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The impacts of plantations and native forests on water security: Review and scientific assessment of regional issues and research needs

This report can also be viewed on the FWPA website
www.fwpa.com.au
FWPA Level 4, 10-16 Queen Street,
Melbourne VIC 3000, Australia
T +61 (0)3 9614 7544 F +61 (0)3 9614 6822
E info@fwpa.com.au W www.fwpa.com.au

The impacts of plantations and native forests on water security: Review and scientific assessment of regional issues and research needs

Prepared for

Forest & Wood Products Australia

by

P. Polglase and R. Benyon

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Researcher:
P. Polglase and R. Benyon

CSIRO Sustainable Ecosystems
GPO Box 284
CANBERRA, ACT, 2601

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Forest & Wood Products Australia Limited
Level 4, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9614 7544 F +61 3 9614 6822
E info@fwpa.com.au
W www.fwpa.com.au

EXECUTIVE SUMMARY

Background and objectives

The National Water Initiative (NWI) aims to restore sustainable water balance to over-allocated systems. It identifies large-scale plantation forestry as an example of land use change that may intercept water otherwise available to other users, including environmental flows.

There is general consensus that policy development be based on the best available science. Recent reviews have described, in general terms, the potential impacts of plantations particularly on surface water availability and recommended areas for future research. There is a need to explicitly examine where plantations and water policy may be in conflict at regional levels across Australia and develop specific recommendations for where research can assist with policy development.

The development of research priorities should thus consider at least:

Where plantations have been developed or are likely to be established in the future.

Areas of surface or groundwater management that are over-allocated or approaching full allocation.

The overlap between the above two regions and the extent to which plantations may be a significant component of the water balance.

Research that can address regional needs to progress policy development in a scientifically transparent way.

The objectives of this review were to:

(i) Interview representatives from all State and Territories to identify progress on policy development, regionally-specific hydrological and other issues they considered important in relation to plantations and water interception (surface water interception, impacts on groundwater recharge and groundwater uptake),and to identify where research can inform policy.

(ii) Undertake spatial analysis of the Surface Water Management Areas across Australia and the impacts of plantations on water flows to illustrate the magnitude of impacts, regions of interest and controlling factors.

(iii) Review other important and relevant information including forest management impacts on water use efficiency, impacts of other crops and management practices on water interception, and the role of native forests in controlling water supply.

(iv) Synthesise the information into a set of specific recommendations for future research to advance science-based policy implementation.

Conclusions

The impacts of plantations on water security have probably been over emphasised when considered at regional and national scale. This is especially so when considered at whole-of-catchment scale, the amount of water intercepted by plantations compared with downstream users and other components of the water balance. Local scale impacts are important in some areas especially where plantations occupy a large proportion of a unit of water management. For several jurisdictions, groundwater issues emerge as the primary concern, despite the recent national emphasis on the impacts of plantations on surface water supplies. For many of the important catchments suppling drinking water and environmental flows, native forests exert the overwhelming control on water availability. In these areas, greater research effort is needed to understand future water availability from native forests. There was strong consensus among the jurisdictions as to research needed to advance science-based policy development. These conclusions are summarised in more detail below.

Groundwater issues are of immediate concern. In recent times there has been a heavy emphasis on the impacts of plantations on streamflows, especially in the Murray Darling Basin. Our review of State and Territories suggests that the impacts of plantations on groundwater should take at least equal, if not higher, precedence. Groundwater regions where plantations are or may be in conflict with water policy include the Lower Limestone Coast of south-eastern Australia, the Swan River and Scott Coastal plains in south-west Western Australia and the Daly River Catchment in the Northern Territory.

Scale and the unit of water management is a key concept
The impacts of plantations on water availability often are considered at the whole of catchment scale. For both groundwater and surface water areas the unit of management is often much smaller. For example, the CSIRO Murray Darling Basin Sustainable Yields project assessed current and future water availability for all 18 catchments in the basin. They concluded that future plantation developments would have minimal impacts on catchment water flows; the impacts of farm dams, bores and climate change assuming higher importance. However, local scale impacts may be important where plantations are a significant component of the water balance in a water management area and where they impact upon other users.

Across Australia, the impact of plantations on the % outflow from Surface Water Management Areas was well described by a combination of: (i) the % of the catchment area that was plantation, and (ii) the % of total catchment rainfall that was run-off. Thus, the relative impact of plantations on catchment outflows increased with % area of plantation and decreased with the proportion of rainfall that was run-off. This suggests that run-off is proportionately lower in low rainfall catchments that are highly vegetated (have high rates of evapotranspiration).

Retrospectivity may present a dilemma in isolated cases
The NWI states that there should be no retrospectivity when developing policy that concerns land use change. But it also requires that over-allocated catchments be brought back into sustainable allocation. This presents policy with something of a dilemma where small, over-allocated, units of water management are largely occupied by plantations that may dominate the water balance and impact on other users. The options available to bring the catchment back into full allocation need to be identified and may be limited.

At national scale, native forests exert far more control on water supplies than do plantations
At regional scale and for many of the important catchments suppling drinking water and environmental flows, native forests exert the overwhelming control on water availability. The majority of Australia's large cities draw some or most (up to 90%) of their water from forested catchments in which the amount of water used by the forests (evapotranspiration) is the largest component of the total water balance. Water use of native forests can be altered substantially by fire and climatic changes that affect forest physiology including rainfall, temperature, humidity and CO_2. The impact of CO_2, in particular, could be of extreme importance but scientific evidence is limited at present. Far more national focus is needed in these research areas to better understand and prepare for future water resources.

Change in agricultural land use also affects water availability
The past decade or so has seen a marked change in agricultural land use and management with a significant shift towards more perenniality and management that aims to retain and use more soil water for increased productivity. There are two implications of this: (i) Much of the analysis to date has been on rates of water use

by plantations compared to an average grassland condition. More assessment is needed of leakage beneath the agricultural phase on which plantations are established to calculate the difference in water use – which is an important consideration, and
(ii) Some jurisdictions consider that changes in agricultural land use and potential impacts on water availability are important. The changes may be smaller than under conversion to plantation but cover larger areas. How these changes are dealt with in a policy sense including a requirement to reverse land use to release water remains a challenge.

