Australian Government
Bureau of Rural Sciences

SCIENCE *for* DECISION MAKERS

AUGUST 2007

REVISED EDITION

Plantations and Water Use

Mark Parsons, Ian Frakes and Adam Gerrand

Science for Decision Makers is a series published by the Bureau of Rural Sciences. It describes the latest developments in scientific advice, assessments or tools relating to agricultural, fisheries and forestry industries, including their supporting communities.

Its purpose is to make rural science more accessible to those needing to quickly understand the benefits and implications of the most recent research as a basis for decision-making.

For information on how to subscribe to this series, please see the back of this paper.

Key Points

1. Competition for water has become a major issue in many catchments around Australia. Plantations are a relatively minor land use across Australia and currently occupy a few percent of most catchments. However, because trees use more water than pasture, plantation expansion has become an issue in catchments where water is in short supply.

2. The effects on runoff of land cover change such as reforestation depend on the proportion of the catchment affected. Because rainfall and hydrological factors are highly variable, in small catchments it is difficult to measure an impact if reforestation is less than 15-20% of total catchment area. This threshold is lower in larger catchments. Stream flow from small sub-catchments may become more intermittent if a large proportion is reforested.

3. The plantation forestry industry reports that it is aiming to increase the plantation area in the headwater catchments of the Murray Darling Basin by a total of less than 50,000 hectares by 2020. Studies of two catchments in that region indicate that such forecast plantation expansion may reduce stream flow by up to about 1%. At a local scale, and in particular years, the impact may be significant if new plantations are concentrated in particular sub-catchments.

4. Guidelines can be developed to minimise the impact of reforestation on water supplies. For example, water use is less if plantations are located in elevated parts of catchments or in lower rainfall zones, or if distributed in smaller blocks across a catchment. Water use is also reduced for several years after a plantation is thinned.

Introduction

Increasing demand for water across Australia has led to a growing concern about the potential for land use change to affect the availability of water. Large-scale plantation forestry has been identified in the National Water Initiative as having the potential to intercept significant volumes of water. This paper provides a brief review of scientific literature relating to water use by vegetation in catchments, and shows current plantation areas in major catchments. The paper highlights that there are still a number of limitations to current data and analysis and that are a number of key areas for further research. The paper also addresses assumptions used in previous studies on this topic and summarises results of recent studies based on likely plantation expansion scenarios.

Some hydrological principles

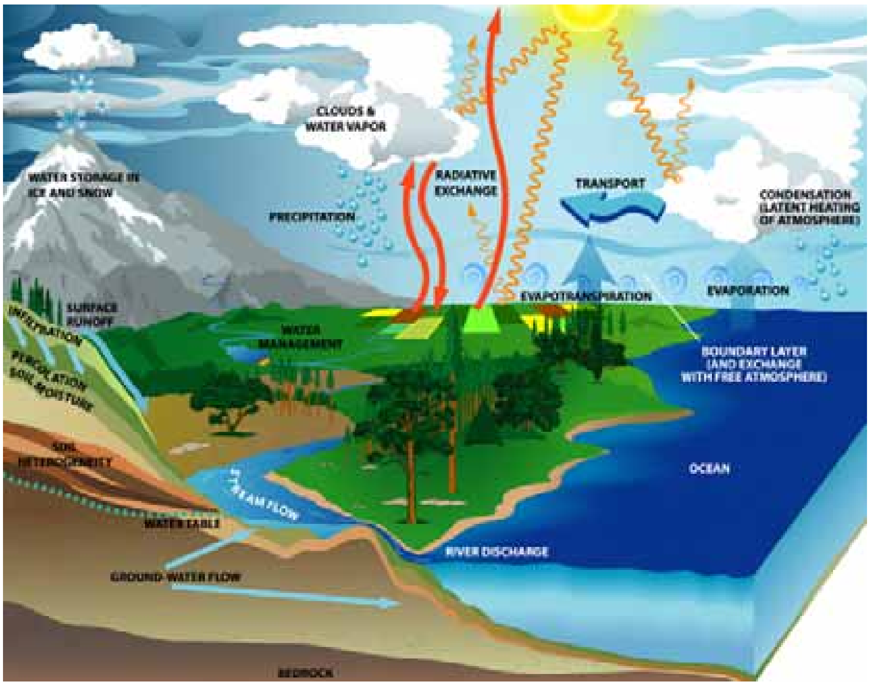
The general pattern of movement of rainfall through a catchment is shown in Figure 1. The proportion of rainfall used by plants depends on soil type and depth, plant type, condition and stage of plant growth and crop management.

