Plantations, Farm Forestry and Water

A Discussion Paper

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A mosaic of native forest, pine plantations and harvested areas in a landscape in ACT Forests.

Plantations and farm forestry in lower-rainfall areas are using an expanded range of species. The ironbarks in this plantation have the potential to produce high-value wood. Research and Development programs will further improve the utility of a number of 'non-traditional' plantation species.

Foreword

Sustainability entails balancing and accommodating multiple and sometimes conflicting values. The further development of plantations and farm forestry in Australia will continue to face the challenges of achieving economic and ecological balance at farm, landscape and regional levels. One example, already with us, is to effectively manage the interactions between tree plantations and hydrogeological processes.

Plantations for Australia – The 2020 Vision has given a much-needed impetus to commercial forestry development. The continuing expansion has already triggered significant changes in land use in some regions. It is also widely recognized that well-planned and strategically located reforestation offers a major opportunity to redress the hydrogeological imbalance that is the root cause of dryland salinity on farms. There is, however, a concern that expansion of forests will diminish the amount of water available to other land uses such as irrigated agriculture. The perceived competition for water between forest plantations and other uses is potentially detrimental to the orderly progress of and judicious investments in resource development for multiple benefits.

Recognizing the need for a participatory approach by and dialogue between various interest groups, CSIRO Forestry and Forest Products, with the support of Agriculture, Fisheries and Forestry Australia (AFFA) and the Joint Venture Agroforestry Program (JVAP) organized a national workshop, *Plantations, Farm Forestry and Water* on 20 – 21 July 2000. The aims of the workshop were to:

- Review the scientific principles underlying interactions between communities of trees and hydrogeological processes at the landscape level;
- Examine the potential positive and negative impact of tree crops in the context of land use;
- Explore current and future scenarios of selected ecosystems (regions) as case studies; and
- Prepare a discussion paper based on the above analysis to provide balanced information for all concerned with land management and development of land use policies.

The workshop content focussed on regions where industrial and farm activities are advancing rapidly: southern and south-western Australia, where the extent of development and available information provide a reasonable basis for case analysis.

The papers presented at the workshop were reviewed and published as a proceedings[13]. A synthesis of the papers, the views which emerged from structured discussion, and an executive summary, are presented in this discussion paper.

This report, a new addition to RIRDC's diverse range of over 700 research publications, forms part of our Joint Venture Agroforestry R&D Program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

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The context

Australia is committed to ecologically sustainable development. Sustainability is a balancing act involving accommodation of and tradeoffs between multiple and sometimes conflicting values. In recent years there has been a surge of investment and activity in plantations, farm forestry, and general revegetation in Australia. Incentives for these 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 the *Plantations for Australia – The 2020 Vision*[10] has given a much-needed impetus to commercial forestry development. This vision, if fulfilled, would more than double the present land base under plantation forestry. Revegetation with deep-rooted perennials on a large scale is being proposed by a variety of land management agencies as one important option for saving the land and water from increasing salinisation. The purposes of these programs include wood production, mitigation of land degradation, enhancing bio-diversity, carbon sequestration and bio-energy production. The extent, structure, composition and life cycle of planted forests will therefore vary widely. The level of these current and proposed activities is influenced by many factors, and varies substantially between regions. Cumulatively, they have the potential to bring about a large change in agricultural land use.

The development of plantations and farm forestry faces the challenge of achieving economic and ecological balance at farm, landscape and regional levels. One major challenge, already with us, is the management of the interactions between tree plantations and hydrogeological processes to achieve sustainability. Well-planned and strategically located reforestation can redress the hydrogeological imbalance that causes dryland salinity on farms. Concerns have arisen, however, that in some situations expansion of plantation forestry on a large scale could diminish hydrogeological flows and threaten water availability or water quality for other uses. The term 'farm forestry' can refer to a continuum of reforestation from small-scale alley farming and scattered woodlots on farms through to industrial scale plantations on farmland. Largescale reforestation can reduce water yields of catchments (surface and groundwater), and increase river salinity by decreasing the dilution. In some areas of Australia, industries and towns which depend on limited resources of fresh water have limits or caps placed on their use of the water. Competition for water resources between plantation forestry and other uses can lead to disruption of industries, community conflict and is also detrimental to the the process of resource development for the multiple benefits. Balanced land and water use policies, and effective discussion and communication between stakeholders and land management agencies, and good quality biophysical data and predictions are necessary for attracting investment for a range of industries including commercial forestry and revegetation programs necessary for combating land and water degradation. This is particularly so because investment in plantation and farm forestry for economic and/or environmental outcomes is invariably long-term in nature. Debates on forestry and water often become adversarial, as though there is a simple universal solution of the complex issues that deserve consideration. This is not the case – interactions are diverse, ecosystem-specific and related to goals of land management and land use.

The 'Plantations, farm forestry and water' workshop held in July 2000 addressed the urgent need for a balanced analysis of this sensitive issue. Diverse views and expectations were presented in the context of the best scientific information available. Issue reviewed included: biophysical issues related to planted forests and water, the nature of impacts at the catchment scale, regional and ecosystem-specific factors, commercial and environmental considerations, trees and their role for managing land and water degradation, and the tradeoffs needed to achieve balanced policies.

Plantations, farm forests and water

Trees planted for commercial or environmental purposes may use more water than the crops or pastures they replace at the same site. The planned expansion of Australia's commercial forest plantations by 2020 can therefore cause a reduction in surface water flows and recharge to groundwater in some areas depending on the scale of planting. The tradeoffs between the multiple benefits accrued by forestry enterprises, and some reduction in total water available is the key issue.

The impact of forests on water will not be uniform across all the areas planted: it will be strongly ecosystem-specific, being influenced by the nature of the water flows, landscape features, area and density of plantings, and management. Impacts on water will be greatest in high-rainfall areas. Many recently-established plantations are in areas of relatively moderate rainfall (600-850 mm) where their effects on water flows will be considerably less than those of plantations which have been established in high-rainfall areas. In such areas, the reduction in usable water resources (streamflow and recharge) would typically be about 100 mm per year (one megalitre per hectare of planted area) reducing to zero where the rain is less than 500 mm per year. Plantings in higher-rainfall zones (e.g. 850 - 1500 mm) will result in greater reductions in streamflow. If extensive afforestation occurs in these zones, it will reduce water yield from these catchments, which currently have high water productivity. The water allocated for downstream users will therefore be less secure.

New tree plantings will also be beneficial for limiting the expansion of salinised land and improving water quality in some areas. Often, the issues of water availability and land salinity occur simultaneously. The critical factor here is get the right balance - between rainfall, location and size of the plantings in the catchment context, local vs. regional impacts – and to move towards a holistic and balanced approach to land use.

Proportion of area planted

About 90% of the *Pinus radiata* (the species which comprises the highest proportion of the current plantation estate in Australia) plantations established in Australia in the past are on areas that receive less than 1000 mm of rainfall annually, and large areas exist within the 650-850 mm zone. The effects of these plantations on water flows will be considerably less than those of plantations established in higher-rainfall areas.

The new plantation area of two million hectares proposed in the *2020 Vision* is also small in relation to the nation's total medium rainfall catchment area. For example, in the Greater Green Triangle[*] area where the plantation estate established since 1860 is still expanding, the total area planted by 2020 is likely to be about 10% of the total area previously cleared for agriculture.

Expansion of forest plantations will have effects on water resources roughly in proportion to the level of landscape afforestation that occurs. This will be further influenced by the way the plantations are managed: for example their rotation length, thinning regime and inter-rotation fallow period, and site quality which determines growth rate.

The enhanced water use of a stand of trees can account for significantly more water abstraction from the soil and groundwater than annual crops and pastures. In a catchment, the impact on water resources is moderated by the area planted, its' location, the species used, the climate and the way the plantations are managed.

Some arguments about the negative hydrogeological effects of forestry are coloured by the apprehension of 'wall to wall forests' replacing traditional agriculture, and those plantations constantly having full canopies. This concern is an-over simplification. In most areas new forests are established as discrete and fragmented tree communities across the terrain. Even where plantations occur contiguously, they exist at any given time as a mosaic of age classes, site qualities and stand densities, giving rise to a range of impacts on water fluxes.

When establishing new plantations in areas where water availability is a critical issue, the planning of land use should take into account overall ecosystem processes and economic imperatives.

Effects on flow for downstream water users

Plantations will have the maximum effect on surface water flows if they are established in high-rainfall areas, especially if these areas are sources of water for downstream water users. If plantation expansion is mainly centred around moderate rainfall zones (600-850 mm) as it has been historically, its effect on water resources for downstream users will be far less than that of plantings in higher-rainfall zones. Expansion of plantations into lower-rainfall areas will probably have negligible effect on downstream water resources. At the local scale, new plantations on cleared land will alter dry-weather flows in unregulated rivers, causing them to revert to the flow patterns they had before the land was cleared.

The introduction of tree species which are not local to an area may reduce dry-weather flows to levels below those experienced historically. This can be expected to occur if the planting covers a significant proportion of the catchment area and the new plantations are managed to achieve significantly higher leaf area than that of the original native vegetation. Widely-spaced agroforestry plantings and appropriate planting designs are important management tools available in this context.

Where plantations are established in parts of a catchment that are hydrogeologically isolated from streams most of the time, the impacts on streamflow will be negligible or very little.

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[*] South-eastern South Australia and south-western Victoria

Effects of species

Industrial-scale plantings of hardwoods and softwoods have approximately the same overall effects on surface and groundwater resources in comparison with cleared land. Different tree species, however, show patterns of water use, growth and survival that vary significantly with climate and watertable depth. Their capacity to grow and maintain leaf area, ability to grow roots through harsh soil conditions, salinity tolerance and other physiological attributes can give rise to different outcomes in relation to site water balance. Matching tree species with sites is necessary to ensure the viability of tree planting programs, especially where trees are planted in new and often harsh environments.

Differences may also occur if tree crops are managed for different end uses. For example, *Pinus radiata* plantations are managed for pulp and sawlog production over a cycle of 25-35 years with 3-4 thinnings, whereas most of the current *E. globulus* plantations are grown for chipwood production and hence on a rotation of 10-15 years.

Effect on floods

Tree plantations of all types reduce peak runoff rates during flood-producing storms. Compared with agriculture they moderate peak flows. The smaller peak flows lessen flood damage, landscape erosion and river siltation by trapping sediment. Better river water quality is maintained by lower turbidity and sediment loads. These are clear beneficial effects to both landowners and downstream water users. River flows during smaller storms are also diminished, resulting in reduced flushing – possibly to the detriment of aquatic habitat.

Changes through time

The impact of afforestation on streamflow will vary throughout the life of managed plantations as leaf areas change. When plantations are thinned or harvested the impacts will diminish, such that the long-term average effects on water resources will be less significant. The nature of the tree harvesting cycles in catchments and the location of the trees in relation to terrain features also alters the hydrogeological response time. The time taken for streamflow to re-adjust after a land-use change is much shorter than the time needed for land or stream salinity to change.

Effect on watertables and ground water

Watertables and underground water resources will be affected by the changed recharge patterns under plantations, through enhanced interception of rainfall and increased transpiration. Planted tree species that draw water directly from the watertable can achieve higher growth rates using this extra water, but can depress the level of the groundwater. However, the ability of trees to use ground water in any significant amount seem strongly dependent on the depth to watertable. The ensuing effect is likely to be local, not extending beyond the plantation area. In many situations this is recognised as a beneficial approach for maintaining the productivity of limited areas of salinised land suffering from degradation. Where the potential reduction of deep and high quality groundwater (e.g. in the Green Triangle Region) is of concern, the important considerations should include the nature of the land in which trees are planted, its overall hydrogeological features and the extraction of the ground water by other users.

Trees for salinity control

Patterns of land and stream salinity (especially in Western Australia) are still changing as a result of clearing native forest and woodlands during the past century. Positive effects of afforestation can be identified in some landscapes suffering from dryland salinisation. Where the causes of dryland salinity (e.g. in the upper Murray-Darling Basin catchments) can be linked to local groundwater behaviour, strategically located woodlots and plantations can check or slow its spread, and eventually rehabilitate damaged areas. The salinity of river flows can also be reduced. These benefits could be manifested in a few years in catchments with local groundwater systems. But the efficacy of plantations depends on the use of improved methods based on hydrologic knowledge and analysis, a better understanding of how different tree species can be grown and managed in their new environments, and the extent and strategic placement of tree plantings in the terrain.