Plantation management can increase wood production per unit of water used
An important question for the plantation industry may be the cost:benefit ratio of having to pay for water versus the volume of wood produced. Using a process-based model of forest growth and water use, we show that site selection and silviculture (for example, spacing and nutritional management) can increase wood production with a proportionately lower increase in water use. Generally, the best silviculture that maximises productivity also increases water use efficiency.

There was strong agreement on the priority research needs
The States are Territories were asked to nominate priority areas for research to help them better inform and apply policy. The following summarises their main requirements as they relate to plantations and water availability:

(i) Prediction of water use by plantations, especially at finer scales of space and time. This was cited as the top priority by all jurisdictions except the ACT (where plantation impacts are not considered an issue) and Victoria. Most States were comfortable that their hydrogeological models of water flows across and through the landscape were adequate, except for predicting rates of plantation water use which is often the largest component of the water balance compared with rainfall. The ability to predict impacts at local scale (say the order of 100 ha or so) was considered important and needs to account for differences imposed by species, soil depth and texture, presence of groundwater and impeding layers, site preparation climate, spacing, weed control, thinning and rotation length.

(ii) Monitoring of water use by plantations across large-scales.
Monitoring ideally needs to be inexpensive, cover large scales, be temporally sensitive and account for total stand water use. Prediction of water use using biophysical models can be used for planning purposes, but improved monitoring methods such as those incorporating remote sensing techniques are needed to directly measure water use by plantations and other vegetation, and to account for inter-annual and seasonal differences.

(iii) Methods to assess 'significance' and 'thresholds'. Nearly all jurisdictions were concerned with having methods to test for 'significance' and 'thresholds'. 'Significance' needs to take into account scale and concentration of plantings as it affects local versus regional water users. 'Thresholds' apply to catchments that are approaching full water allocation and where new developments would send them into over-allocation. The best method to identify levels of 'significance' is to run across the whole of catchments or water management areas verified models of water use by plantations and their impacts on other consumptive users and environmental flows. The resulting spatial information can then be interrogated to determine the expected impacts for any given area of plantation in the landscape.

Recommendations

On the basis of this review we developed a short list of recommendations for future research. As far as possible, the recommendations have national relevance, are specific to indicate the types of research that might be undertaken, the reasons for them and the outcomes that would be derived.

Recommendation 1. Consolidate national data sets to further develop and test process-based models and improve prediction of plantation water use.

Across the relevant research agencies in Australia there are now extensive data sets on rates of tree transpiration for a range of sites, species and silvicultural regimes. Total site water use includes transpiration, rainfall interception by the canopy and evaporation from soil. Transpiration is not always the dominant component. The two main models of forest water use in Australia are 3-PG and CABALA, both of which explicitly model the three components of evapotranspiration and are sensitive to soil, climatic and management parameters.

Combined with the data sets there is a good opportunity to test and improve models for their ability to predict water use at relatively fine spatial and temporal scales of resolution. The improved models of water use would have applicability to both groundwater and surface water environments and could be linked to those of catchment water flows used by State agencies.

The outcomes would be policy and forest management informed by verified model(s) of plantation water use and model outputs to estimate the impacts of plantation establishment on water interception.

Recommendation 2. Identify cost effective and practical methods to monitor plantation water use and impacts.

It is relatively straightforward to measure all components of the water balance directly but is limited to relatively small areas with uniform soil, climate and plantations species, age and condition. It will be important to continue, and perhaps increase monitoring of streamflows and groundwater levels. In future, monitoring might also include remote sensing of water use across regions and large catchments and offer ways to extrapolate from site to whole catchments and regions and to better monitor seasonal and spatial variation in water use.

It might also be possible to gain indications of potential impacts of recent forestry developments and changes in forest management practices using forest inventory data already being routinely collected by forest managers. Further analysis is required to determine whether variables such as basal area, height and stand volume can provide useful indicators of forest water use.

Recommendation 3. Develop and apply methods to determine 'significance' and 'thresholds'.

The impacts of new plantation developments on water availability can be assessed by spatially explicit, biophysical models of plantation water use and seasonal and annual catchment water flows. When applied across the whole of catchments, sub-catchments or groundwater regions, they can be used to assess the impacts of any given development proposal on water availability. Their reliability will depend upon meeting the objective in Recommendation 1 above – having improved models of plantation water use. The modelling would enable exploration of the relative effects of various site-scale factors to be evaluated, including position in the catchment, soil type, species and management. The same models should be applied in demonstration catchments in all States to enable direct comparison and cross-checking of the various different methods currently being used to evaluate plantation impacts. Case study catchments will need to have reasonably long-term, good quality streamflow data available to enable verification of model predictions.

Recommendation 4. Investigate and apply methods to assess the net benefits and impacts of plantations on economic, environmental and social values.

In some cases, jurisdictions may wish to take account of social, economic and other environmental impacts of plantations in catchments when developing and applying tests of significance. The net benefits and trade-offs will vary from region to region and depend on the particular issues considered to be of importance.

It would be beneficial to undertake select case studies to assess the net impacts of existing (and possibly future) plantations according to a set of regionally appropriate criteria. As far as possible the impacts should be quantifiable and presentable in terms of economic costs or returns, although externalities that have no market value should also be considered (for example, biodiversity enhancement). Other land uses and their net impacts should also be considered for comparison. Such a balance sheet would help place plantations into a whole of catchment context and ascribe an overall value for land use per unit volume of water used ($ ML^{-1}).

Recommendation 5. Investigate climate change and management impacts on native forests and catchment water flows.

To ensure long-term security of water supplies for most of the capital cities and the Murray Darling Basin, far more needs to be invested in research to quantify the impacts on water use, water yield and water quality resulting from rising CO_2 levels, climate change and associated other changes in native forests (for example increased bushfire frequency or intensity).

This research could include:

- The impacts of fire on forest functioning, water use and hence streamflows.
- Modelling studies to estimate the impacts of management interventions (For example, thinning, planned burning) on forest water use and water yield.
- Physiological studies to identify the impact of increasing levels of CO_2 on forest water use.
- Investigation of evidence of historical impacts of increased CO_2 on forest growth and water use, such as through interrogation of the Landsat data series.
- Long-term controlled experiments to examine physiological responses of common eucalypt species to elevated CO_2 and changing climate.

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1. INTRODUCTION

The National Water Initiative (NWI) aims to:

- Restore sustainable water balance to over-allocated systems
- Assess impacts on surface and groundwater resource (that is, not rainfall)
- Increase security of water access entitlements
- Trade water to achieve most profitable use and environmental outcomes
- Address land use change.