Annual crops and pasture use less water than perennial vegetation, including trees, primarily because of their shorter growing seasons and shallower root systems. The canopies of native and plantation forests intercept more rainfall than pastures or other crops, which adds to their higher evapotranspiration.[1]

Runoff and stream flow increase when forests are cleared to make way for farming, as occurred over large areas of Australia following European settlement. Until the 1980s, most plantations were pines established on native forest sites. Since the 1980s, most plantations–pines and eucalypts–have been established on sites from which the forest was cleared many years previously to provide farmland.

Runoff and stream flow change following clearing of forest and reforestation of farmland. Data from many published studies show that the amount by which runoff changes depends on rainfall (Figure 2). For example, where mean annual rainfall is 1,000 mm/year, on average the runoff changes by an amount equivalent to 200 mm/year of rainfall.[2] The change in a particular location will also depend on soil type, topography, position of a plantation in the landscape and the annual distribution of rainfall.

FIGURE 1 The Hydrological Cycle of Water Through the Environment.

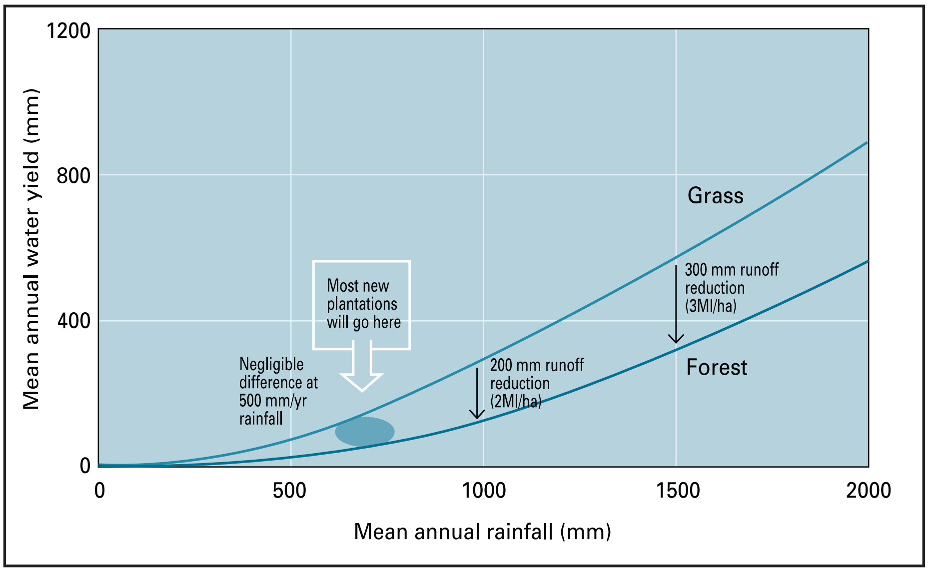


Source: United States Global Change Research Program

1 Evapotranspiration is the sum of water vapour that diffuses into the atmosphere from vegetation, soil and water surfaces.

2 100 mm of rainfall equates to 1 megalitre per hectare.

FIGURE 2 Water Yield is Higher from Grassed Catchments than Forests.