Rehabilitation of landscapes where groundwater is dominated by regional scale processes is problematic (i.e. Western Australia). These are likely to require more extensive afforestation at scales that result in major switches in land use from agriculture to forestry. If such changes in land use occur, the time taken for benefits to be apparent is likely to be several decades.

At both regional and local scales, the sustainability of plantations in salt-affected areas will be an issue. This bears directly on the viability of forest-based industries established there and an understanding of the tradeoffs between economic and environmental benefits.

Growth and management of stands

An over-riding issue is the commercial viability of the new plantations themselves. First, this requires development of new infrastructure and markets for the tree products. Second, the tree species used in plantations must survive and grow at rates that justify the investment. Even when trees are planted primarily for environmental benefits, where the trees drive the change in ecosystem processes and towards better land use practices, it is essential that the trees are managed well and their potential productivity in a given environment is realised. Otherwise, the expected role of trees in driving carbon, water and mineral flows, and enhancing biodiversity, will not be fulfilled. In stark contrast to the ongoing attention given to other farming activities, many environmental plantings of trees on farms receive scant attention to management beyond planting, leading to lost opportunities for obtaining a product from the tree crop. This situation, important for both economic and environmental outcomes, is slowly but steadily changing.

Knowledge gaps

There is a body of knowledge available now with which we can improve land management practices by further development of plantations and farm forestry. The level of this information varies between catchments and regions, as does the extent to which available information is being used in land planning process.

As we progress through the implementation of the *Vision 2020* it is also clear that, despite significant achievement, the knowledge needed to maximise benefits from the *Vision* plan is not adequate considering the environmental and economic mosaic within which plantation forestry is being promoted. New information is needed on the biophysical factors that affect tree growth, their water use, and the diverse and ecosystem-specific hydrogeological effects when trees are established on formerly cleared land. Current debate on forests and water is based on a narrow classification of site water availability in terms of ‘low, medium or high’ rainfall. This takes no account of other critical factors including evaporation, landscape features and terrain, properties of the regolith and other land capability features. Rainfall alone is an inadequate predictor of ecosystem processes and function, given the complexities discussed in this paper. An increasing number of field observations show that the simplistic and common assumptions about tree growth in the so-called ‘low-rainfall zone’, based on meagre and often unreliable information on rainfall, require significant revision.

Continuing efforts are required to close the significant knowledge gaps which exist so that the effects of large-scale new tree plantings on water resources can be more fully assessed and current controversies and misconceptions addressed. These gaps, not in order of priority, include:

- The relative water use of various tree species in different climates, their productivity and their ability to draw upon groundwater located at various depths.
- The temporal patterns of water use (and groundwater levels) by managed tree plantations throughout rotations.
- Tools for managing productivity and drought risks in new forests (and species) in areas prone to drought.
- The survival rate of various tree species in low-rainfall and/or saline soil water environments and their ability to grow roots through salinised soil profiles.
- The changes in dry-weather flows from afforested versus cleared catchments.
- The hydrogeological attributes of catchments, and the ‘effective’ catchment area. This should lead to a system of classifying landscapes in terms of their interactions with water resources, ecosystem function, susceptibility to degradation and potential for rehabilitation.
- Effects of isolated, small units of farm forests distributed throughout diverse terrain in a landscape on the overall water balance of the catchment, compared to the effects of contiguous plantation forestry in the landscape.
- Methods to locate salt in landscapes, and assess its mobility under various land uses.
- Decision support systems for locating, designing and managing trees integrated with overall land use.
- Further verification of the forest hydrogeological models and improved capacity to account for the dynamics of forest management in space and time.
- Improved models for aggregating local effects to larger scales at the catchment and regional level.
- Tools to evaluate tradeoffs.
- Policy and legal frameworks to fairly and reliably allocate rain, surface and groundwater to a range of users and to the environment.

There is a need for researchers to fully describe the climatic, topographic, soil, geologic and groundwater attributes of their experimental sites in a consistent manner, and to contribute these descriptions to the data bank needed for classifying catchments. Second, experimental sites need to be monitored for a duration long enough to detect the effects of the imposed land use change. Gathering and interpreting this information will take 10 or more years. This is a short time compared with the timescale of the commercial tree plantation industry, and the planning horizons for changing land use in Australia.

The way forward

There are clearly no simple and universal criteria for debating and analysing the potential impacts of plantation forestry, farm forestry, and other revegetation programs on water flows and water access in our vast country. The overwhelming point that has emerged is the need to recognise the diversity of ecosystem-specific processes and impacts that are relevant to local and regional economic, environmental and social contexts. It follows that it is imperative that the forestry and water debates be guided by balanced analysis including science, economics, policy, politics and community needs. In all regions where major land and water use changes are envisaged, the tradeoffs of water availability and quality for local and downstream users need to be assessed. Similar analysis of tradeoffs is essential where impacts of land use on groundwater and its use are critical issues.

Plantation establishment is just one land and water-use change that is currently occurring in Australia. Others include increased use of irrigation, new cash crops which replace grazing, and several other activities, which use water at an increasing rate. In such a complex situation an examination of the impacts of forestry on land and water in isolation is unlikely to provide sound and lasting policies and solutions. The analysis of tradeoffs needs to be inclusive of economic and environmental values of greatest importance to a region. The methods for assessing the impacts are available, but knowledge of the key factors needed to apply the methods to specific sites is meagre. They clearly vary between locations and regions.

Alley farming with eucalypts and silky oaks mixed with grazing in Billabong Creek Catchment, New South Wales.

1. Background

Australia’s rainfall and streamflows are highly erratic. Compared with other continents, streamflows are also small. Clearing of forest and woodland for agriculture during the last century has greatly increased the volume of water moving through catchments, and much of this water has been allocated for irrigation. In many regions, commitments to existing water users consume a large part of the available water, leaving little for requirements of new enterprises. One major enterprise, already expanding rapidly in some regions, is tree planting on cleared land. Reforestation of cleared land is perceived to reduce streamflows and therefore intensify the competition for water. On the other hand, strategically located tree plantations can help reverse land and water quality degradation, especially where dryland salinity is a severe threat to farmlands. We need to understand and recognize the impact that expanded areas of tree plantations will have on water and land resources.

Recent initiatives aimed at natural resource management in Australia will affect rural productivity and the land and water resources the community depends upon. These initiatives include:

- *Plantations for Australia: the 2020 Vision*, which promotes the case for a major expansion of commercially productive forest plantations[10];
- The policy development document *Our Vital Resources – National Action Plan for Salinity and Water Quality* that outlines the action needed to ensure that our water and land management practices will sustain productive and profitable uses, as well as our natural environment[1];
- *Basin Salinity Management Strategy – 2001-2015* in which the Murray Darling Basin Commission outlines its plan to attract capital investments into forestry and vegetation management schemes[12]; and
- *National Investment in Rural Landscape 2000*, an investment strategy proposed by National Farmers Federation and Australian Conservation Foundation. This strategy calls for a large-scale investment program including reforestation of farming land for economic and environmental recovery of rural Australia[9].

In addition several State Governments have land degradation mitigation strategies that have revegetation and reforestation as a key component and seek to promote investment and co-investment in relevant programs (e.g. WA Salinity Strategy; Vegetation Banks).

All these initiatives call for significant revegetation and/or reforestation activity for commercial and environmental outcomes in large areas of the landscape that had previously been under agriculture. In most cases, the large-scale revegetation will advance only if commercially favourable returns are likely – to either small or large private investors.

The Plantation *2020 Vision* initiative that emerged in July 1997 sets out a framework to treble the nation’s (then) forest plantation area by the year 2020. To achieve this goal, it will be necessary to establish new plantings of 80 000 ha per year (a fourfold increase in the new planting rate in the early 1990s), adding 2.2 million ha to the 1996 plantation area of 1.1 million ha. After the plan was announced the planting area increased from about 55 000 ha in 1997 to 65 000 ha in 1998 and 95 000 ha in 1999 (National Plantation Inventory 2000).

The *National Action Plan for Salinity and Water Quality* initiative was announced by the Prime Minister in October 2000. AFFA estimates that the annual costs for land and water degradation are up to $3.5 billion, and given current trends, within 20 years Adelaide’s drinking water will fail World Health Organisation standards in two days out of five. The Murray-Darling Basin Commission has produced draft strategies for Integrated Catchment Management and Basin Salinity that explicitly recognise the role of tree planting to arrest land and water degradation. As well, the National Farmers Federation and the Australian Conservation Foundation espouse ‘a much larger role for trees in rural landscapes in the form of ... forest and forest industries, with commercial plantations and agro-forestry, ranging to revegetation with indigenous vegetation’.

All initiatives have common ground in that they address significant environmental, economic and social issues that threaten rural areas. They also recognize substantial non-market benefits including rural employment, improved farm profitability, land and water salinity abatement and carbon sequestration. These benefits may accrue over a long period.

Cumulatively, the potential impact of these initiatives and policies on land use in Australia would be very large indeed. A major unknown in this is the potential effect that the projected plantings will have on water resources, including surface runoff, streamflow and groundwater. It is already clear that the perceived competition for water between plantations, farm forestry and other users would be detrimental to the orderly progress and investment in resource development envisaged in various initiatives. It is well established that the patterns and amounts of water use differ markedly between different vegetation types, for a number of physical and biological reasons. For example, annual crops have different seasonal water requirements from perennials, and deeply rooting trees can access a greater depth of soil water than shallow-rooted pastures. While there are estimates available that indicate the magnitude of these effects, they need to be more thoroughly assessed and verified to predict the extent of decline in available water resources which may occur as a result of enhanced tree planting in different areas at various times.

The principal water issues related to the expansion of tree planting on cleared agricultural land are:

- What will be the impact on the currently available water resources in rivers? How might these resources change regardless of whether or not trees are planted?
- How will dry-weather flows in unregulated streams be affected?
- What effects will tree plantations have on watertables and underground water resources?
- How can plantations be used to arrest rising stream salinity and the spread of salinised areas in farmlands?
- How long before benefits from tree planting are seen?
- How do we plan the best use of tree plantations at farm to regional scale?
- What are the key issues for consideration as tradeoffs for sustainable resource developments?

This discussion paper addresses these issues. It is based on reviews and discussions held at the workshop in July 2000[13]. The approach taken is based on our understanding of how trees, land and water interact in landscapes and how, in some environments, this interaction affects salinity. In some cases, tree plantings are without doubt beneficial, where land salinisation can be arrested or at least delayed. In other cases, there is potential for diminished streamflows in dry weather, or lowered groundwater levels. It is clear that plantations will have impacts that differ across different ecosystems and climatic regions, and that a tradeoff in available water resources may occur if the effects of the plantings are not properly considered. We present, in summary form, the information already known that is relevant to the plantations and water issue. It applies that knowledge to a few key regions in Australia where critical land or water resource issues exist, and identifies areas where more information or analyses are required.

Many of the current debates on water, plantations and farm forestry assume that forests impact on water resources in a universal way. We hope this paper will allow such assumptions and opinions to be placed in proper perspective.

Even before the introduction of agriculture, humans have changed the balance of forest and grassland over many millennia, mostly through the widespread use of fire. The occurrence of fire from natural causes such as lightning also constantly disturbed the state of the natural vegetation. It is misleading, therefore, to surmise that the landscape and its water resources were in static equilibrium before European settlement occurred in Australia. However, mechanization of agriculture vastly accelerated the removal of native forest and woodland, and replacement by pasture and annual crops, in the past 80 years. This, together with the rabbit pest and more frequent fires, has sharply increased the rate of change of land cover. The consequences are the major cause of accelerated land and water resource degradation facing us now. We must not assume that the landscape and its water resources have now achieved a new state of static equilibrium.