It states that (NWC 2004):

'The intention is therefore to assess the significance of such activities on catchments and aquifers, based on an understanding of the total water cycle, the economic and environmental costs and benefits of the activities of concern, and to apply appropriate planning, management and/or regulatory measures where necessary to protect the integrity of the water access entitlements system and the achievement of environmental objectives.'

And further:

'In water systems that are fully allocated, overallocated, or approaching full allocation:

a) Interception activities that are assessed as being significant should be recorded (for example, through a licensing system);

b) Any proposals for additional interception activities above an agreed threshold size, will require a water access entitlement:

- *the threshold size will be determined for the entire water system covered by a* water plan*, having regard to regional circumstances and taking account of both the positive and negative impacts of water interception on regional (including cross-border) natural resource management outcomes (for example, the control of rising water tables by plantations);…*

c) A robust compliance monitoring regime will be implemented'.

The NWI identifies 'large-scale plantation forestry' as an example of land use change that has the potential to intercept significant amounts of surface and groundwater. Jurisdictions (regions and State governments) are in the process of implementing the NWI through water plans that will take affect by at least 2011.

The NWI states:
'A major objective of the NWI is to secure the integrity of water access entitlements and environmental outcomes. As part of this COAG agreed that land-use change activities, that have the potential to intercept significant volumes of surface or ground water, need to be addressed.

COAG acknowledged that there is an acceptable level of interception that is part of the mix of land use in catchments, and that interception activities, such as large scale plantations, also have positive benefits on the environment and the productivity of water resources. The intention of the NWI framework on interception is not to pre-determine whether an activity is a significant interceptor, but instead to determine whether the volume intercepted from any land-use change activity is "significant" in the context of the water system within which it occurs. "Significance" will be determined through the planning process, which is based on best available science and informed by socio-economic analysis and community and industry input.'

The NWI thus acknowledges that a test of 'significance' may apply not only to water interception but could include assessment of other environmental and economic benefits. Note that one of the state policy experts consulted in preparing this report advised that some people with an interest in the water interception issue have interpreted the words 'planning process' to refer to the development planning process and not to the water allocation planning process.

The NWI goes on to say:

'The NWI framework on interception is intended to apply to future proposals for land-use change rather than retrospectively.'

One of the jurisdictional representatives suggested that '*the interpretation of the term "retrospectively", as implied by the NWI, can be made in a number of ways. One interpretation can be that there will be no punitive actions taken against existing plantation forest rotations, but it does not necessarily mean plantation forests should not be included into a water accountability framework that may require future management actions. Furthermore, inclusion in a formal accounting and management framework may provide positive gains with the granting of licensed water allocations for much of the national forest estate, particularly where there is evidence of a long and continuous forest history*.'

Herein lies something of a dilemma for water policy makers. The purpose of the NWI is to bring over-allocated catchments back to full allocation – and that means reducing the consumptive pool of water. The NWI talks both of licensing any significant intercepting activity (in which they include plantations) for the water intercepted, but also states that interception should not be retrospective – that is, not applied to plantations already established. The main difficulty may arise for those units of water management (such as sub-catchments) in which plantations are clearly a substantial interceptor of water and thus provide a lever for releasing water.

Interpreting the NWI signals, the important issues that need to be considered for research in the plantation context therefore include:

- 'Interception' as defined by impacts on other users, not on rainfall runoff.
- Relationship to near allocated, fully allocated, or over allocated systems and in the context of competition for available water (the 'consumptive' pool).
- Issues of 'significance' and 'thresholds'.
- The identification of an appropriate baseline for water flows and changes in other land uses that provide a context for potential plantation impacts.
- Retrospectivity.
- Inclusion of triple bottom line outcomes.
- Other forms of dryland agriculture and land use change as an interceptor of water.
- The requirement for a transparent monitoring regime.

Research is needed to inform policy so that any allocations of water entitlements are based upon the best available information so as to meet the requirements of the NWI while retaining a fair and equitable system of water allocations.

There have been several recent reviews of the impacts of plantations on water security (see for example Keenan *et al*. 2004, Benyon *et al*. 2007). These provide a useful, general background on the some of the underlying principles of water use by plantations, especially on streamflow and include discussion of water use by other dryland agricultural crops.

The issue of plantations and water use needs to be placed in the context of the, unique hydrological balance of each region, catchment, or water resources management unit. Identifying research needs should go beyond generalisations and be based on the specific circumstances and needs of each jurisdiction.

The development of research priorities should thus consider:

- Regional geographies where plantations have been established or will likely be established and where there is potential competition for water (particularly for water resources allocated to consumptive use).

- The specific hydro-geological conditions of areas of concern, for example impacts on:
  - Groundwater, the sustainable extractive use of the resource and the separate issues of recharge to groundwater and direct uptake from groundwater.
  - Surface water and downstream consumptive use and environmental flows.
- Where there is an immediate need to provide information for policies that are well advanced.
- Within each of region of interest, the need to address specific knowledge gaps and especially in fully allocated regions/catchments, for example:
  - The whole of the rotation water balance, including patterns of water use that vary greatly by stage of stand development.
  - The components of the water balance (interception of rain by the canopy, tree transpiration, evaporation from soil) as they vary according to stand management.
- Scaling from site to landscape.
- The extent to which research may be generally applicable nationally and easily adopted.
- Monitoring requirements.

Although not mentioned specifically in the NWI, we believe there is potential for substantial changes in the generation of water resources from native forests over the coming decades as a result of changes in forest cover, physiology and growth rates due to long-term rises in atmospheric CO_2 levels, climate change and associated changes in the frequency and severity of bushfires, pests and diseases. Sustainable water allocation requires an accurate understanding of the total quantity of the resource which includes the likelihood of future changes in water yield from native forest catchments. For this reason, we have also included discussion of the research needs in relation to water use and water yield from native forests in this review

The objectives of this review were to:

1. Engage with all State and Territories to identify, in relation to plantations and water interception:
   - Progress on policy development.
   - Specific hydrological and other issues.
   - Needs for research to inform policy development.
2. Assess nationally, the scale of impacts of plantations on surface water flows to identify the magnitude of impacts, regions of interest and controlling factors.
3. Briefly review some of the important, other relevant information, including:
   - Management impacts on water use efficiency (volume of wood produced per unit of water used).
   - State of knowledge on the impacts of other crops and management practices on water interception.
   - The potential for long-term changes in evapotranspiration and water yield from native forests in some critical water supply catchments resulting from rising CO_2, concentrations in the atmosphere, climate change, large scale disturbances such as wildfires and forest management.
4. Synthesise the available information and develop specific recommendations for future research to inform policy and industry.