Source: Zhang *et al.* 2003

Change in stream flow after reforestation or clearing of forest is largely proportional to the catchment area affected. A number of studies have demonstrated that it is statistically difficult to detect reliably the effects on runoff if the proportion of the catchment area reforested is below a certain threshold. This is probably because rainfall and the hydrological effect of the catchment surface, soil profile and vegetation vary across catchments. The threshold is typically 15-20% of smaller catchments but lower in larger catchments (Zhang *et al*. 2006). The proportion that will cause a measurable change in a larger catchment also depends on the variation of rainfall and runoff across the catchment. Impacts of reforestation in larger catchments will depend on the location of planted areas in relation to rainfall and other land uses across the catchment.

The level of the water table can be lowered by trees. A greater proportion of rainfall may then recharge groundwater rather than contributing to runoff. Reforestation and clearing may therefore also affect the pattern of stream flows. Flood peaks may be lower and there may be more frequent low or zero flow days following reforestation.

Because groundwater and surface water are linked in much of Australia, a decrease in groundwater recharge can also diminish the volume of streamflow by decreasing baseflow (Fullagar *et al*. 2006). Reduced baseflow recharge can be particularly important in dry periods when there are long intervals between rainfall events. The impact on groundwater will be related to the area of plantation, the depth of the water table and plantation management practices.

Different groundwater situations

Too much groundwater in Western Australia

As discussed above, clearing deep-rooted vegetation to provide farmland can lead to rising water tables. Where the groundwater is saline, this can cause surface soils and streams to become saline. Over 1.8 million hectares of agricultural land in Western Australia's wheat belt is threatened by salinisation.

Revegetation of affected areas can reverse salinisation. Commercial plantations of maritime pine (*Pinus pinaster*) and other species are being used as part of a salinity management strategy because they are considered cost-effective and potentially profitable for land owners.

Western Australian salinity control programs that include reforestation have slowed the rise of salinity in the Kent River, stabilised salinity in the Warren River and reduced salinity in the Collie and Denmark Rivers.

Competition for groundwater in lower south east South Australia

In contrast to Western Australia's wheat belt, where rising groundwater is bringing salt to the surface, south east South Australia has little usable surface water, and groundwater is a valuable resource for agriculture and other uses.

There have been pine plantations in south east South Australia since the late 1800s. The plantation area in the region increased from about 129,000 hectares in 2000 to 153,000 hectares in 2005. About 90% of the increase is blue gum plantations. The increase has led to measurable impacts on groundwater levels and concern over plantations reducing groundwater supplies for irrigated agriculture. The water planning process is therefore including plantation forestry as a significant water user.

In 2004 a threshold for forest expansion without a water allocation was introduced. A water allocation is required for additional new plantations when this threshold is exceeded in a management area. The aggregate plantation expansion threshold across all management areas was 59,000 ha of new plantations established after 2002.

The water access entitlement for forestry plantations is equivalent to the estimated reduction in recharge which occurs when grassland is converted to forest allowing for times when the site is not fully occupied by trees. Because pines have a longer production period than eucalypts, they tend to intercept more water and therefore require a larger water access entitlement.

The National Water Initiative

Australia's governments have entered into the Intergovernmental Agreement on a National Water Initiative (NWI). Paragraphs 55 to 57 of the NWI are concerned with the management of land use change activities that have potential to intercept significant volumes of surface or groundwater now or in the future and may be undertaken without a water access entitlement. Farm dams and bores, the interception and storage of overland flows and large-scale plantation forestry are noted as examples of activities of concern. The Parties to the NWI agree that:

1 In water systems that are fully allocated, over-allocated or approaching full allocation, interception activities assessed as significant should be recorded and any proposals for additional interception activities above an agreed threshold size will require a water access entitlement.

2. In systems that are not yet approaching full allocation, significant interception activities should be identified and estimates made of the amount of water likely to be intercepted. These systems should be monitored with regard to their ongoing level of allocation.

The intention of the framework is to assess the significance of activities based on an understanding of the total water cycle and of the economic and environmental costs and benefits of the activities of concern. The assessment of significance and the setting of threshold sizes for interception activities will be done in the context of the water systems in which they occur. The treatment of interception activities may vary between catchments and jurisdictions.