2. Water Balance in Landscapes

The impact of historical land use changes cannot be quantified for certain because we have no direct measurements of streamflow behaviour or salinity before land clearing and agriculture became widespread. The study of water balance is a comparatively recent science, so the only information we have about the early hydrological environment comes from explorers' notebooks and narratives passed down from the indigenous population and the new settlers. But given the extent of known clearing that has taken place (e.g. some 15 billion trees in the Murray Darling Basin alone), we can surmise that even in unregulated rivers, annual flows and their seasonal distributions are quite different now compared with 150 years ago. Total flow volumes are now greater than they were before European settlement, and streams that dried up in summer are now likely to maintain some flow for longer periods.

The trend to re-establish trees on cleared farmland will act to return streamflows back towards their pre-clearing state. This will be a local effect confined to the areas that are revegetated. Thus, annual water yields may decline, and dry-weather flows may disappear. On the other hand, salt discharge into streams and expanding dryland salinity may be abated. The magnitude and economic consequences of these impacts can be evaluated only through assessments of the hydrologic changes which occur after plantations are established, and where they are established.

In the past several decades, much of the scientific comprehension essential for these hydrologic evaluations has been developed. It has been necessary to gather basic experimental data for the appropriate tree species in the varying soil and climate conditions across the continent. The final steps now involve assembling this information into a framework that can be used to predict the hydrologic impact under various scenarios. As more data become available, the accuracy and reliability of these predictions can be improved. However, we are already faced with choosing between options for land use, and the decisions that have to be made have some urgency. Application of existing knowledge is therefore the key, even though significant gaps remain in it.

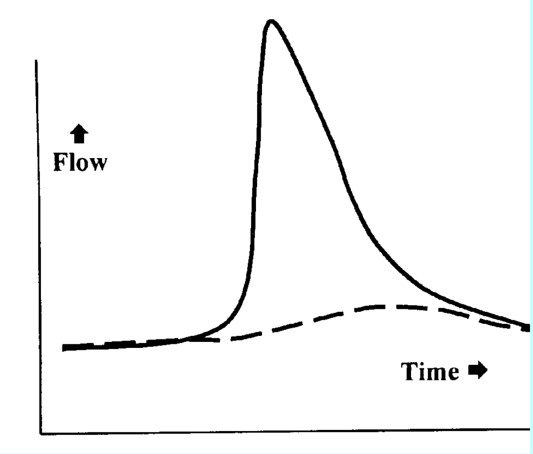
2.1 Principles and processes affecting water flows

In this section we outline how water, topography, soil and vegetation interact in the landscape. It emphasises the factors and processes that change when tree plantations are established in land under pastures or annual crops.

2.2 Surface water flows

Streamflow usually has two components: stormflow and baseflow (see box). Major stormflow runoff occurs only when the rainfall intensity is greater than the soil's ability to receive it as infiltration, or when the soils are saturated. This type of runoff is common in mountainous or monsoon-prone regions. Minor stormflows usually occur when lower-intensity rain runs off from parts of the catchment that are more or less permanently wet, generating the many 'freshes' that occur in streams whenever rain exceeds a few tens of millimetres.

Stormflow and baseflow



Stormflow (—) is the runoff that appears during and shortly after rain. Baseflow (- -) maintains flow in the stream when rain is not falling; it first passes through the soil and emerges as groundwater flow through the streambed and banks. Minor stormflows and baseflow are important for maintaining the ecological health of streams.

Flood flows resulting from storms can be collected in reservoirs and released later as regulated streamflow. But unless the storages are very large, most floodwaters flow into the sea, and contribute little to the useable water resource. The impact of plantations on such flows is quite beneficial, through the moderating effect they have in reducing flood peaks, replenishing soil water and preventing erosion. Forests generally yield better quality water than cultivated land, and reduce the rate of siltation in reservoirs. Plantations and farm forests have negligible effects on the quantity of water that can be captured by reservoirs during these high flows.

Left-over rainfall

Both streamflow and groundwater recharge are residual quantities, that is, the leftover rainfall that is not evaporated from the soil or the plants. So any change in plant evaporation has a highly leveraged effect on incremental water resources. For example, in a region where annual rainfall and evaporation values are 1000 and 950 mm respectively, a decrease in evaporation of only 50 mm brought about by forest clearing could well double streamflow from the region. Conversely, a complete and permanent conversion of cleared land to forest can reduce streamflow to zero. If the planted forest is managed as a mosaic of different age classes with periodic thinning and harvesting, streamflow will fluctuate between these extremes, depending on the temporal extent of forest cover.

Apart from these intermittent high flows, streamflow is determined primarily by how much water is stored in the soils of a catchment. Drainage from the soil supplies water to the watertable (recharge), which flows downslope towards the stream, appearing as baseflow. The wetter and more permeable the soil, the higher the recharge. Larger recharge rates result in stronger flows from springs and larger seepage areas in lower hillslope positions. These maintain flows during dry weather, and provide the wet soil areas where surface runoff is generated during small or moderate storms. Any factor that diminishes soil water therefore has a direct effect on runoff volume during storms, and baseflow between storms. Vegetation acts to reduce soil water in two ways: by interception and by plant transpiration.

2.3 Interception loss

Rainfall interception loss on bare soil is zero. In forests, interception loss is the amount of rain that wets the canopy and evaporates from there. This reduces the amount of rain that reaches the soil. Tree canopies can retain several millimeters of rain, and the total evaporation during prolonged rain can exceed this amount many times over. On an annual basis, the interception loss from pine plantations can be 20%-30% of rainfall, while for eucalypts the loss is 10%-20%. These losses are determined mainly by the size of the leaf area. In plantations leaf area is higher and more persistent than in pastures or annual crops, and evaporation of intercepted water from tree canopies is more rapid than from low grasses because of greater energy exchange with the atmosphere. Grasses and low annual crops therefore intercept only a fraction of the water intercepted by tree canopies.

2.4 Plant uptake and transpiration

Australian native vegetation

The Australian native vegetation communities in most climatic environments (rainfall less than 1000 mm) have evolved such that they exploit essentially all of the available soil water, leaving little for residual streamflow. Thus, most of the river flow in the Murray Darling Basin comes from small parts of its catchment where the amount of rain (or snow) far exceeds the vegetation’s ability to use it.

The loss of water vapour through microscopic openings on leaf surfaces (stomata) as part of the process of photosynthesis is called transpiration. If supply of soil water is plentiful and as long as the vegetation is not dormant, transpiration proceeds at a rate that depends on the energy available from solar radiation and heat from the atmosphere. When water in the soil is partly depleted, physiological response by the plant constrains the rate of transpiration, eventually reducing it to near zero when the roots have no access to water. Because stomata do not close completely, plant desiccation and death can occur when water stored in the plant tissues is exhausted. The way plants adapt to these limiting processes differs between vegetation types (e.g. pastures vs. trees) and between different tree species (e.g. pines vs. eucalypts), and is a critical factor in how plants use soil water.

Tree roots explore a greater depth of soil than do those of annual crops or pastures, and have a greater ability to extract moisture from soil at low soil water content. Evergreen trees transpire throughout the year. Thus, trees can transpire a greater total volume of soil water than shallow-rooted plants.

Interception and transpiration reduce soil water content and recharge to watertables. The largest reduction occurs with tall, leafy evergreen plants with deep roots. Vegetation change can have a highly leveraged effect on streamflows: the effect can be positive or negative, depending on the nature of land use change and the environment where it occurs.

The influence of vegetation on water resources is greater than other effects, with the possible exception of climate change.

2.5 Groundwater

The critical factor that influences groundwater is recharge; that is, the percolating water that passes through the root zone. Groundwater resources stored below watertables are similar to surface waters in that they have inflows, outflows and storages. But the similarity ends there. Inflow to groundwater (recharge) is almost impossible to measure reliably, flow rates through the groundwater conducting system must be inferred indirectly, the properties of the conducting medium are usually highly variable, and their boundaries are almost always unknown. Separate groundwater systems may also interact on a local or regional scale. However, groundwater resources are affected by land use changes.

Recharge to groundwater is not uniform across landscapes (see box). The hillslope location where recharge is overtaken by discharge is the 'hinge point'. Above this point, strategies for groundwater control imply manipulation of recharge. Below the hinge point, extraction or interception of groundwater is the only means available for manipulating the groundwater level. Estimating the rate of travel and time of residence of groundwater before it passes from the upper recharge zone into the lower discharge zone is therefore important for its management – both for accessing the water for consumptive use, and for controlling its level.

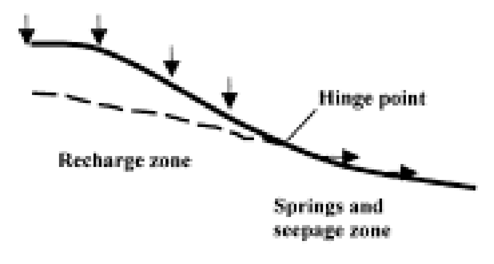
The rate of travel of water through underground aquifers is slow, ranging from millimeters per day in clays to metres per day in gravelly aquifers. The flatter the topographic relief, the slower the rate of travel. Where the travel rate is low, there is opportunity for roots to extract moisture from the watertable. If this rate of moisture extraction matches the accumulated groundwater flow from upslope, then the hillslope below the vegetation does not receive any groundwater recharge flowing from the upslope area. Thus, in sloping terrain, it is sometimes possible to totally intercept shallow groundwater flow before it reaches a downslope seepage area. Conversely, if groundwater is supplied to seepage areas through pathways that are deeper than the root zone (e.g. via regional aquifers), then roots are unable to affect the groundwater flow by intercepting it. In this case, the suggested strategy for manipulating groundwater discharge has been to reduce recharge at its source, that is, by reducing recharge at locations where the regional groundwater is replenished – which may be a great distance from the discharge areas.

In relatively flat areas, the rate of groundwater travel may be so slow that the effects of vegetation on groundwater resources are wholly local. This is because the vertical water fluxes associated with tree plantations overwhelm the lateral flow rates of slowly moving groundwater.

2.6 Salt and water

Salts may have accumulated in soils from wind-blown sea sprays, from the weathering of rocks, or from ancient marine sedimentary deposits. They are transported by groundwater and their concentrations in soil water rise where water evaporates or is transpired. Thus, soils in the root zone of vegetation tend to accumulate high concentrations of salts in a characteristic bulge. Saline seepages at the surface display this bulge to the extreme, where salt crystals cover the land surface during dry periods. Water moving through or across these zones in wetter periods carries salt-laden water into streams.

Recharge varies across landscapes



Near ridge-tops with thin soils and fractured bedrock, percolating water quickly passes through the root zone. In mid slope positions, more water is absorbed by the deeper soils there, leaving less to drain to the watertable. In footslopes, groundwater flow tends to emerge in springs and seepages, so recharge there is zero.

The water recharge in hillslopes can mobilise salts in different ways. Under high recharge rates, fresh rainwater leaches salt from the soil profile to the watertable, eventually purging the profile locally. Soils can therefore be salt-free, but the underlying groundwater may be the recipient of the salt, which moves downslope towards saline seepages and streams. On the other hand, locally reduced recharge (under a tree plantation for example) can be the cause of local salt accumulation in the root zone if saline inflows continue from upslope.

Salt storages in the profile are quite dynamic, moving vertically and laterally through the soil and landscape, in short or long timescales. Their manipulation requires good understanding of the salt stores and their location, and how they are mobilised by recharge, groundwater movement and water use by vegetation.

Groundwater is simply a detained storage for water that passes through the soil profile. It is not static after it joins the watertable, but moves under gravity towards seepages and streams. Whether it is used as a resource or manipulated for salinity control, it can be managed only if we know how it responds to changed recharge inputs and the rate at which it travels through various subsurface pathways. The time taken for its journey can be only a few days from streamside areas, or it can be many decades in extensive regional groundwater systems. The amount of water intercepted or taken up by the vegetation determines how much of it remains as a stored resource, and how much can lead to landscape degradation through saline discharge

Two-year-old radiata pine plantation on farm at 700mm rainfall in Billabong Creek Catchment, New South Wales.

3. Planted Forests and Water Issues

The development of plantations and farm forestry is faced with the challenges of achieving economic and environmental outcomes at farm, landscape and regional levels. One major challenge is management of the interactions between water, plantations and land use to achieve sustainability in the broad sense.