Reviews of each State are presented. South-east South Australia and Victoria are discussed in greater detail as case studies to illustrate some of the important, specific principles of the impacts of plantations on water security for groundwater (south-east South Australia) and surface water (Victoria).

2. PLANTATIONS AND WATER IN CONTEXT

Intercepting activities can potentially include any long-term or permanent change in land use that results in reduced availability of surface or groundwater. Plantations have been specifically identified as an intercepting activity because in the past 20 to 30 years the majority of new plantations have been established on land previously cleared for agriculture and because such conversion almost inevitably results in a decrease in streamflow. This has been demonstrated in numerous paired-catchment studies, reviewed by Hibbert (1967), Bosch and Hewlett (1982) and most recently Brown *et al*. (2005).

Zhang *et al*. (2001) examined the reasons why differences in water use occur between forests and herbaceous vegetation and concluded that: (i) forests generally absorb more of the incoming solar radiation, resulting in higher evapotranspiration, (ii) forests can have higher canopy interception (although not always the case) due to higher or more persistent leaf area and greater canopy roughness; (iii) forests often have much deeper root systems than pastures and many agricultural crops, enabling trees to access water from deep in the soil profile, or from groundwater and thus maintain higher water use rates during drier periods of the year.

The quantity of interception resulting from conversion from one vegetation type to another will depend in part on the water use of both the previous and new land use. For example, at a given location, the difference in water use between native forest and plantation is usually somewhat less than between grassland and plantations. As another example, conversion from native eucalypts to pines, can sometimes increase mean annual streamflow over the long-term due to lower water use prior to canopy closure in each rotation (Bren and Hopmans 2007). To estimate the interception effect of a land use change, it is necessary to understand the water use of the previous land use as well as the new land use. In stating this, it is not our intention to imply any particular policy prescription, such as what is the appropriate baseline against which to gauge the level of interception resulting from a change in land use.

Since the 1980s, and particularly since the mid 1990s, the majority of new plantations have been established on ex-agricultural land. While it is now generally accepted this conversion will result in reduced groundwater recharge and reduced streamflow, there remain some uncertainties as to the extent to which these changes are influencing water availability in particular catchments. Generalised models of mean annual water use and streamflow from forests and grassland, such as the curves developed by Zhang *et al*. (2001) provide indications of the likely magnitude of the effect of converting between herbaceous vegetation and forest and thus can play a useful role, particularly in providing first-cut estimates of the likely long-term effect of land use change on mean annual catchment yields. For any specific catchment, the Zhang *et al*. (2001) relationships have an uncertainty in the order of ±50 to 200 mm year $^{-1}$ and provide predictions only of the impacts on long-term mean annual flows. For more precise predictions of land use change impacts on water resources, including inter- and intra-annual variations in the impacts, more sophisticated modelling, supported by local observations of streamflow or vegetation water use is needed.

Much of the recent emphasis has been on surface water issues and impacts of plantations on streamflows. It is essential that groundwater is included in any discussion. The following two sections describe relevant issues of groundwater and surface water availability that need to be considered when assessing plantation impacts.

2.1 Groundwater issues

In the past decade, the impact of new commercial plantations on groundwater resources has become an issue in several parts of Australia. State agencies responsible for groundwater management in SA, Victoria and WA have started to develop policies to account for and manage potential impacts on groundwater of converting grazing land to plantations. Section 3 reviews the specific circumstances in each state where interaction between plantations and groundwater is currently an issue.

Conversion from agriculture to plantation can influence groundwater in two ways: (i) Groundwater recharge is usually reduced, and (ii) In some circumstances, trees may directly access groundwater if the deeper roots of the trees access the watertable. During the 1980s and 1990s there was an emphasis on the beneficial effects of planting trees for salinity control. In some areas, clearing of deep rooted, perennial native vegetation for agriculture has increased groundwater recharge. Salts stored at depth have been mobilised by rising groundwater. In some circumstances replanting trees can have beneficial effects by lowering water tables and reversing the salinity trend. The circumstances under which trees provide salinity benefits have been covered extensively elsewhere, and it is beyond the scope of this report to summarise them in detail.

There are some groundwater flow systems in which salinity is not an issue and where reduced groundwater recharge, or increased groundwater uptake by vegetation, reduces the quantity of groundwater available to other users. In such circumstances, the reduced recharge or increased uptake may need to be accounted for when determining how much groundwater can sustainably be allocated after allowing for the needs of groundwater dependent ecosystems.

Perth, for example, is now heavily reliant on groundwater, which supplies at least 60% of total water use. Proposed measures to increase groundwater recharge include removing about 25,000 ha of pine plantations from above the Gnangara groundwater mound. This is the first case in Australia where commercial plantations are to be removed to increase water supplies. The potential to increase groundwater recharge through controlled burning of native vegetation is also being examined.

The entire south-east of SA is heavily dependent on groundwater for urban, industrial and agricultural water supplies. Issues around impacts of plantations on groundwater in this region are discussed in detail in Section 3.1. Since July 2007, new plantations in certain areas have been required to acquire a water license to account for deemed groundwater uptake.

Similarly, in the Hawkesdale Groundwater Management area of south-west Victoria, groundwater allocations are also now taking account of estimated groundwater recharge interception and uptake by plantations.

Table 1 summarises some of the observations over the past decade on groundwater use by plantations. This is not intended to be an exhaustive list, rather the purpose is to illustrate some of the range of variation and related site factors. In some locations, depth to groundwater has been shown to be the main determinant of whether the trees use groundwater (for example, south-east SA). At other sites, physical or chemical restrictions to deep root penetration can prevent trees accessing groundwater (for example, Riverina NSW). Stocking density and species can also have an influence as can groundwater salinity however, few commercial plantations have been established over saline groundwater at shallow depth.

