestry systems to mimic native vegetation in groundwater control, and outlined the prospects for meeting water use targets with more research and development.

In summary, **'there is no single, viable land-use system capable of controlling leakage over the (Murray-Darling) Basin as a whole.'** (Stirzaker *et al.* 2000). However, the target area where most salt is mobilised to the rivers is the 600-800 mm yr⁻¹ rainfall zone, and for this zone only agroforestry and perennial pastures are moderately effective in salinity control and reasonably profitable. Continued development of high-water-using crops and pastures, while increasing profitability, will not be effective against salinity. The real potential lies with new agricultural and tree crop systems that mimic native vegetation's capacity to use rainfall and restrict recharge, and to combine these with more conventional profitable crops in phased rotations or companion plantings. Their research and development will take 5-25 yr.

The implication of this analysis is that R&D to increase the yield and water use of existing crops and pasture systems will not be effective in managing salinity. Rather, public policy needs to focus on research for, and development and adoption of, a more fundamental objective of mimicking water use of native vegetation.

The draft Basin Salinity Management Strategy advocates this by requiring investment in innovation, research and industry development for new tree crops and by setting the market pre-conditions for investing in 'salinity benefits' that may become tradeable salinity credits in the longer term. These preconditions comprise the setting of end-of-valley targets to 'cap' future salt loads exiting the individual tributary catchments, and establishment of a second credit/debit register under the strategy that records the less certain salinity benefits and deficits associated with land use change and past land management practice, respectively.

A proposed vegetation bank will deliver the public investment into new forestry schemes on a contestable basis, and according to criteria that seek to gain the greatest salinity benefit at the least cost. In the short term, the salinity benefits will be acquired by governments and may be shared between governments as they seek to meet their targets accountably. With time, other investment proposals may seek to purchase and trade these as salinity credits. It is assumed that by building this market-based approach to forestry for environmental services, private capital will be attracted to salinity control.

The States of South Australia, Victoria and New South Wales, along with the Basin, all have salinity strategies promoting reforestation on farms in the 600-800 mm rainfall zone. Thus, the potential for trading off surface water yield in the pursuit of salinity benefits is an issue requiring further data and analysis.

A policy balance sheet

Having outlined the three policy options of water trading under 'capped' conditions, facilitating the adoption of commercial forestry, and controlling salinity with forestry and new farming systems, there is need for multi-objective analysis to determine whether there is a net benefit in the forestry option or whether in the long run the trade-offs are so significant that policy correction is required. Table 1 summarises the benefits and trade-offs on economic, environmental and social parameters.

Table 1. Benefits and trade-offs from forestry for salinity management

Value	Benefits	Trade-offs
Economic	New capital and regional economic development Diverse, profitable enterprises	Marginal profitability and risky in salt hazard zones Longer crop cycle
Environmental	Salinity control Carbon sequestration Nutrient reduction Nature conservation protection	Objectives of salinity control and profitability not fully compatible Water trade offs Uncertain outcomes Questionable biodiversity benefit
Social	Adjustment out of grazing Asset base for inter-generational transfer	Community concerns with visual impacts and displacement of farm families Negative perceptions of greater corporate involvement

In summary, commercial forestry on farms can have multiple objectives; contributing to economic development and diversification, providing environmental services, and facilitating social mobility out of current non-sustainable grazing enterprises. However coincidence of these three benefits is not guaranteed and there is a significant element of trade-off around them. On economic grounds, if forestry is to be focused on those areas where there is the greatest salinity benefit, the enterprise is marginally profitable and more risky compared to traditional enterprises. Also it is difficult to estimate on the basis of current data the quantum of salinity benefits that will flow to governments in return for their investments. Expansion of commercial forestry in the higher-rainfall environments where profitability is assured incurs a higher rate of trade-off with surface water resources and does not give the best outcome for salinity. In some areas there is community resistance against large-scale forestry in rural landscapes. However, both the National Farmers Federation and the Australian Conservation Foundation have proposed expansion of forest plantations and farm forestry to 19 M ha as part of a proposal to address national land and water degradation problems (Virtual Consulting Group and Griffin Pty Ltd 2000). The key is integrating forestry with other sustainable farm enterprises, through effective catchment and farm management planning.

What this analysis tells policy makers is that revegetation either as forestry integrated with farming or as non-commercial conservation and biodiversity

protection plantings are options, but to be successful their spatial locations are critically important.

Further knowledge is required

The technical papers of this workshop and its conclusions will make a very useful contribution to the planning and policy for reforestation for salinity control. Meanwhile the Murray Darling Basin Commission is investing in and supporting others in acquiring the full range of knowledge needed to support spatial decisions:

- Better modelling and regionally relevant outputs on the scale of water yield trade-off;
- Assessment of land use change scenarios for regions and the Basin as a whole, in economic and social terms;
- Influencing R&D and further innovation in commercial forestry and non-commercial revegetation options;
- Long-term investment in the data needed for best planning of the location of forestry options in the landscape;
- Continued development of the investment ‘vehicles’ needed to drive this land use change in areas of marginal profitability; and
- A major project on mapping land use changes and assessing their sustainability.

This is very much work-in-progress for various research institutions, and the integrated knowledge output will be very influential on implementation of the Basin Salinity Management Strategy. It will be up to the Commission with its partner governments to interpret this into policy interventions that will influence the growth of forestry, spatially. Two options to be considered are statutory land use planning and acquisition of water rights for forestry, but there is more policy research to be done before they can be thoroughly evaluated.

Conclusion

The Commission is committed to reforestation as a key component of the Basin Salinity Management Strategy. It acknowledges that there are significant trade-offs in developing sustainable land uses that can effectively control salinity, as there are for commercial farm forestry in the more profitable environments. The logical conclusion is that the only prospect for an optimum outcome is to ‘get it right spatially’. That is, there are good prospects for forestry properly located in the landscape, where reduction in recharge has the greatest impact on saline watertables and salt stores, and where the trade-offs with other profitable land uses and with surface water yield are minimised. This requires a level of knowledge and invites policy intervention that will challenge governments and their landholding communities.

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