Australia’s total plantation area in 1999 was 1 337 300 ha, made up of 71% pines and 29% hardwood (mostly eucalypts). The 2020 Vision target is 3.3 million ha. Almost 95 000 ha were planted in 1999. Of this, 89% was eucalypts. This altered balance between eucalypts and pine plantations does not imply that existing pine areas will be replaced by eucalypts, but rather that greater areas of eucalypts will be established on cleared farmland that presently carries only very small areas of remnant forest. Most of the plantation expansion is foreseen in Western Australia, South Australia, Victoria and NSW.

Expanded plantation areas can impact on the proportion of rainfall that eventually appears as streamflow or groundwater. The sum of these sources (stores) comprises our water resources. They are unevenly distributed, and are affected in different ways by vegetation change. The effects on water resources of the total expanded plantation area is therefore not the critical issue. The issue is where the plantations will occur, and what size they will be in relation to the affected landscapes and the nature of the water resources. In some cases, the effects will be confined to the farm scale; in others, the effects may have an impact on water yield or quality of water available downstream. The diverse nature of these impacts needs to be firmly established and understood in any analysis about the relative benefits or disbenefits of afforestation.

The actual effects of tree plantations on the water balance and availability of water resources depend on regional weather attributes, vegetation cover, plantation management and rotation length. Any integrated approach to the management of water resources in a specific climatic region must take into account *all* uses and practices which impinge on water availability and demand. In addition to water use by new plantations, for example, existing agricultural practices and infrastructure are relevant: pumping of stored water; flood irrigation and leaking irrigation channels that can be wasteful of water; while the overall impact of farm dams on water yield is unknown.

3.1 Regional water issues

We now consider case studies of representative regional perspectives and issues where industrial forestry and farm forestry are advancing rapidly. The aim is to highlight the diverse regional factors driving plantation establishment and land use changes, their environmental attributes, and the likely impacts of plantation forestry on land and water resources. The water and plantation issues in the four regions described below are examples of scenarios which occur elsewhere in the country. These regions also have rainfall and commercial infrastructure necessary to support a viable forest plantation industry. The analysis illustrates the spectrum of tradeoffs that must be considered while embarking on large-scale plantation development in any region. The tradeoffs become complex where there is competition for access to water resources, where river salinity is increasing, where agricultural land is being degraded by dryland salinity, and where environmental flows need to be restored.

Land use patterns are changing in these regions for other reasons, and their effects on water resources should also be critically assessed.

3.2 The Murray Darling Basin: southern high-rainfall region

In the north-eastern catchments of Victoria within the Murray Darling Basin (Fig. 1), a forest plantation base sustains a viable and valuable industry. The existing plantation area is 39 000 ha (almost all softwood), on land which originally was mostly native forest. Based on criteria of suitable soils and rainfall – minimum 650 mm per year – an additional 400 000 to 450 000 ha of cleared private land has been identified as suitable for the establishment of commercial plantations[16].

The north-eastern river catchments in Victoria contribute 38% of the total water for the Murray Darling Basin System, although they comprise only 2% of the total System area. Consequently, the north-east is a strategic and very important source of water in the basin. A significant increase in the forest plantation base could impact on the Basin’s overall water yield.

These catchments also discharge a high salt load into the Murray River as a result of clearing the native vegetation over the past century.

Figure 1. South-eastern Australia; the numbers at the top indicate the value of isohyets in millimetres per year

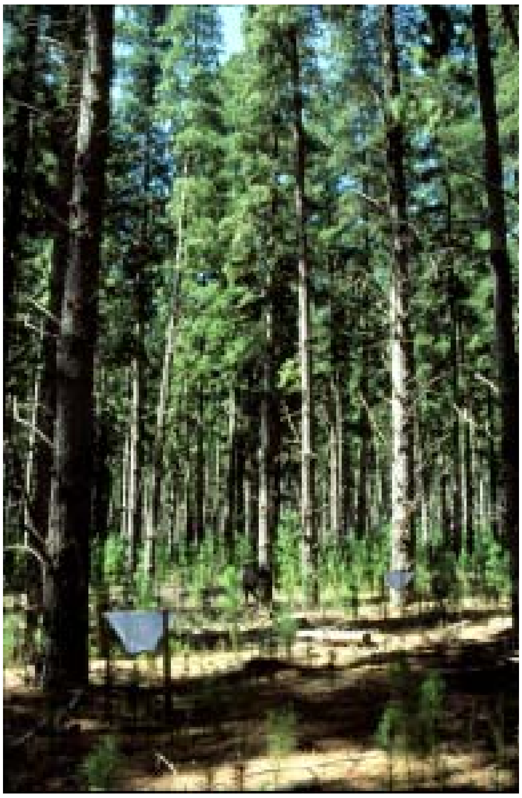
This salt load currently contributes about 31 EC (Electrical Conductivity) units annually to the river salinity at Morgan, South Australia. If no salinity intervention programs are implemented, it is expected that the salt load will increase by 1% annually over the next 30 years, raising the river salinity at Morgan by a further 10 EC units. Within the north-eastern catchments themselves the estimated rate of spread of saline discharge areas is 5.8% per annum without intervention, resulting in an additional 117 000 ha of salt-affected land over the next 30 years[14].

In New South Wales, an analogous situation occurs in the Middle and Upper Murrumbidgee Basin, the catchment upstream from Wagga Wagga (Fig. 1). In this basin, mean annual rainfall varies from 500 mm in the west to 2500 mm in the southern mountain regions. The median annual runoff from the entire basin (26 863 km^2) is 185 mm. In the high-rainfall sub-catchments, mean annual runoff exceeds 800 mm. Again, this portion of the Murrumbidgee Basin is a major source of water resources for downstream water users. The region already supports extensive tree plantation areas in the higher rainfall regions (mostly softwoods). A hypothetical scenario[20], where an assumed land cover of grassland was completely afforested by pines, has predicted that local declines of runoff of up to 500 mm are possible in the wettest parts of the catchment. Smaller declines would occur elsewhere, but the loss in runoff would exceed 100 mm over 75% of the catchment where grassland is replaced by trees. The productivity of tree plantations, in general, increases if the trees do not suffer from water stress, other variables being equal. Therefore, future expansion of plantations could exert pressure to access locations in the higher rainfall zones. The wetter the area where plantations are established, the greater will be the impact on residual water resources. However, in practice, new plantations would rarely replace land under pasture completely; rather plantations are likely to be established in small units occupying varying proportions of individual farms and the landscape.

3.3 The Green Triangle

The Green Triangle region includes the south-east of South Australia and the south-west of Victoria, an area of 55 000 km^2 (Fig. 1). All but 7% of the area has been cleared of native vegetation, and land use is now dominated by rain-fed agriculture (4 600 000 ha). An estimated 83 000 ha is irrigated – mostly pasture, but including an increasing area of vineyards. There is a well-established softwood forest plantation industry covering 150 000 ha, 3% of the area. The wood and paper products manufacturing sector, with a gross annual output of more than one billion dollars, supports a dynamic value-adding forest industry vital to the regional economy.

The region's annual rainfall varies from 420 mm in the north to a little more than 800 mm in the south, so much of the area is semi-arid. Most of the rain infiltrates the permeable soils, with the result that the region's water resources are primarily drawn from underground aquifers. Recharge to the near-surface unconfined aquifer occurs in winter and spring, and is estimated to be only 10-15 mm in the north, increasing to more than 150 mm in the south. Extraction of water from the aquifer is regulated in separate management zones, such that the volume extracted does not exceed the long-term average annual recharge in each zone. In 40% of these zones, the permissible annual volumes for extraction account for the full estimated recharge volumes. The total annual water volume allocated for extraction in all zones is about 1 000 000 ML[7].



A thinned stand of radiata pine near Mount Gambier, South Australia

Harvested logs in a 35-year-old radiata pine plantation near Mount Gambier, South Australia

Until 1990, tree plantation areas were expanding at a modest rate of 1500 - 2000 ha per year of radiata pine. This is changing. Currently, there is a shift towards Tasmanian blue gum (*Eucalyptus globulus*) plantations, which are being established at 20 000 to 40 000 ha per year on rain-fed farmland. If this momentum continues, in less than ten years the blue gum estate will exceed the pine estate which has been established gradually since the 1880s.

The changed nature of the vegetation cover will affect the quantity of rain that passes through the canopy, transpiration and hence the amount of rain which infiltrates the soil. The interception loss of a fully closed radiata pine canopy is about 20% to 30% of annual rainfall while for blue gum this may be 15% to 20% of the annual rainfall. The interception loss from pasture is smaller, but not zero. While accurate data for the interception loss are not yet available, the best approximation will for the annual interception loss is about 150 mm per year for pines and 110 mm per year for blue gum, in a 700 mm annual rainfall zone. It should be noted that the difference in aquifer recharge between trees and pastures in this environment is not entirely due to the difference in recharge but also due to the difference in transpiration. In the worst case, with all plantations unthinned and of the same age, the net reduction in recharge may be less than 100 000 ML, or about 10% of the current annual extraction rate. However, the loss will be reduced to a fraction of this amount because planting, thinning and harvesting operations would occur progressively and at any time there will be a mosaic of canopy cover and age class of plantations in the region. Thus, the impact of forestry on water would be moderated by the proportion of the area where the tree canopy is absent or incomplete.

The net effect of stand thinning and harvesting on groundwater is not known for certain. A recent study of blue gum sites in the Green Triangle suggests that thinning changes the balance between interception and transpiration more than it changes water use of the tree stand. It appears that the remaining trees are able to transpire more water (presumably because their roots have less competition), even though the interception loss is diminished by partial removal of the stand canopy.

A second factor of concern in the Green Triangle area is whether blue gums are more capable of exploiting aquifer water than pines. There is evidence to show that pine plantations do not extract water from the aquifer where they are established on sites with a deep soil profile. The relative water uptake rates by pines and eucalypts from groundwater is likely to depend on how deep the watertable is, rather than on large differences between tree species. This question needs to be resolved, especially in regions where groundwater is the major water resource and where plantations are being established in areas with varying depth to watertable.

The water issues in the Green Triangle region are clearly different from these in the high-rainfall areas of the Murray Darling Basin. The latter area is a net exporter of water, a provider of water resources for downstream users. The issues there relate primarily to whether an expanded plantation forestry will significantly diminish the water flowing from the region. In the Green Triangle, the issue is the perceived threat that expanded plantation forests pose to the water resources for other competing land users (including irrigators) of the region. Most rain that falls there is stored underground and used locally in a competitive and strictly regulated way. No large artificial storages exist to buffer the water demands from one year to the next. Some water flows from the region to the sea during wet periods. Local recharge is consumed close to where rain falls. Expanding plantation forests would significantly affect recharge to the aquifers and this tradeoff should be evaluated in relation to the economic value of the industry and the needs and value of other water users.

3.4 The Macquarie Valley

The Macquarie River is the largest river in the Central West of New South Wales (Fig. 1). Its flow is highly regulated by the water storages of Lake Burrendong and Lake Windemere, and discharges into the Ramsar[*]-listed Macquarie Marshes. Downstream from the Marshes, the Macquarie and Castlereagh Rivers join before flowing into the Darling River. The eastern quarter of the Valley has an annual rainfall of 600-800 mm, and becomes progressively drier towards the west. The Macquarie Basin supports a diversity of rain-fed and irrigated agricultural enterprises, providing 11% of the gross value of New South Wales agricultural output. Plantation forestry in the higher rainfall areas of the Valley is a significant industry. Expanded and innovative plantation forestry is seen as a future land use option and an economic driver for the region, potentially valuable for checking the increasing salt loads in the river and for controlling dryland salinity at the farm level, particularly in the middle half of the Valley where rainfall is 400-650 mm[15].

Salinity in the river is increasing as a result of land management practices over the past century. A recent study into the costs of salinity in the Macquarie Valley estimated that the current costs

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[*] The Convention on Wetlands, signed in Ramsar, Iran, in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

are about $30 million per year[8]. The Murray-Darling Salinity Audit in 1999[11] predicted that in a ‘business as usual’ scenario, end-of-valley salinity would exceed 800 EC by the year 2020, and 1500 EC by 2050. Where the river enters the Macquarie Marshes, salinity would rise to 2110 EC by 2100, well above the threshold of 1500 EC for healthy wetland ecosystems.