Given that many factors influence groundwater accessibility and uptake, it is not possible to broadly generalise as to actual groundwater use by plantations without at least some basic knowledge of local conditions. Factors known to influence groundwater use by plantations include climate, depth to groundwater, location of root impeding layers, groundwater and soil salinity, soil depth and texture and species propensity to have a deep root system. Generalised models can be developed for particular groundwater systems, as has been the case for the Green Triangle, for example (Benyon *et al*. 2008), however before being transferred to other regions, model applicability needs to be verified through local studies. However, predicting the maximum or peak rate of water use at any time during a rotation may be possible if site conditions are known.

Table 1. Summary of recent estimates of plantation water use and factors controlling the amount of groundwater use. The shaded sites are those where substantial groundwater use was indicated. Data from CSIRO (unpublished).

Species	State	Site	Rainfall (mm)	Water use (mm)	Factor affecting groundwater use
E. globulus	SA	water table > 6m	614	612	
E. globulus	SA	water table < 6m	675	1059	Water table depth
E. globulus	WA	wide spaced	608	572	
E. globulus	WA	1200 sph – deep soil	608	813	Soil depth/ stocking
P. radiata	SA	water table > 6m	667	661	
P. radiata	SA	water table < 6m	586	985	Water table depth
E. grandis	NSW	heavy sodic soil	530	457	
E. grandis	NSW	light soil	628	988	Soil type
C. maculata	NSW	light soil	583	1331	Species
Farm trees	WA	contour belt	438	580	Species
E. kochii	WA	- shallow fresh water	370	300-400	
E. kochii	WA	+ shallow fresh water	370	1800	Presence of water table

2.2 Surface water issues

In the past decade, concerns over impacts of new plantations on surface water have been largely focussed on the Murray Darling Basin (MDB). Between the mid 1990s and early 2000s, various reports produced 'worst case scenarios' for the likely future impacts of plantation developments. Some authors incorrectly assumed that the Vision 2020 aim of a trebling of the national plantation area by 2020 applied equally to all regions of the country, and used this as a base-case scenario in the MDB. In reality, the rate of increase in the plantation area in the MDB has been much lower than required to treble the plantation area there by 2020. Recent modelling, using more realistic plantation development scenarios, indicates the potential impacts of new plantations on water allocations in parts of the MDB where plantations are expanding, is relatively low.

The scale at which effects occur is important. To use the MDB example again, when considered only at the whole-of-basin scale, the effect of new plantation developments over the past 15 years on water availability is negligible because plantations occupy a tiny fraction of the total land area of the basin. At the catchment scale, plantations also usually occupy a relatively small percentage of the landscape. In the 52,000 km^2 Murrumbidgee catchment, for example, plantations occupy about 2%. As we move to smaller scales, we do begin to see plantations occupying more significant proportions of the landscape. Commercial plantations tend to be concentrated together. If we move to a scale of less than 1,000 km^2, plantations can occasionally occupy 20% or more of individual sub-catchments, while at the scale of less than 100 km^2, they can occupy as much as 80-90%.

Furthermore, it is often the impact on other users that is important rather than simply the amount of rainfall that is intercepted. For example, Brown *et al.* (2007) applied realistic plantation expansion scenarios in the Murrumbidgee catchment, and examined the impacts on water allocations down stream assuming the plantations went into low and high impact areas. Reductions in mean annual flows in two tributaries were expected to exceed 15%, but in the majority, predicted reductions were <8% (Figure 1). The Forest Cover Flow Change model (Brown *et al.* 2006a) was used to estimate impacts on flow duration curves. These were then fed into water allocation models for a 100-year climate sequence. In the Murrumbidgee Irrigation Area, the effects of the high impact scenario on mean annual water allocations was only about 0.4 % (Figure 2) and in most individual years, impacts were close to zero (Figure 3). In only 1-in-100 years did impacts exceed 5% and in only 1-in-50 years did they exceed 3%. This research highlights the need to understand impacts on seasonal and inter-annual flows and interactions with water allocation rules if impacts of new plantations on surface water allocations are to be properly accounted for.

In catchments that are largely un-regulated (no large storage reservoirs to even out inter- and intra-annual fluctuations in flow), impacts on seasonal flows, particularly on dry season flows, can be of even greater importance. Conversion from grassland to forests can have a proportionally greater impact on dry season flows than on mean annual flows. In such cases, ecosystems and water users that depend on limited dry season flows can be adversely affected. In assessing the impacts of plantations on surface water, an understanding of the degree of regulation of the system, the water allocation rules, the effects of land use change on seasonal flow patterns are as important as understanding the impacts on mean annual flows.

The challenge for scientists is to provide policy makers and resources managers with models and simple decisions support tools that are flexible enough to account for each set of individual circumstances at a scale appropriate to implementation of policies. This will enable users to understand the appropriate way to apply the models, the input data required and the uncertainties associated with the predictions of changes in water availability.

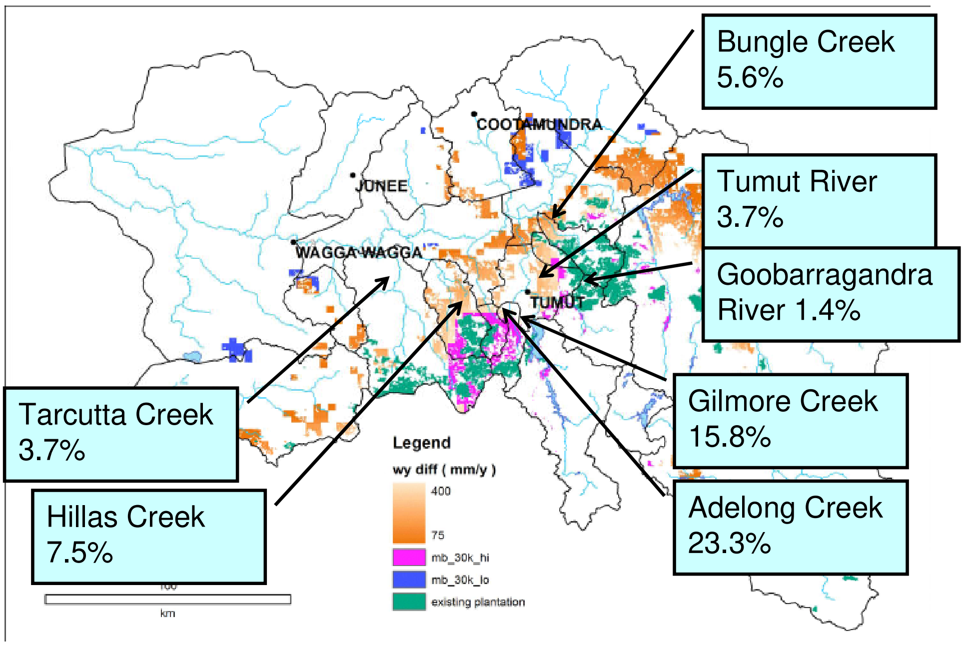

Figure 1. Predicted maximum percentage reductions in mean annual streamflow from tributaries to the Murrumbidgee following establishment of a hypothetical 30,000 ha of additional plantations in low (blue) and high (pink) impact areas. (Alice Brown, CSIRO, unpublished).