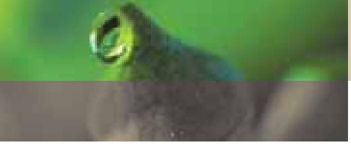
Plantations for salinity mitigation: Forest Products Commission forester Jason Lette (right) and Don McKinley inspect maritime pines on Mr McKinley's property near Moora. Photo courtesy of Forest Products Commission, Western Australia.

Water use over the plantation cycle

Due to land availability and cost, most new plantations are likely to be established in areas with 600 to 800 mm average annual rainfall. When agricultural land is reforested, run-off reductions will be minor for the first five years and increase to a peak 10–20 years after planting (Zhang *et al*. 2006). From Figure 2, the additional water use when the trees are mature and water use has peaked is about 100 to 150 mm/year. The cycle starts again when the plantation is harvested and replanted.

Pine plantations are usually thinned two or three times during a production cycle of 30 or more years. Thinning increases streamflow for several years (Bren *et al*. 2006). About 56% of Australia's plantations are pines. Eucalypt plantations are typically grown on a cycle of 10 to 15 years and some of these are also thinned.

As a result of these fluctuations in water use during the production cycle, only a proportion of a plantation estate will be at peak water use at any given time. The impact on run-off will, on average, generally be less than indicated in Figure 2. For a typical pine plantation production cycle, average water use has been estimated to be around 70% of peak use (Pratt Water 2004b).



Plantations as a land use in Australia

Plantations have been a part of the landscape in Australia for at least 130 years. The total plantation area reached about 1 million hectares in 1995 and nearly 1.82 million hectares in 2006. A comparison of plantations and other major land uses is shown in Table 1.

Governments and industry organisations endorsed a notional target of 3 million hectares of plantations by 2020 to meet regional industry development targets and salinity and other environmental objectives (Plantation 2020 Vision Implementation Committee 1997). Whether that target will be achieved and where additional plantations will be established depend on a range of commercial factors, including availability of investment funds and the supply and price of land in particular regions.

Land use proportions in some catchments are shown in Table 2. Plantations grown for commercial timber production are generally not commercially viable in areas that receive less than about 600 mm annual average rainfall. Only the land where average annual rainfall exceeds 600 mm is therefore included in the table. The catchments shown together include 65% of all Australian plantations.

Previous studies on the water use impact of commercial plantation expansion have tended to over-estimate the area of commercial plantation expansion over the next two decades. The area of potential plantation expansion in a particular region can be readily estimated from the plans of plantation companies and other organisations operating in that region. For example, these plans show that for the headwater catchments of the Murray-Darling Basin the total plantation expansion target is less than 50,000 hectares by 2020 and that the new plantations would be focussed around the timber processing industries located at Tumut, Tumbarumba, Albury and a number of places in north east Victoria. This is significantly less than the several hundred thousand hectares that has been assumed in other studies, and also indicates that the streamflow impacts from plantation expansion in this region will be significantly less than outlined in those reports.

A recent CSIRO modelling study of the Murrumbidgee catchment (Brown *et al.* 2007) assumed the area of plantations in that catchment would increase by 30,000 hectares. The maximum basin-wide impact on water use was found to be between 0.2% and 0.7% of average annual flow, and would most likely be in the lower half of that range.

TABLE 1 Land use, Australia.

Land use	Area (million hectares)	Proportion of total land area
Plantation forests	1.8	0.2%
Agriculture		
- Agricultural and horticultural crops	26.7	3.5%
- Grazing	442.4	57.5%
Total	469.1	61.0%
Native forests and woodlands		
- Public native forest where timber production is permitted	11.4	1.5%
- Forests in nature conservation reserves	21.5	2.8%
- Other categories	129.8	16.9%
Total	162.7	21.2%
Total land area	766.0	100.0%

Sources: Australian Bureau of Statistics; Bureau of Rural Sciences. Plantation area is as at 2006.