Government agencies have developed salinity control strategies with objectives that will protect within-valley land and water resources, aquatic and terrestrial nature conservation values, indigenous cultural heritage and built infrastructure, as well as the shared water resources of the Murray and Darling Rivers. The strategies recognise the importance of including market-based approaches to revegetation and plantation forestry.

The role of forestry for salinity control in the Macquarie Valley would be to reduce recharge to groundwater, and thereby prevent the further expansion of saline discharge areas lower down in the landscape. This strategy accepts the premise that tree plantations, if correctly placed in the landscape, can have the maximum effect on groundwater recharge and minimum effect on surface water yield.

A recent investigation has assessed the economic and salinity outcomes of salinity intervention options in the Valley. Preliminary results indicate that if 35% of the cleared land in the upper Macquarie is converted from grazing to plantation forestry, then after 100 years of 30-year plantation rotations, salt loads into Lake Burrendong would still increase by about 45%, and annual water yield from the catchment surface water yield would decrease by 200 gigalitres - about 5%[15]. It is also estimated that the ‘business as usual’ scenario could lead to end-of-valley salt load doubling by 2020 and trebling by 2100. The Valley’s comparatively low rainfall means that the commercial incentives for tree plantation establishment are somewhat less than in higher rainfall areas. The attractiveness of tree plantations therefore depends on their public as well as private benefits. The public benefit, in this case, accrues to the in-valley as well as downstream water users in the form of reduced river salinity. The environmental benefits to the Macquarie Marshes, by preserving them, cannot be quantified readily, but they must be valued as essentially priceless. The private benefit accrues to the landowners and industries who sell and process the wood products and whose lands are protected from the ravages of dryland salting.

The local economic viability of plantations in the Macquarie Valley is therefore only one factor that should influence their future establishment. In view of anticipated increases in river salinity and its disbenefits, ‘business as usual’ is not an option. Farm forestry clearly has a place in the valley to mitigate the encroaching effects of salinisation for the overall public benefit and as a driver for the much needed economic and employment growth in the region.

Maintaining current water flows for irrigation and the river environment appears to be incompatible with reducing the salinity problem. If tree plantations are used to minimize salt mobilization from farmland, then river flows (and salt loads) will be reduced. However, we are less certain about the effect on salt concentrations in river waters. These may rise during low-flow periods and may affect in-valley water users.

Broadscale revegetation (afforestation) at strategic locations in the landscape appears to provide opportunity for the use of trees to manage salinity with relatively modest reduction in streamflow over time. The nature and management of forested catchments is critical to achieve a desired outcome. The modelling already done for a future scenario shows that we require a better understanding of hydrogeology at local scales, and better knowledge of tree water use, growth and survival where plantations could be established. Modelling of river flows should examine not only the changed salt loads, but also the in-valley variation in river salt concentration.

3.5 Western Australia: south-western region

The south-western region of Western Australia includes 18 million ha of agricultural land where the annual rainfall varies from 1400 mm in the south-western corner to around 250 mm at the limit of agriculture (Fig. 2). The rainfall pattern is strongly seasonal, with wet winters and dry summers. Expanding areas of dryland salinity and salinisation of water supplies are major problems that threaten sustainable agriculture in the region. The problems have been emerging since the 1920s, but only since the 1970s has the full extent and seriousness of the situation been realised. Currently, production from 1.6 million ha of agricultural land is affected by salinity. Although salinity has always been a major feature of the landscapes in the lower rainfall zones (<600 mm per year) prior to agriculture, salinised areas are increasing rapidly as a result of land clearing in the past century (see box).

The issues confronting the region involve both the salinity of surface waters from higher rainfall catchments, and the effectiveness of tree plantations for controlling dryland salinity. The processes that cause salts to move into surface waters or into saline seepage areas differ across the area, and depend on local geology, topography and water balance. In all areas, the soil regolith contains a store of salts, increasing from 100 t ha^{-1} in the west to 10 000 t ha^{-1} inland. Under natural vegetation, this salt store is largely retained below the root zone and is relatively immobile, but the changeover to shallow rooted, annual agricultural plants has resulted in drainage through the soil profile of up to 200 mm per year, averaging about 25 mm per year over the region. This causes watertables to rise and mobilise the dissolved salt. Revegetation with trees and perennials is seen as the most important tool for restoring the hydrologic balance.

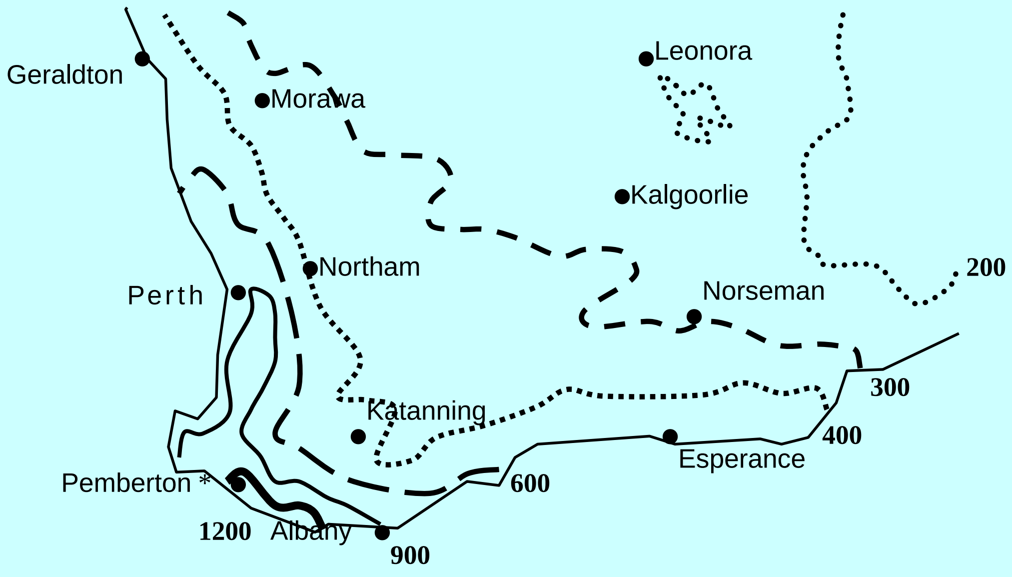
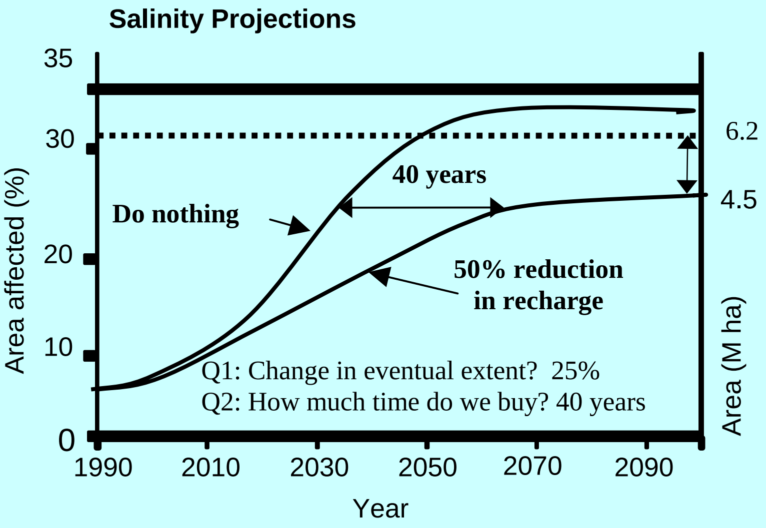


Figure 2. South-western region of Western Australia; the numbers indicate the value of isohyets in millimetres per year

Expanding salinised areas in Western Australia

Areas affected by salinity in Western Australia are still increasing. Predictions indicate that in a 'do nothing' scenario, the area increases to 6.2 million ha by about the year 2075. If sufficient revegetation is established to reduce recharge by 50%, the area salinised by 2075 is 4.5 million ha, 25% lower than the 'do nothing' case. If nothing is done, the 4.5 million ha become salinised by the year 2035. This means that afforestation could delay the eventual salinisation by 40 years, but only partly limits its eventual extent.



The impact of increased recharge to groundwater is felt at different scales, depending on the nature of the aquifers. Some are seasonal and of local extent, others are regional. Aquifers also differ in response time, so the effect of a change in recharge rate may take months or many years to appear. Correspondingly, the remedial effect of tree planting on salt discharge shows the same variability, and may be impossible to predict without adequate knowledge of aquifer properties and the imposed changes in water balance.

For these reasons, Western Australia has supported research over the past 30 years into the processes that drive salinisation, and the effectiveness of tree plantation strategies. The research is necessarily location specific, because the hydrologic balance across the region varies greatly with the climate, and the growth and survival of plantations depends on local environmental factors.

At the same time, legislation has been enacted to control or eliminate new land clearing in water supply catchments, and many areas already cleared have been revegetated. For example, in the Helena catchment the result[4] has been a current reduction in stream salinity 15 mg L^{-1} y^{-1} [23 EC units per year]. Furthermore, the delay between land clearing and the change in stream salinity appears to be 10 to 12 years, suggesting a similar time scale may be needed before the effects of revegetation on stream salinity are seen.

Tasmanian blue gums (*E. globulus*) are being planted on farmland in the wetter areas. With about 153 000 ha established in the last 10 years, there is now a major eucalypt plantation resource in the area. Although the initial impetus for this development was the expected economic and environmental (salinity mitigation) benefit, in reality most of the areas currently under blue gum plantations are not on land affected by dryland salinity. Blue gums were chosen in preference to the softwoods traditionally planted in the south-west, not only for the quality of their woodchip products but also because of their high biomass productivity and the ability of their deep roots to extract water from the saturated groundwater zone. Although there are large areas of successful forestry in the region, balancing productivity and drought risks is an important emerging issue in this drought-prone region, where dry summers are the norm. The blue gum plantations therefore have been confined so far to the >600 mm annual rainfall zone. More recently, major initiatives are in progress to develop a commercially viable revegetation program through the deployment of mallee eucalypts and *Pinus pinaster* in drier areas (<600 mm annual rainfall)[4].

It was initially speculated that dryland salinity in the >600 mm rainfall zone could be controlled if tree plantations were established on 20%-30% of a farm's area. The realities of farm economics will require that these plantings produce a commercial return in their own right either through tree-based products or by the provision of environmental services (credits). Further development and evaluation of tree species that satisfy hydrological, commercial and environmental criteria is needed. And in hindsight, experimental evidence and modelling shows that the hydrology of different landscape types determines whether tree planting can achieve a desired salinity abatement outcome. In particular, choice of the optimum farming methods for salinity control must rely on a good understanding of the subsurface flow systems involved, especially whether they are local or regional in extent.

A productive stand of *Pinus pinaster* in Western Australia

Oil mallee in farm forestry in low-rainfall, salinity prone area in Western Australia

4. Effects of Afforestation on Water

Our knowledge of the effects of afforestation on water resources is usually site specific. Invariably, we are expected to extrapolate observations to other sites where this type of information is not available. This can be done reasonably well if we know how the processes that determine water balance vary across different landscapes, climates and vegetation types. There is good understanding of the physical behaviour of catchments, and how their water balance is affected by soils, topography and climate. This needs to be complemented by knowledge of how different plantation types, tree species, climate, management practices and water interact over the long term.

In this section, we examine several of the key tree-environment interactions that influence water use, and summarise the evidence on how afforestation affects water resources.

4.1 Interactions between water and trees

Significant differences exist between water use patterns of the tree species most favoured for plantations (see box). The key variables that affect water use by trees are leaf area, the rate of water transpiration through leaves and tree rooting patterns.