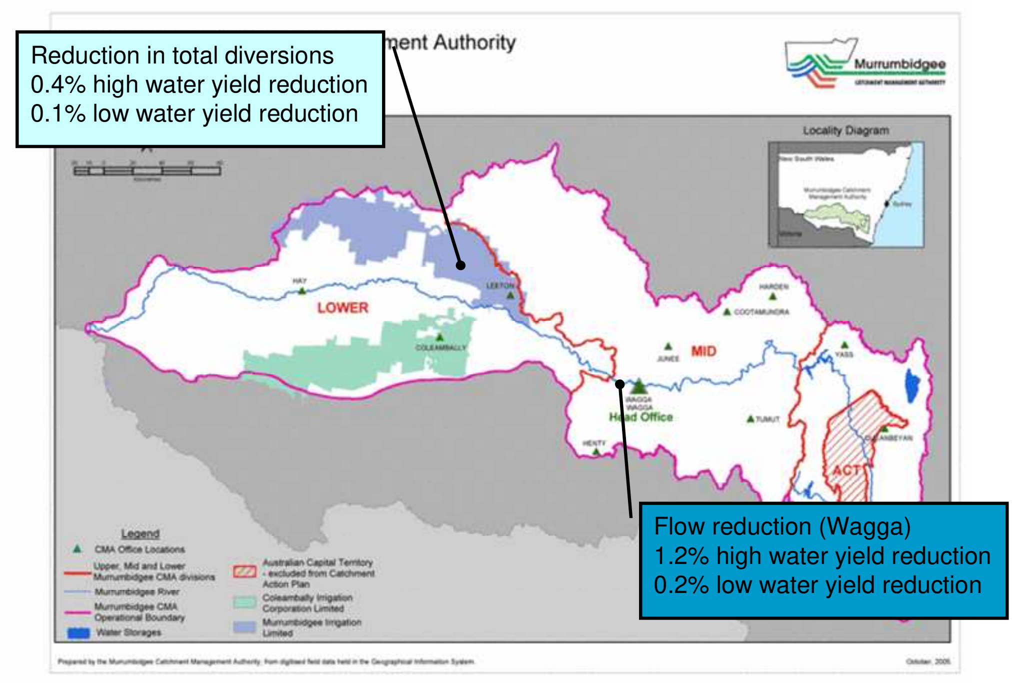

Figure 2. Predicted percentage reductions in mean annual flows in the Murrumbidgee River at Wagga Wagga and in total water diversions for the Murrumbidgee Irrigation Area following establishment of a hypothetical 30,000 ha of additional plantations in the upper catchment. (Alice Brown, CSIRO, unpublished).

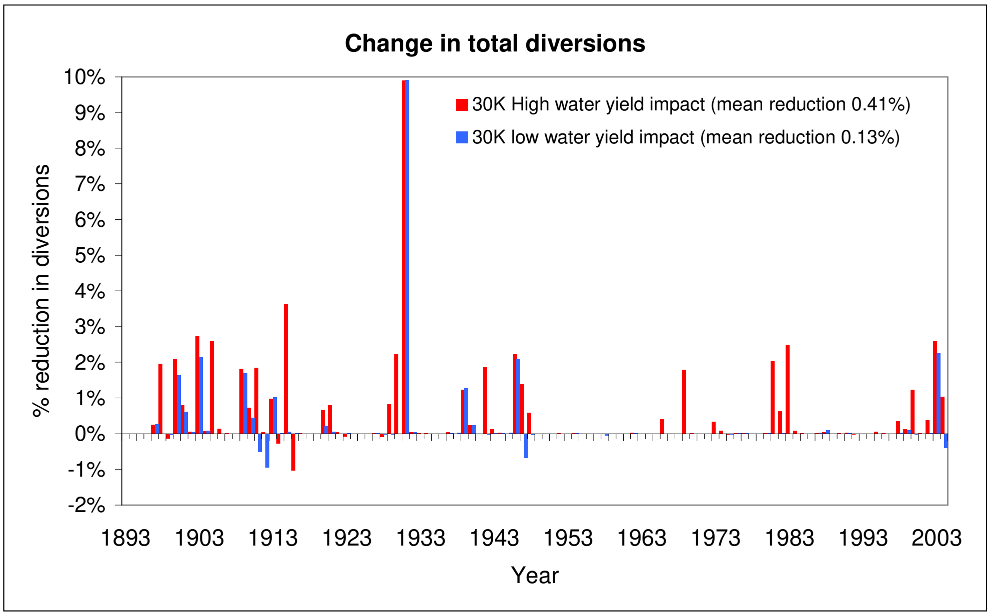

Figure 3. Simulated percentage reductions in total diversions for the Murrumbidgee Irrigation Area each year, over a 100-year climate sequence for a hypothetical additional 30,000 ha of plantations in the upper catchment. (Alice Brown, CSIRO, unpublished).

2.3 Plantation regions

A first step in describing the impacts of plantations on water security is to determine in which geographies and hydrological environments there may be an issue. This may apply to both areas of potential plantation expansion and existing plantations, notwithstanding the fact that the NWI is not intended to apply retrospectively.

Figure 4 shows regions of recent plantation expansion in Australia. Three regions stand out: (i) the Green Triangle encompassing south-eastern South Australia and western Victoria, (ii) Tasmania and (iii) south-western Western Australia. Between 1991 and 2005 the total area planted was close to 700,000 ha and was predominantly *Eucalyptus globulus* (blue gum). If future plantings were to be focussed in these regions then it serves to indicate where there may be potential issues with water policy.