A BRS study (Barratt *et al.* 2007) of the Upper Murray basin (that is, the Murray River catchment upstream of Lake Hume) also assumed an additional 30,000 hectares of plantations. The increase in water use in a year of average annual rainfall was estimated to be from 25 to 35 gigalitres, depending on which sub-catchments the new plantations were established in. The effect in dry, average and wet years is shown in Table 3.

The above studies show a large variation between the impacts of reforestation in particular sub-catchments. This information could be used to plan plantation development to avoid sub-catchments where the water yield impact will be larger. Other ways to reduce the impacts are discussed in the following section.

TABLE 2 Land use in areas above 600 mm average annual rainfall.

Catchment Land use	Millicent Coast	Glenelg, Portland, Hopkins	Lachlan, Macquarie-Bogan	Murrum-bidgee	Upper Murray	Northern Victoria[1]	Tamar, Esk	North-west Tasmania[2]	Western Australia[3]	South east Queensland[4]
Plantations[5]:										
- proportion of catchment	13.6%	7.2%	1.5%	4.0%	2.5%	2.2%	4.1%	9.6%	5.7%	2.5%
- proportion of Australian total	8.8%	9.2%	3.6%	6.2%	2.2%	2.9%	2.2%	4.4%	16.3%	9.6%
Agriculture	72.2%	74.9%	73.9%	53.8%	27.1%	43.1%	29.9%	35.0%	35.0%	47.5%
Forest and woodland	11.1%	17.0%	21.7%	40.0%	68.1%	52.9%	63.9%	54.1%	58.1%	48.2%
Other categories	3.1%	0.8%	3.0%	2.2%	2.5%	1.8%	2.1%	1.2%	0.3%	1.8%

Notes
1. Northern Victoria is the Goulburn, Broken, Ovens and Kiewa River catchments.
2. North-west Tasmania data are for the Smithton-Burnie Coast, Mersey, Rubicon and Forth River Catchments.
3. Western Australia data include all catchments in south west Western Australia from Perth to Albany.
4. South east Queensland data are for the Brisbane, Burnett, Noosa, Maroochy and Mary River catchments.
5. Based on plantation areas as at 2005.

TABLE 3 Impacts of forecast plantation expansion, Upper Murray basin.

Effect / Scenario	Total annual water yield (Gl)	Minimum impact (Gl/year)	Proportion of annual total	Maximum impact (Gl/year)	Proportion of annual total
Dry year	874	12.3	1.4%	16.5	1.9%
Average rainfall	2,694	24.8	0.9%	34.5	1.3%
Wet year	6,572	35.0	0.5%	44.1	0.7%

Note: Gl = gigalitres (1,000 million litres)

Reducing reforestation water use

The position of plantations in the landscape and planting design can affect their water use. Plantations established close to drainage lines intercept more water than those established further away (Figure 3). Planting further away from streams could therefore help minimise impacts on stream flow by helping to maintain stream baseflow. However, there would be a trade-off with tree growth rate, because the trees higher up the slopes may grow more slowly. Plantations established in blocks or perpendicular to the contour may use more water than the same area of plantations established in strips across the contour (Stirzaker *et al.* 2002). Plantations can therefore be designed to reduce water use.

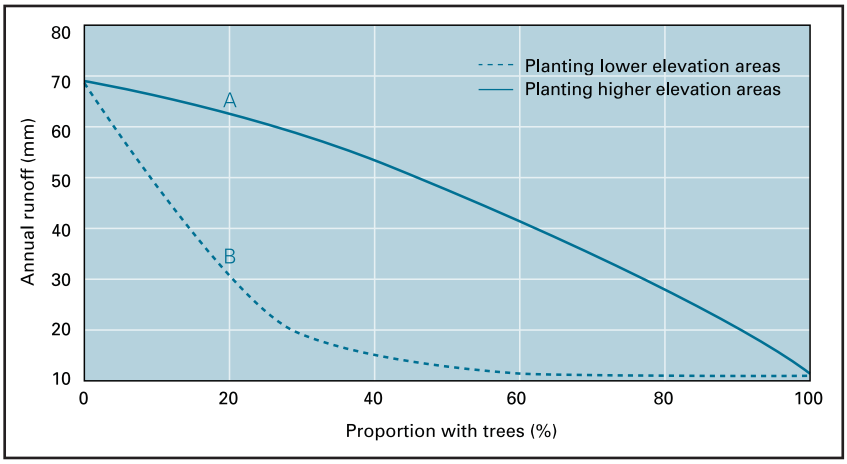
Most of the existing pine plantations were established in large, consolidated areas on native forest sites on public land. Plantations on new sites in the last 10 years have generally been in smaller scattered blocks that occupy small proportions of catchments or sub-catchments. This trend is likely to continue with most plantations established in smaller blocks on private land purchased or leased from landowners or in joint venture arrangements.