4.2 Leaf area

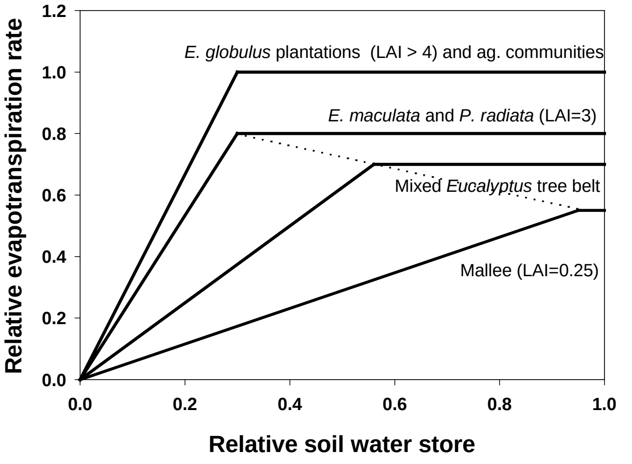
Water use by trees depends on leaf area and the rate of water vapour transfer from leaves. In most Australian environments, native forests develop and retain leaf areas that are in dynamic equilibrium with long-term mean annual rainfall (a rough surrogate of the amount of available water), and most rainfall is transpired. This relationship seems to be independent of vegetation types, at least among Australian eucalypts.

4.3 Leaf transpiration

The rate of transpiration per unit of leaf area is determined by the difference in water vapour pressure between the inside and the outside of the leaf, and by leaf conductance to water vapour. Conductance to water vapour is controlled by opening and closing of the stomata.

Trees and water use

A convenient basis for comparing patterns of water use is to express actual water use of plant canopies as a proportion of the maximum possible evaporation rate, which depends on available energy and wind convection. This proportion is referred to as the crop factor (k). It varies with tree species and the available moisture in the plant root zone. The dependence of k on soil water is shown for stands of different tree species[21].



This illustrates first, that when soil moisture is high, some tree stands like blue gums (*E. globulus*) and actively growing crops transpire water at the maximum possible rate, corresponding to k=1. *Pinus radiata* and mallee species transpire water at about 80% and 55% of the maximum rate respectively. Second, when the relative soil moisture drops below a threshold value, water use declines, until it approaches zero when the soil is totally dried out. The threshold where this occurs also appears to vary from one tree species to another.

A high rate of stomatal conductance results in high rates of water use. For a given stomatal conductance, the maximum rate of transpiration occurs when the leaves are surrounded by dry air. Stomata however are also highly sensitive to the dryness of the surrounding air (measured by the vapour pressure deficit, or VPD), so that as VPD increases, stomata close to prevent excessive loss of water through the leaves. This stomatal closure in response to dry air means that maximum rates of transpiration usually occur at a relatively low VPD. As VPD increases from zero, transpiration increases very quickly before leveling off at a plateau, or even decreasing at very high VPD.

Under well-watered conditions, there can be substantial differences between species in the relationship between stomatal conductance and VPD. For example, at low VPD, stomatal conductance can be up to four times larger for *E. globulus* than for *P. radiata*, but in very dry air, the stomata of blue gum leaves close more and inhibit water loss to a greater degree than do those of pines.

The physiological behaviour of plantation species therefore affects water use in a way that is highly climate dependent. In an environment with hot, dry winds – assuming plentiful soil moisture – pines would be expected to use more water than eucalypts. In humid environments, the converse may be true.

As the soil dries out, stomatal conductance changes in a complex fashion. If water supply to the roots is limited because the soil is dry, the leaf stomata must close as the VPD increases or the leaves would wilt because the rate of water supply to the leaves would not be able to keep up with the rate of water loss. In some species it is possible that the roots send chemical signals to the leaves when the soil is dry, enhancing the stomatal response to VPD.

Water loss also has the effect of cooling the leaves. In hot environments during summer there is a risk that if the stomata close too much, leaf temperatures will increase to lethal levels. At sites where trees are stressed by dry soils during drought, eucalypts often respond by shedding leaves, thereby lowering their water use and making the limited water available to a smaller leaf surface area, so that leaf temperatures can be reduced below lethal levels.

In the longer term, species selection occurs, and trees that maintain larger leaf areas during summer (e.g. *E. globulus*, *E. nitens*, *E. grandis*, *Corymbia maculata*) do not survive in these conditions. Survival and growth of plantation species introduced to areas where soil moisture is persistently depleted, either by drought or the plantation itself, will be a problem. Selection of provenances within species may also be important in improving the potential for good survival and growth of species planted in these areas.

4.4 Tree rooting patterns

Root architecture differs between tree species, and this can cause differences in water use rates (see box). Some *Eucalyptus* species are also known to withdraw soil water from very deep in the soil profile, and to take up fresh and moderately saline groundwater at rates of up to 3 mm per day.

Some tree species are likely to be more effective for controlling downslope saline seepages than others. However, other physical factors (e.g. slope, hillslope length, soil permeability) also affect watertables and seepage zones. Thus, the efficacy of plantations for saline discharge control must be treated as a site-specific question.

Generally, if plantations have rooting patterns capable of extracting water from sources additional to rainfall (i.e. groundwater), they are likely to sustain a higher leaf area. Up to a limit, this should result in greater productivity and greater water use, at least in the same species. The greater leaf area will not be sustainable if such plantations have depleted all the stored soil water, if flows of groundwater to the plantation are lower than the excess of evapotranspiration over rainfall, or if groundwater uptake results in a continuing rise in salinity in the root zone.

Water extraction by tree roots

At a site near Deniliquin, groundwater use rates of *Corymbia maculata* (spotted gum) and *E. grandis* (flooded gum) plantations were compared. The spotted gum produced a much greater root length density in the capillary fringe above a shallow, fresh watertable than the flooded gum, and transpired water at close to the maximum possible rate[17]. With far fewer roots in the capillary fringe, flooded gum had less access to groundwater and transpired 400 mm per year below the maximum possible rate[17]. Despite this, the flooded gum had a greater stem volume per hectare at age 4, probably because the spotted gum was allocating more growth into roots rather than stems.

In Western Australia, blue gums depleted soil water to depths up to 9 m, but their effect on lowering groundwater was localised to some tens of metres beyond the edge of the plantation.

A few generalisations can be made, based on physiological observations and supported by field studies of water use. These are:

For well-watered soil conditions

- *E. globulus* plantations transpires water at close to the maximum possible rate.
- *P. radiata* plantations transpire water about 70% of the maximum possible rate.
- When the air is very dry, *P. radiata* transpires more water than *E. globulus*.

For drying soil conditions

- The risk of death in *E. globulus* grown under otherwise well-watered conditions is high in drought-prone environments.
- Other eucalypt species (e.g. *E. nitens*, mallees) show different patterns of water use in drying soil, and probably different sensitivity to drought.

For all conditions

- Trees of all species intercept more rainfall than crops or pastures. But interception by crop and pasture is not zero, as some have believed.
- Deeper roots of all tree species can extract more water from the soil than those of crops or pastures and thus also reduce recharge.
- There is significant genetic variation between tree species in their ability to use groundwater.

All these differences should be recognised and accounted for to provide a better basis for matching species with landscape features for sustainable reforestation programs.

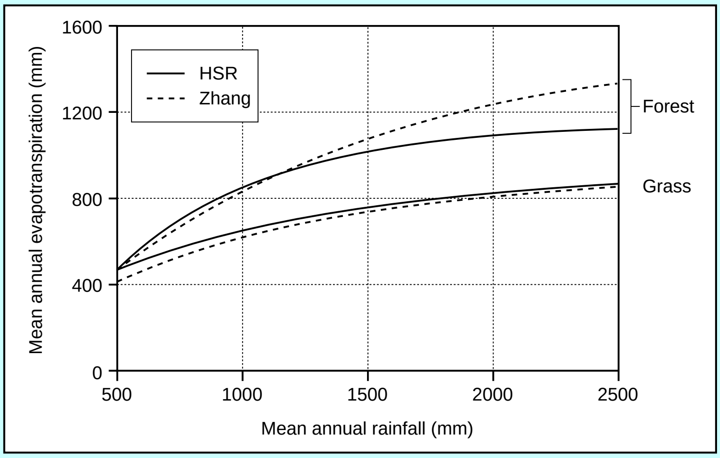
4.5 Annual water yields

Annual water yield is the sum of surface and groundwater outflow from a catchment. By using annual data, we can neglect the seasonal differences in rainfall and groundwater storage, and compare the longer-term differences in water yield caused by various land uses. Water yield itself is highly variable from year to year, basically because of differences in annual rainfall. The major water loss is evapotranspiration (ET), the sum of evaporation from plants (including both transpiration and evaporation of intercepted water) and evaporation from the soil surface. ET is far more uniform than rainfall from year to year in a given plant community. The biggest change in catchment water balance resulting from tree plantations is their effect on evapotranspiration, so the following discussion concentrates on this aspect.

In southern Australia, mean annual ET is usually less than 650 mm in grasslands, but can approach 1300 mm in forests. ET tends to increase with mean annual rainfall (see box).

Evapotranspiration in forests and grasslands

A relationship between mean annual ET (and hence runoff) to mean annual rainfall in Victorian catchments with different proportions of grassland and forest cover has been developed[6]. It is based on long-term annual rainfall/runoff data for 19 large catchments, with mean annual rainfalls ranging between 500 and 2500 mm. The relationship demonstrated that there were clear differences between ET rates for grassland and eucalypt forest catchments. This was illustrated with a pair of curves that denoted the differences along a rainfall gradient.



According to these curves, a fully forested catchment evaporates 40 and 215 mm more per year than a fully grassed catchment with mean annual rainfalls of 600 and 1300 mm, respectively. The climatic zones where Australian plantations have been established historically, and where future plantations are envisaged, have 500-1200 mm of rainfall annually[19].

Studies done so far have not discriminated between different types of forest cover, or the changing dynamics of forest canopies where plantations are progressively thinned and harvested. A managed plantation has, on average, smaller and changing leaf area than an untended forest, so its ET would be correspondingly smaller than its unmanaged counterpart.

Plantations established on cleared land take time to develop, and during the establishment period the water yield changes gradually as canopies and roots develop (see box). Even before tree canopies change the character of the vegetation cover, land preparation for tree planting (e.g. deep ripping, contour furrowing) can also retain more runoff on hillslopes and reduce streamflow during rain.

Pines intercept about 10% more rainfall than do native eucalypt forests, which is enough to account for the higher water use by pines observed in Australian studies. But experience in South Africa shows that water use by intensively managed eucalypt plantations exceeds that of pines. Differences in climate, soils, tree species or insect predation in South Africa may account for this contrary result. There are insufficient Australian data to compare the water use of intensively managed pine and eucalypts plantations in the same environment.

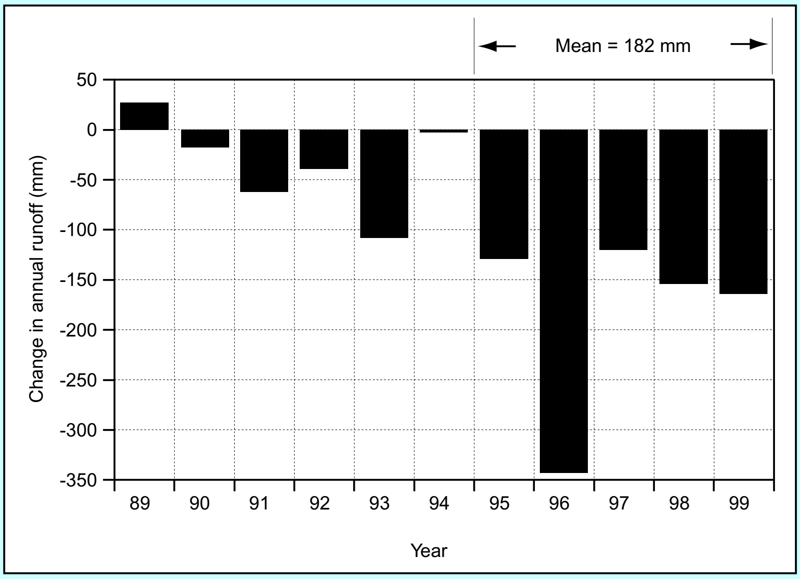
Using the data that we have, estimates have been made of the reduction in mean annual water yield that would result from complete afforestation of grassland with pine or eucalypt plantations. The reductions in mean annual water yield are greatest in high-rainfall areas, and pine afforestation has a greater impact than native eucalypt forests. For areas with 800 mm mean annual rainfall, mean water yield may drop by 165 mm under eucalypts and up to 220 mm under pines. In particularly wet years, yield reductions may exceed these mean annual changes. These estimates, however, do not take into account the dynamic nature of the site occupancy of plantation estates in a given catchment or landscape.