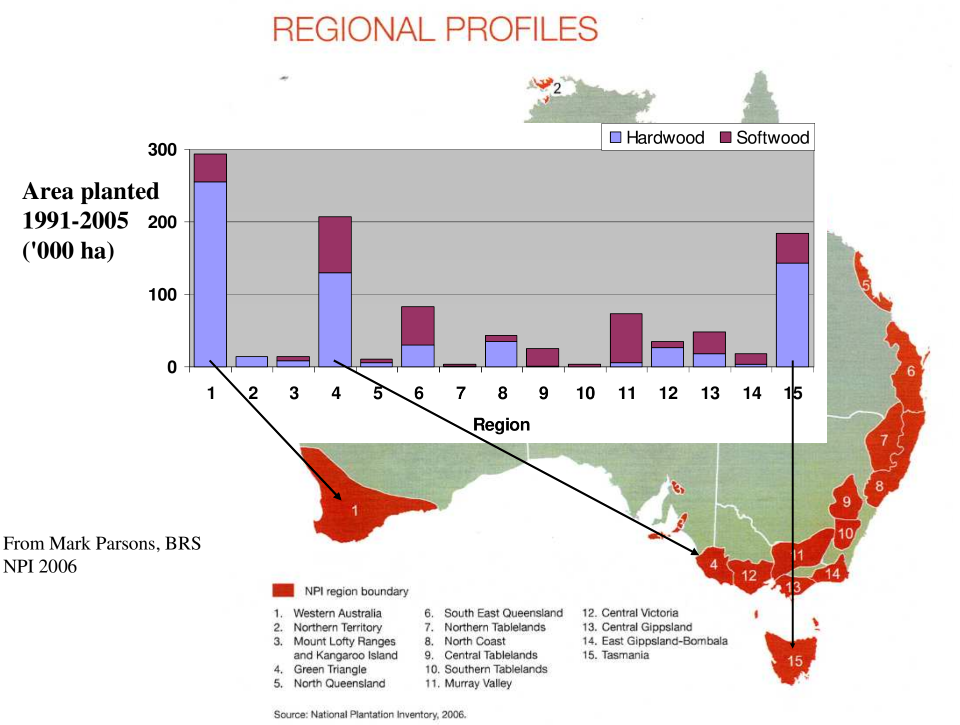

Figure 4. Areas of recent expansion of plantations in Australia (Parsons *et al.* 2006).

The above analysis was extended to consider the units of land across which water is managed. These may range from catchments to sub-catchments and smaller divisions to units within groundwater management zones. The National Water Commission identifies Surface Water Management Areas (SWMAs) which we have used here (Geoscience Australia 2004) to overlay with current plantation areas and estimated 'water interception' by plantations. This is defined as the mean annual reduction in streamflow or recharge under mature plantations compared to an average pasture or grass condition. It is based on the results of Zhang *et al.* (2001) who compiled a data set of more than 250 catchments globally, classified as either grassed (herbaceous plants), mixed (a mixture of herbaceous plants and trees) or forest (>70% canopy cover of trees). We used spatial layers for the SWMAs and overlayed areas of plantation and rainfall data at a 1 km scale. From that we calculated for each 1 km^2 of plantation the water use and amount of water intercepted compared to a baseline condition and then summed these across the SWMA to give total interception (GL) for the SWMA.

These values were then compared with estimated values for outflows in each SWMA (ANRA 2009) to determine water as a percentage of the outflow.

Our results (Table 2) are intended to be indicative only; to compare plantation areas between SWMAs and provide an unverified approximation of how much water is intercepted by plantations compared to a hypothetical baseline condition of grassland. It is important to note, however, that a large proportion of the plantation estate in Australia has been established on ex-native forest sites and not on land previously cleared for agricultural land use. The estimates of 'interception' therefore, may not represent actual changes to streamflow that have occurred due to past plantation establishment. The values for interception are also annual averages – they do not account for more localised impacts on sub-units such as tributaries nor consider critical or drought years. We are also aware that in some of the SWMAs there is large spatial variation in rainfall. This will have implications for the outcomes of our analysis. For example, if the plantations are concentrated in the higher rainfall parts of a particular SWMA, their impacts could be proportionally greater than our analysis. Furthermore, we have not familiarised ourselves with any of the particular circumstances in each catchment that may have resulted in deviations from our estimates due to local conditions.

Another important piece of information is an estimate of the extent to which SWMAs are 'stressed' or have sustainable yields of water. That is work in progress across Australia. For example the CSIRO has recently completed a Sustainable Yields Project for the MDB catchments (CSIRO 2008a) which was an intensive exercise. As a means of approximation and for reasons of consistency across catchments, we have used estimates of the 'Diversion Development Levels' (DDLs) for each SWMA (ANRA 2009). These are not assessments of water allocations but the extent to which water in the catchments has been developed and thus indicates the current or average water use compared to a sustainable yield for environmental flows. They are also for just SWMAs and not Groundwater Management Areas but remain a useful way to illustrate and identify the relative role of plantations at catchment and sub-catchment scale. In areas where there are significant surface water/groundwater interactions, our estimates of interception may translate to differences in recharge to groundwater rather than changes in streamflow. In some cases, such as for the Millicent Coast (Table 2) the catchment crosses State boundaries.

Table 2 shows all those SWMAs where water interception by plantations is estimated to be greater than 10% of catchment outflows. Values ranged up to about 50% for the Millicent Coast in the Green Triangle (South Australia) and the Tambo River in Central Gippsland (Victoria). In these catchments the percentage of the catchment established to plantation was 13 and 24%, respectively. The DDL was rated as 'Low' for the Millicent Coast and 'Medium' for the Tambo River. It should be noted that in the Millicent Coast, the geology and hydrogeology are such that surface water is a small component of the overall water balance. Most of the rainfall not used by vegetation recharges the groundwater. As a proportion of the total water balance (surface flows and groundwater recharge) interception by these plantations is probably somewhat less than the 50% indicated by our analysis.

Of the 19 SWMAs in Table 2, only two had a DDL rated as 'Over developed', being the Gawler River in the Mount Lofty Ranges (South Australia) and the Broken River in the Murray Valley (Victoria). In each of these, the area of plantation was 3.5% and 2% respectively, and the percentage of outflow intercepted was 22% and 12%.

Table 3 shows the 25 SWMAs rated as being 'over-developed' and where data were available for catchment outflows. Only the Gawler and Broken catchments contain plantations that intercept greater than 10% of the outflow. Water interception was 5-10% of the outflow in 4 catchments and was less than 5% in the remaining 19 catchments.