It is likely to be easier to target parts of the landscape for reforestation using a 'farm forestry' approach. Using this approach, the owner can choose sites for trees and keep other areas for pasture or cropping. Farm forestry can also provide shade, shelter and land protection benefits that enhance agricultural production and can produce an additional source of farm income.

The effect of plantations on water yield can potentially also be minimised by:

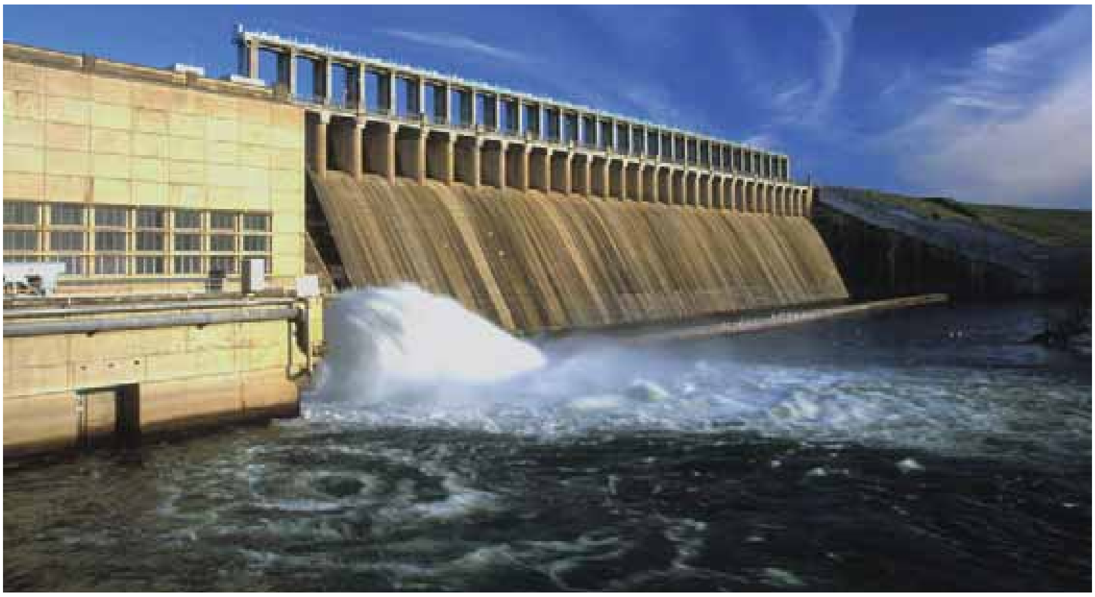
- targeting new plantation establishment in lower rainfall areas (<800 mm/year) where reductions in water yields are smaller;
- dispersing plantations across the landscape and keeping them to less than 20% of a catchment;
- phasing planting to give a spread of age classes; and
- thinning plantations to maintain them at a lower stocking density.

FIGURE 3 Position in the Landscape Affects Runoff.
In this modelled example, planting the highest 20% of the catchment could reduce runoff by about 5 mm/year (A) while planting the lowest 20% could reduce runoff by about 40 mm/year (B). The difference is due to the proportion of runoff that the tree roots are able to intercept before the water reaches the stream or groundwater.