4.6 Changes in seasonal flows

So far, we have described the impacts of tree plantations on annual water yields from catchments. In river basins where large reservoirs have been constructed, the seasonal flows are buffered by the river storages, and water released for downstream users is highly regulated. But where rivers are not regulated, seasonal flows are more relevant than annual mean flows. In particular, dry-weather flows and their persistence concern catchment managers. In dry conditions when ET continues in the absence of rainfall, soil water is depleted rapidly; seepages that sustain baseflow dry up, and streamflow ceases.

Water yield from a developing pine plantation

Changes in water yield in a developing pine plantation have been measured at a high-rainfall site near Tumut, NSW. Water yield from the pine catchment, compared with an adjacent grassland catchment, decreased as the canopy and roots developed. The decline in water yield increased steadily for 10 years, and is continuing. The major reduction that occurred in 1996 during a comparatively wet year (1100 mm rainfall versus the mean rainfall of 850 mm) illustrates the sensitivity of yield changes to rainfall[19].



Under these conditions, the influence that enhanced ET from tree plantations exerts on residual streamflow can be high.

In spite of the importance of dry-period flows to water users and aquatic habitat in smaller river basins, there has been little information gathered to assess the effect of tree plantations. Seasonal flows from newly afforested catchments will probably revert to a semblance of their behaviour before the land was cleared (see box).

Because of the leverage effect where rainfall and ET are closely matched, it is misleading to transfer results from one site to another where [rain minus ET] is different. Before land clearing was widespread, this value was very close to zero. Since clearing, ET has been reduced, so streamflows persist. But [rain minus ET] fluctuates erratically between positive and negative values from wet to dry years, even on a seasonal basis, and thus streams often dry up. Pine and eucalypt plantations exhibit different seasonal patterns of water use, so their impacts on seasonal flows – particularly dry-weather flows – will also differ.

These effects on dry-weather flows can be estimated with appropriate analyses. The data collection for this kind of investigation requires ten or more years, and the investigations are costly. Even then, the information gained is site-specific and applicable only to the imposed land use change. This should not preclude field experiments to resolve these questions. Nevertheless, resource agencies and researchers have accumulated large data banks on streamflow; these deserve to be analysed to obtain information on the behaviour of dry-weather flows in relation to land use changes.

A complementary approach is to use ‘best bet’ analyses to predict changes in water yield and its seasonal behaviour based on models of interactions between vegetation, soils and climate. The development and credibility of such models have improved rapidly in Australia, and has been underpinned by detailed studies of tree water use in different climate and edaphic (soil) conditions. It is clearly necessary to continue development and application of these modelling tools at sites where tree plantations may be established.

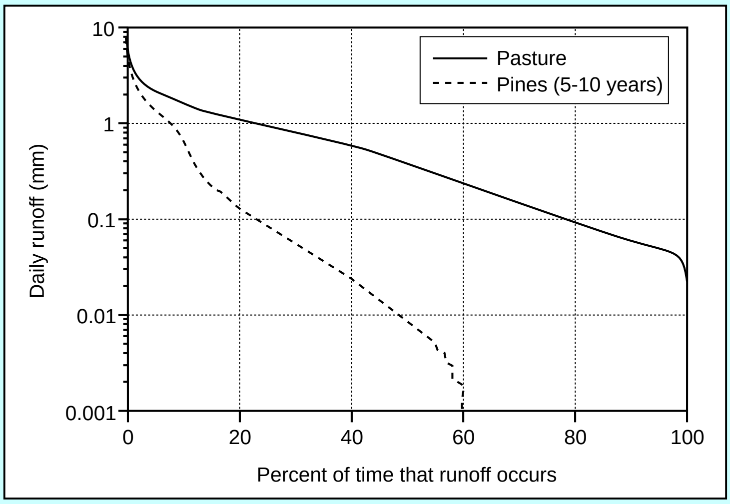
4.7 Impacts on peak flow runoff

Reductions in peak flow can be expected when grassland is converted to plantation forest for several reasons including:

- Interception losses in tree canopies reduce the quantity of rainfall reaching the ground;
- Soil moisture is depleted to greater depths in plantations, so they can absorb more rain before the soil becomes saturated and surface runoff occurs;
- Soil structure under forests allows easier infiltration than in grassland, particularly where livestock have compacted the surface soil; and
- In forests, smaller areas of saturated soils exist adjacent to streams, thus reducing the volume of runoff from these areas.

Changes in dry-weather flows

One of the best local examples of altered dry-weather flows has emerged from the Tumut (NSW) catchment experiments, which compared daily flows from adjacent pasture and pine catchments. The daily runoff from the two catchments is shown, expressed as percentage of time that a certain flow is exceeded. Changes occurred in the duration of daily flows of all magnitudes. Most significantly, the afforested catchment now ceases to flow for almost 40% of the time. In comparison, the pasture catchment continues to flow all year round[19].



New Zealand experience shows that flood peaks decrease by about 60% after grassland is converted to pine plantations. These results are typical of experience with storm runoff after land use is changed from pasture to forest. The benefits for flood damage and landscape erosion are obvious – by reducing flood flows, maintaining land stability and soil cover, preventing river silting and preserving water quality. However, during very minor flood flows, the changes may conflict with downstream water needs, such as the environmental flows needed to sustain aquatic ecosystems, or river flushing to improve water quality.

Flood flows from plantations are more similar to those from native forests than from cleared land. Therefore, afforestation probably results in a return to pre-clearing river flow regimes in catchments where there are no large artificial storages. However, if flows in these streams are already highly allocated for riparian users, then conflicts between agricultural and environmental water needs can be expected.

4.8 Effective catchment areas

Some parts of landscapes may become isolated periodically, in a hydrological sense, from discharge areas or streams. This occurs when upper parts of hillslopes dry out, and there is no downslope water movement from these areas. Then, the streams only receive subsurface flow from nearby parts of hillslopes. These streamside areas constitute the *effective* catchment area for the stream. Its size varies seasonally with rainfall and evaporative demand, and depends on topography and soil permeability.

The effective catchment area is always smaller than the area inside the watershed. The concept only applies where water movement in the landscape follows local topography and not where streams are fed by regional groundwater systems. This has implications for the effects of afforestation in landscapes. If a land use change occurs outside the effective catchment area, then the change has no hydrological effect. If the land use change is inside the effective catchment, then it will affect streamflow.

Identification and measurement of effective catchment areas at locations where tree plantations are planned should be an essential planning tool where water availability is an issue. Specifically, if the plantations are located mostly outside the effective catchment area, then the competition issue diminishes in importance. The effects of plantations or any other land use change in parts of a catchment that rarely contribute to streamflow – especially in dry weather – can be disregarded as far as streamflows are concerned.

The basic methods for applying the concept to catchments with local groundwater flow systems have been developed, but work remains to be done before a useable planning tool is available.

4.9 Time response of landscapes to change

A change in hydrologic balance may be manifested as a rapid response in streamflow, or as a gradual change over many decades. The response time in any situation is determined by a combination of the length of the vegetation growth cycle and how long it takes for the landscape to readjust to the change. Thus, an ‘instantaneous’ change to vegetation caused by wildfire in a small catchment with highly permeable soils, for example, usually results in an immediate increase in streamflow over the following few days or weeks. In a larger catchment with less permeable soils, it may take months for the streamflow to adjust.

Recovery of the vegetation (after disturbance such as fire, harvesting, clearing) has its own timescale depending on how it is managed (replanting etc.). In forests, this may be several decades, as illustrated by the stunning example of decreased water yield that occurred in Melbourne’s water supply catchments after old-growth forest was destroyed by fire in 1939, and replaced by natural regrowth of the same forest species. Now, 60 years after the fire, annual water yields are still several hundred millimeters less than the pre-fire yield. Water resources in other major catchments are also probably readjusting as a result of past clearing. For streamflow responses, the effects are probably fully manifested by now, because the present crops have small hydrological timescales (months) compared with the native vegetation they replaced (decades). The same may not be true for salts that have also been mobilised. Because of the mechanisms involved, salts move more slowly through the landscape, and it is unlikely that equilibrium has been reached with the altered vegetation. However, it is important to realise that the situation is transient rather than static, and we need to know where we are ‘on the curve’. The implications for this are discussed in the following section.

The time taken to feel the full effects of deforestation or reforestation on streamflow will therefore be decades where rotations are long. For salts, it may well be longer, because we are intervening in landscapes where salt movement is already undergoing long-term change. Managing water and land resources in an environment of expanding forests will require better understanding of the timescales over which the impacts will be felt. Plantation expansion itself occurs at varying time scales in different environments, with overlapping cycles of harvesting and replanting.

Break of slope plantations of blue gum in Honeysuckle Creek Catchment in Victoria

5. Effects of Afforestation on Salt

In general, fully stocked stands of trees will use more water than other kind of vegetation. Where rainfall is less than evaporation, the leaf areas that develop use essentially all the available water. An important corollary is that in low to moderate rainfall zones (less than about 800 mm per year), salts accumulated in the subsoil because there was insufficient percolation of water to purge this salt.

Now, where rainfall is less than 800 mm, high recharge under crops or pastures compared with trees is responsible for the increase of saline discharge areas. Thus, after vegetation clearing for agriculture, catchments with higher rainfall tend to yield more fresh water, while drier catchments tend to salinise.

Australia-wide, the Bureau of Rural Sciences (BRS) has estimated that there are about 5.5 million ha of land subject to salinity hazard that also have potential for commercial tree plantations (see box). Most of this is cleared privately owned land in the eastern States. But factors such as infrastructure, market, return on investment and cultural attitudes may mean that only 10%-20% of this land is likely to be actually available for plantation development, unless these impediments are removed. From a forest industry perspective, even a fraction of this land area is a significant potential resource.

Saline hazard areas for tree plantations

About 86 million ha of agricultural land are subject to salinity hazard in Australia. This estimate is based on the extent of lands that are likely to contain salts that can be mobilised together with surplus rainfall (rain minus ET) of less than 125 mm per year. Of this area, 5.5 million ha is judged to have some potential for commercial tree plantations. This requires an annual rainfall greater than 600 mm, with less than 5 consecutive months of rainfall less than 40 mm[18].

Whilst it is a useful initial study, the BRS analysis used an assessment of plantation potential carried out ten years ago[2], which assumed areas with annual rainfall of less than 600 mm may be unsuitable for commercial plantation forestry. This assumption was reasonable then, but in the last few years there has been a great increase in interest in developing new systems suitable for low-rainfall (400-600 mm) zones. For example, oil mallee and maritime pine plantations are already being established in low-rainfall areas of Western Australia to provide both forestry products and also contribute to ameliorating salinity problems. On the basis of the 600 mm lower limit the BRS analysis suggests there are virtually no areas in Western Australia where plantation forestry can contribute to dryland salinity mitigation. This is clearly incorrect and the area of land across the whole nation subject to salinity with potential for commercial tree plantations would be dramatically increased if areas in the 400-600 mm rainfall zone were included in the BRS analysis. In many environments annual rainfall alone is an insufficient criterion to demarcate the land use potential for farm forestry based enterprises.

The current salt stores in catchments have taken many millennia to accumulate so we can assume that they are not increasing, at least at timescales of hundreds of years. What is important is the location of salt stores in landscapes, the rate of mobilization of this salt, where it moves to and why.

The rate of discharge of salt into a saline seepage area (and then to the stream) depends only on the groundwater processes that carry salt to the discharge areas. If plantations do not influence this rate of salt delivery, then the effects of trees on salt within the catchment will be small. If the rate does change but the total salt store does not, trees will affect only the timing of salt delivery and not the volume delivered. If part of the salt store can be immobilised, then salt loads will be reduced permanently. However, this also implies a reduction in water throughput, so water yields become smaller and, due to reduced dilution, salt concentrations may remain unaffected.