Source: Vertessy *et al.* 2003

Hume Dam, Upper Murray Valley; 2.5% of the catchment above Hume Dam is currently covered by pine plantations.



Plantation benefits

Reforestation with plantations can provide substantial environmental, social and economic benefits.

Plantation forestry typically leads to lower soil erosion and chemical use than agricultural land uses. Water quality is therefore likely to be better following reforestation of farmland, provided plantations are targeted to not reduce fresh water flows to salt affected streams.

Plantations provide the majority of timber used in Australia to manufacture products for home building, paper and other products. Much of this is processed locally and timber industries are major employers in some regional communities. For example, plantation forestry uses about 9% of the land used by primary industries in the Green Triangle region[3] above 600 mm average annual rainfall. However, the plantation sector in that region generates 30% of the gross value of primary industries and 23% of the employment generated by primary industries.

Limitations of current data and analysis

Rainfall is the most important spatial variable in hydrological studies. However, data for a catchment is often only available for one or a few measurement stations that may not accurately reflect the variability across the catchment. This limitation is more significant in larger catchments (100s to 1,000s of km^2) and where rainfall is low and highly variable from year to year.

Models developed to analyse plantation water use and stream flow are based on studies of catchments with relatively stable vegetation cover. They may not accurately reflect 'transitional' effects, where reforestation is gradual or where streamflow is still responding to past events. Some models assume a simple separation into forest or non-forest vegetation cover, whereas forest structure varies greatly between catchments and regions. Models may therefore not accurately represent actual circumstances and changes in land use. Some modelling exercises have been based on reforestation scenarios that are highly speculative. Hydrological data also show that

3 The Green Triangle region comprises south east South Australia and south west Victoria.

Forest hydrology research, north east Victoria.

Photo courtesy of Dr Leon Bren, University of Melbourne.

models can overestimate reduction in water yield in some circumstances. Uncertainty related to modelled estimates is greater in lower rainfall areas (less than 750 mm/year).

Most hydrological studies have been carried out in small experimental catchments of less than 100 ha. Extrapolating the results to larger catchments (thousands of hectares) needs to be undertaken with caution. In larger catchments there are areas that do not contribute to stream flow and this will vary with the size, topography and geology of the catchment.

Plantation management regimes are changing, with faster growing trees, lower initial stocking rates, better fertilisation treatment, earlier thinning and shorter crop cycles. Research based on historical studies may not therefore apply to current circumstances.

Topics that warrant further consideration include:

- Long-term monitoring of stream flows at catchment and regional scales.
- Development of methods for low cost assessment of water use of different types of land cover.
- Comparative studies of water use (interception, evapotranspiration and use of groundwater) and impact on run-off, groundwater/surface water connectivity and stream flow of different land uses and land cover.
- Comparative studies of water use and plantation management practices and species in different climates and soil types.
- Analysis of potential impacts of climate change on water use by different vegetation types and resulting catchment water balance.

- Development of catchment models to assess potential water use demands of plantation establishment that integrate stand level models of water use. These models should focus on lower rainfall regions, model 'transitional effects' and use realistic scenarios of plantation development and management approaches. Model validation should account for the effect of scaling up results from small experimental catchments to larger scale catchments.

ACKNOWLEDGEMENTS

This paper draws on collaboration with Dr Emmett O'Loughlin, Dr Sara Beavis (Australian National University) on work done for the Forest and Wood Products Research and Development Corporation. Dr Lu Zhang of CSIRO Land and Water reviewed a draft. Several current and past staff of the Department of Agriculture, Fisheries and Forestry and Bureau of Rural Sciences contributed to its development. We thank them for their valuable input to this work.

REFERENCES AND FURTHER READING

Barratt, D., Parsons, M., Welsh, W., and Nation, E. (2007). *Investigating land use-change-scenario impacts: potential effects of reforestation on water yield in the Upper Murray River Basin*. Water 2010 Technical Paper 5, Bureau of Rural Sciences, Canberra.

Bren, L. J., Lane, P. and McGuire, D. 2006. *An empirical, comparative model of changes in annual water yield associated with pine plantations in southern Australia*. Australian Forestry 69 (275-284).