This suggests that the approach to revegetating drier catchments to arrest saline discharge might be to restore the original leaf area. Clearly, this is not an option if a region’s agricultural productivity using present cropping patterns is to be maintained. The more realistic question to be studied and answered is whether or not strategic tree plantations on smaller areas can prevent further salinisation, at the same time preserving overall income for landowners and the region as a whole: that is, the integration of trees as a part of the farming system.

5.1 Classification of catchments for salinity control

As discussed earlier, the effect of altered recharge rates on saline groundwater systems can be local or regional. The time to response (change) also differs greatly. The key diagnostic properties of a catchment with respect to its hydrologic response to tree planting are[5]:

- The discharge capacity of the aquifer;
- The nature of the recharge process: diffuse vs localised recharge, its spatial distribution, and the rainfall environment;
- The size of the groundwater system; and
- The salinity of the soil and the groundwater.

If we know enough about these factors at a site, then the preferred strategy for tree use can be selected. In particular, we can estimate whether the response to revegetation will be rapid or slow, and determine the optimum size and location for plantings.

First steps have been taken to generalise the attributes of landscapes and their groundwater systems and to devise a classification system for catchments that is useful for controlling the mobilization of stored salt[3]. The classification emphasises that the **hydrogeological** processes causing land **salination** at a site must be correctly identified; it also lists the data needed to characterise a site's susceptibility to salination, and what is needed to determine whether salination is likely to occur. This type of information is necessary to allow catchment managers to identify the optimum strategies for tree planting in various landscape types, both for salinity control and for sustained land productivity.

Local groundwater systems in landscapes of higher relief extending over a few kilometres are likely to be more amenable to local revegetation strategies. There, shallow groundwater flow may be intercepted and transpired before it reaches the saline discharge areas. If the groundwater is fresh, localised plantings in hillslopes offer opportunities to control salinity. The best positions for such plantings can be found by applying hydrologic models to individual catchments. Although these models require local data on climate, soil properties and topography as well as technical expertise, they are useful planning tools for farm forestry and broad scale plantations. However, the bulk of catchments at risk in Western Australia are too flat, have low transmissivity, or are too salty for small local plantings to be effective; these require revegetation over most of the landscape. There, only about 10% of salt affected landscapes appear to be suitable for local tree plantings.

The areas where regional aquifers dominate groundwater behaviour pose severe challenges to salinity management. In these groundwater systems, there is little opportunity for trees to intercept groundwater once it reaches the regional aquifer. There, the requirement of plantations for salinity control is to reduce recharge to a rate comparable to that under the original native vegetation. Moreover, recharge must be reduced over extensive areas rather than at strategic locations in hillslopes. This requires levels of afforestation that approach the original vegetation cover.

The afforestation area needed in WA for salinity control is much larger than can be supported, in practice, by commercial forestry criteria. Much of the plantings are therefore likely to be noncommercial, unless new markets for the tree products can be developed. Investigations of such products and markets are being vigorously pursued.

Revegetation of saline discharge areas deserves special attention. Trees (of salt-tolerant species) planted in saline discharge areas can lower local watertables for a time, but they do not enhance groundwater discharge from upslope. That is controlled by soil properties and local topography. Salt tends to accumulate in the rooting zone of planted trees, which eventually suffer or die. The area affected by the saline seepage and the long-term salt loads to rivers are probably unchanged.

5.2 Alternative farming strategies

The ability of *E. globulus* to use soil water at high rates and depress watertables is being explored in the context of 'Phase Farming with Trees' (PFT). The concept envisages short-rotation (3-5 years) tree crops that rapidly deplete the water in the soil profile; in the years following tree harvest, agricultural crops can be grown until the increased recharge raises the watertable again[4]. Modelling has shown that PFT could be carried out with an overall rotation period of 15 years, but it would be viable only for certain soil types. The accumulation of salts in the profile may also cause problems. Again, widespread adoption of PFT would be influenced by the commercial value of the short-rotation tree products, which could include biomass for energy production, and would entail major shifts in farming traditions.

In normal short-rotation plantings that do not involve the PFT strategy, *E. globulus* plantations on farmland may experience water stress during the second and following rotations. This is because the first crop, often managed to get high growth rates, would have used (depleted) the water stored in the soil when the site was under pasture. In the absence of a sufficient fallow period to allow re-charge of the profile, the subsequent tree crop (also managed to obtain rapid growth and therefore high leaf area) may run into water stress earlier in the life cycle. In some environments tree deaths are known to occur. Thus the knowledge of this long-term interplay between available water, site environment and management strategies is necessary for balancing productivity goals and drought risks.

‘Alley farming’, where tree belts are interspersed with strips of land for annual crops, is another strategy being practised in the south-west. The aim is to locate and space the tree belts in hillslopes such that subsurface water percolating downslope is intercepted before it reaches the saline seepages. In essence, the tree belts transpire water at a rate that matches the increased recharge under the annual crops. Optimum outcomes from this approach require good understanding of site attributes and local hydrology; in particular, alley farming is likely to be most successful where watertables are controlled by local topographic features rather than by extensive regional aquifers.

The magnitude of the dryland salinity problem and the scale of the revegetation needed to have an impact on it are very large in Western Australia and elsewhere. Greater efforts in farm forestry are necessary if there is to be a prospect of making a significant impact on salinity at a large scale in Australia. To be effective, it will need to be practised over larger areas, both at farm and regional scale. Significant benefits are possible, however, at a farm and catchment scale and these are encouraging further expansion. In several cases, the beneficial effects of afforestation will be apparent more to downstream landowners and water users than to the properties where plantations are established. Planting programs need to be better targeted by incorporating, for example, knowledge of the effective catchment areas in landscapes discussed earlier. Where it can be practised to advantage, farm forestry will need to use new planning tools to select the locations in catchments that optimise on-farm tree and agricultural productivity. It is also essential that planted trees are tended and managed well to fully realize their growth potential.

It is therefore likely that the incentive for reforestation will be strongly influenced by the intrinsic value of the products at the farm gate and the value of the environmental services it can potentially provide beyond the farm gate. The issues of incentives are particularly evident in the lower rainfall regions where dryland salinity is a major threat. In these cases, the questions to be answered relate to the productivity and sustainability across rotations of trees growing in saline environments, and the availability of tools to measure their environmental value.

References

[1] AFFA (2000) Our Vital Resources – National Action Plan for Salinity and Water Quality http://www.affa.gov.au:80/docs/nrm/actionplan/index.html

[2] Booth, T.H. and Jovanovic, T. (1991) Identification of land capable for private plantation development. Report of the National Plantations Advisory Committee, Appendix B, 1-92.

[3] Coram, J. (ed.) (1998) *National Classification of Catchments for Land and River Salinity Control*. Water and Salinity Issues in Agroforestry No. 3, RIRDC Publication No. 98/78;. 37, 16, 6 p.

[4] Harper, R.J., Mauger, G., Robinson, N., McGrath, J.F., Smettem, K.R.J., Bartle, J.R. and George, R.J. (2001) Manipulating catchment water balance using plantation and farm forestry: case studies from South-Western Australia. In: Nambiar, E.K.S. and Brown, A.G. (eds). *Plantations, Farm Forestry and Water*: *Proceedings of a national workshop*. 20-21 July 2000. RIRDC Publication No. 01/20, Canberra, 44-50.

[5] Hatton, T. and George, R. (2001) The role of afforestation in managing dryland salinity. In: Nambiar, E.K.S. and Brown, A.G. (eds). *Plantations, Farm Forestry and Water: Proceedings of a national workshop*. 20-21 July 2000. RIRDC Publication No. 01/20. p. 28-35.

[6] Holmes, J.W. and Sinclair, J.A. (1986) Water yield from some afforested catchments in Victoria. *Hydrology and Water Resources Symposium*, Griffith University, Brisbane, 25-27 November 1986. The Institution of Engineers, Australia, Preprints of Papers, 214-218.

[7] Hopton, H., Schmidt, L., Stadter, F. and Dunkley, C. (2001) Forestry, land use change and water management: a Green Triangle perspective. In: Nambiar, E.K.S. and Brown, A.G. (eds). *Plantations, Farm Forestry and Water*: *Proceedings of a national workshop*. 20-21 July 2000. RIRDC Publication No. 01/20. p. 36-43.

[8] Ivey – ATP (2000) The cost of dryland salinity to agricultural landholders in selected Victorian and New South Wales catchments: Interim Report – Part 2. A report prepared for the Murray-Darling Basin Commission, Canberra.

[9] Madden, B., Hayes, G. and Duggan, K. (2000) *National Investment in Rural Landscapes: an investment strategy for NFF and ACF with the assistance of LWRRDC.* 44 p. http://www.nff.org.au/

[10] MCFFA (1997) *Plantations for Australia: The 2020 Vision.* Implementation Committee, Ministerial Council on Forestry, Fisheries and Aquaculture, Department of Primary industries and Energy, Canberra. 88 p.

[11] Murray-Darling Basin Ministerial Council (1999). *The Salinity Audit: A 100-year perspective*. Murray-Darling Basin Commission, Canberra. 39 p.

[12] Murray-Darling Basin Ministerial Council (2000) (Draft) *Basin Salinity Management Strategy – 2001-2015*. The Council, Canberra. 36 p. http://www.mdbc.gov.au/naturalresources/policies_strategies/projectscreens/pdf/salinity_man_strat.pdf

[13] Nambiar, E.K.S. and Brown, A.G. (eds) (2001) *Plantations, Farm Forestry and Water: Proceedings of a national workshop*, 20-21 July 2000, Melbourne. Water and Salinity Issues in Agroforestry No. 7; RIRDC Publication No. 01/20. 62 p.

[14] North East Catchment Management Authority (NECMA) (1999) Draft North East Salinity Strategy. NECMA, Wodonga.

[15] Powell, J. (2001) Revegetation for salinity management in the Macquarie Basin: a case study in the Murray-Darling Basin. In: Nambiar, E.K.S. and Brown, A.G. (eds). *Plantations, Farm Forestry and Water: Proceedings of a national workshop*. 20-21 July 2000. RIRDC Publication No. 01/20. p. 51-54.

[16] Riddiford, J. (2001) Potential water issues associated with farm forestry expansion in high-rainfall areas of the southern Murray-Darling Basin. In: Nambiar, E.K.S. and Brown, A.G. (eds). *Plantations, Farm Forestry and Water: Proceedings of a national workshop*. 20-21 July 2000. RIRDC Publication No. 01/20. 55-57.

[17] Theiveyanathan, T., Benyon, R., Polglase, P., Myers, B. and El-Gendy, R. (2000) Irrigation management for tree plantations in the southern Murray-Darling Basin. In: Connellan, G.J. (ed.). *Water – Essential for Life*. Proceedings of the Irrigation Association of Australia 2000 National Conference, Melbourne, 23-25 May 2000. p. 52-61.

[18] Tickle, P., Keenan, R., Walker, J. and Barson, M. (2001). Can commercial tree planting help dryland salinity mitigation and meet greenhouse gas abatement objectives? Bureau of Rural Sciences Research Report. Canberra. (In press).

[19] Vertessy, R.A. (2001) Impacts of plantation forestry on catchment runoff. In: Nambiar, E.K.S. and Brown, A.G. (eds). *Plantations, Farm Forestry and Wate:. Proceedings of a national workshop.* 20-21 July 2000. RIRDC Publication No. 01/20. 9-19.

[20] Vertessy, R.A. and Bessard, Y. (1999) Anticipating the negative hydrologic effects of plantation expansion: results from a GIS-based analysis on the Murrumbidgee Basin. In: Croke, J. and Lane, P. (eds). *Forest Management for the Protection of Water Quality and Quantity*. Proceedings of the 2nd Erosion in Forests Meeting, Warburton, 4-6 May 1999, Cooperative Research Centre for Catchment Hydrology, Report 99/6, pp. 69-73.

[21] White, D.A., Beadle, C.L., Battaglia, M., Benyon, R.G., Dunin, F.X. and Medhurst, J.L. (2001) A physiological basis for management of water use by tree crops. In: Nambiar, E.K.S. and Brown, A.G. (eds). *Plantations, Farm Forestry and Water: Proceedings of a national workshop*. Publication No. 01/20, RIRDC Publication No. 01/20. p. 20-27.