Brown, A. E., Podger, G. M., Davidson, A.J., Dowling, T.I., and Zhang, L., 2007. *Predicting the impact of plantation forestry on water users at local and regional scales*. An example for the Murrumbidgee River Basin, Australia. Forest Ecology and Management (in press).

EconSearch Pty Ltd 2005. *Economic Impact of the Timber Industry in the Green Triangle Region, 2003/04*. Green Triangle Regional Plantation Committee Inc.

Fullagar, I., Brodie, R., Sundaram, B., Hostetler, S. and Baker, P. 2006. *Managing connected surface water and groundwater resources*. Science for Decision Makers Series, Bureau of Rural Sciences, Canberra.

Keenan, R.J., Parsons, M., O'Loughlin, E., Gerrand, A., Beavis, S., Gunawardana, D., Gavran, M., Bugg, A. 2004. *Plantations and Water: a review*. Report prepared for the Forest & Wood Products Research & Development Corporation, Bureau of Rural Sciences, Canberra, 88pp plus maps.

O'Loughlin, E. and Nambiar, E. K. S. 2001. *Plantations, farm forestry and water: a discussion Paper. Water and Salinity Issues in Agroforestry No. 8*. Rural Industries Research and Development Corporation, Canberra.

Parsons, M, Gavran, M and Davidson, J. 2006. *Australia's Plantations 2006*. National Plantation Inventory, Bureau of Rural Sciences.

Plantation 2020 Vision Implementation Committee 1997. *Plantations for Australia The 2020 Vision*. Ministerial Council on Forestry, Fisheries and Aquaculture, Canberra.

Pratt Water 2004a. *The Business of Saving Water*. Pratt Water, Campbellfield.

Pratt Water 2004b. *Plantations Feasibility Project*. Pratt Water, Campbellfield.

Productivity Commission 2003. *Water rights arrangements in Australia and overseas*. Productivity Commission, Melbourne.

Stirzaker, R., Vertessy, R. and Sarre, A. (eds) 2002. *Trees, Water and Salt: An Australian Guide to Using Trees for Healthy Catchments and Productive Farms*. Publication No. 01/086, Rural Industries Research and Development Corporation, Canberra.

Van Dijk, A., R. Evans, P. Hairsine, S. Khan, R. Nathan, S. Paydar and L. Zhang 2006. *Risks to our shared water resources of the Murray-Darling Basin*. Murray-Darling Basin Commission, Canberra. MDBC publication 22/06.

Vertessy, R., L. Zhang and W. R. Dawes 2003. *Plantations, river flows and river salinity*. Australian Forestry 66(1): 55–61 and response by P. Townsend 66 (4) 300–303.

Zhang, L., W. R. Dawes and G. R. Walker 1999. *Predicting the effect of vegetation changes on catchment average water balance*. Cooperative Research Centre for Catchment Hydrology. Technical Report 99/12.

Zhang, L., W. R. Dawes and G. R. Walker 2001. *Response of mean annual evapotranspiration to vegetation changes at a catchment scale.* Water Resources Research 37(3): 701–708.

Zhang, L., T. Dowling, M. Hocking, J. Morris, G. Adams, K. Hickel, A. Best and R. Vertessy 2003. *Predicting the effects of large-scale afforestation on annual flow regime and water allocation*. CRC for Catchment Hydrology Technical Report 03/5.

Zhang, L., R. Vertessy, G. Walker, M. Gilfedder and P. Hairsine 2006. *Afforestation in a catchment context – understanding the impacts on water yield and salinity*. CSIRO Land and Water Science Report 55/06.

IN THIS **SERIES**

Visit our website at www.brs.gov.au to download copies of these papers, or call +61 2 6272 4282 to subscribe.

Contact

For more information contact:

Tim Clancy
Programme Leader
Bureau of Rural Sciences

Email tim.clancy@brs.gov.au
Phone +61 2 6272 5582

DISCLAIMER