Table 2. Catchment statistics for all SWMAs where the amount of water interception by plantations is estimated to be greater than 10% of the catchment outflows.

STATE	SWMA NAME	Diversion Develop't Level (DDL)	Catchment area (ha)	Mean rainfall (ML/ha)	Runoff/ Rainfall (%)	Area of plantation (ha)	%Catch't that is plantation	Total water interception (GL)	%total outflow intercepted
SA	Millicent Coast (SA), Sub Catchment 1	L	646,400	6.77	4.8	86,500	13.4	108.8	52.0
VIC	Tambo River	M	417,400	8.22	9.5	100,200	24.0	160.3	49.2
SA	Millicent Coast (SA), Sub Catchment 3	L	318,400	7.15	6.6	41,500	13.0	54.8	36.3
SA	Gawler River	O	162,400	5.49	3.6	5,700	3.5	6.9	21.7
VIC	Glenelg River (Vic)	H	1,194,300	6.99	7.6	92,200	7.7	125.4	19.8
QLD	Brisbane River	H	1,049,600	9.57	2.9	24,500	2.3	53.8	18.2
WA	Denmark River	L	255,900	8.46	9.6	27,000	10.6	36.9	17.7
WA	Albany Coast	L	1,932,600	4.89	3.4	54,300	2.8	56.7	17.4
VIC	South Gippsland	L	629,100	9.36	14.2	72,100	11.5	140.0	16.7
QLD	Elliott	L	68,400	10.48	7.1	3,700	5.4	8.3	16.3
WA	Kent River	L	245,700	8.57	8.0	20,200	8.2	23.5	13.9
WA	Harvey River	M	196,000	10.34	6.2	8,000	4.1	16.4	13.1
VIC	Latrobe River	M	467,400	9.90	15.7	43,200	9.2	93.5	12.9
VIC	Broken River	O	639,800	6.19	6.0	14,700	2.3	29.5	12.4
QLD	Maroochy River	L	146,000	16.37	27.6	23,300	16.0	81.2	12.3
QLD	Mary River (Qld)	M	941,800	11.34	19.1	74,400	7.9	216.5	10.6
QLD	Noosa River	M	183,300	14.77	39.5	36,500	19.9	110.6	10.3
WA	Moore-Hill Rivers	L	2,450,600	5.06	1.4	13,200	0.5	17.6	10.0
SA	Broughton River	M	597,400	4.59	2.3	8,000	1.3	6.2	10.0

Table 3. Catchment statistics for all catchments rated as being 'over-developed' according to ANRA (2009).

STATE	SWMA NAME	Diversion Develop't Level (DDL)	Catchment area (ha)	Mean rainfall (ML/ha)	Runoff/ Rainfall (%)	Area of plantation (ha)	%Catch't that is plantation	Total water interception (GL)	%total outflow intercepted
SA	Gawler River	O	162,400	5.49	3.6	5,700	3.5	6.9	21.72
VIC	Broken River	O	639,800	6.19	6.0	14,700	2.3	29.5	12.38
SA	Gawler River - Sub Catchment Little Para	O	24,600	6.13	2.0	200	0.8	0.3	8.36
NSW	Murrumbidgee River - Unregulated	O	5,218,400	6.10	12.2	108,500	2.1	266.5	6.86
SA	Myponga River	O	14,600	8.19	2.5	100	0.7	0.2	5.56
NSW	Lachlan River - Unregulated	O	5,988,700	5.25	3.4	33,500	0.6	53.4	5.07
NSW	Macquarie River - Unregulated	O	6,167,200	5.40	4.4	37,600	0.6	62.5	4.23
SA	Onkaparinga River	O	91,500	7.51	9.2	1,600	1.7	2.6	4.16
VIC	Goulburn River	O	1,669,600	8.48	8.8	19,400	1.2	35.5	2.84
NSW	Upper Murray River (NSW Part Only)	O	519,300	10.57	46.1	28,000	5.4	60.7	2.40
SA	Torrens River	O	83,800	6.90	17.6	1,300	1.6	2.0	1.96
NSW	Namoi River - Unregulated	O	3,385,600	6.62	3.2	4,900	0.1	6.7	0.94
VIC	Loddon River	O	302,700	8.53	10.8	2,300	0.8	1.6	0.58
NSW	Murrumbidgee River - Regulated	O	2,926,600	4.10	10.1	6,600	0.2	6.4	0.53
VIC	Campaspe River	O	392,600	6.16	6.7	800	0.2	0.6	0.40
NSW	Namoi River - Regulated	O	744,700	5.71	12.4	1,100	0.1	0.9	0.16
NSW	Gwydir River - Unregulated	O	1,950,400	6.77	6.9	1,100	0.1	1.4	0.16
VIC	Mitta Mitta River	O	621,300	11.61	19.7	300	0.0	1.1	0.08
NSW	Murray (Hume to Border) - Regulated (NSW Part	O	1,859,400	3.83	38.0	4,800	0.3	2.1	0.08
NSW	Macquarie River - Regulated	O	1,228,400	4.83	9.1	500	0.0	0.4	0.07
VIC	Upper Murray River (Vic)	O	392,800	11.16	49.8	700	0.2	1.4	0.06
VIC	Ovens River	O	752,100	10.52	21.1	300	0.0	0.7	0.04
VIC	Kiewa River	O	174,100	12.66	30.4	100	0.1	0.3	0.04
NSW	Border Rivers (NSW) - Regulated	O	381,100	6.13	34.0	200	0.1	0.2	0.02
VIC	Mid-Murray River (Hume to SA Border) (Vic)	O	464,300	3.77	221.2	400	0.1	0.1	0.00

Regression analysis was used to identify those variables that control the percentage of catchment outflows intercepted by plantations. Data for most variables were highly skewed, requiring that they be log-transformed for statistical analyses. A number of independent variables were tested but the best correlation was found using a combination of plantation area (%) and the percentage of rainfall that is run-off (Table 4, Figure 5). When either of these independent variables was tested, the correlation was either reasonable (R^2= 0.70 for %plantation area) or non-existent (R^2=0.002 for percentage of rainfall that is run-off). In combination however, the variables give an R^2 of 0.94 for log-transformed data (Table 4).

Table 4. Coefficients and R^2 values for linear regressions on log-transformed data showing that a combination of plantation area (%) and runoff/ rainfall (%) explains nearly all the variation in % catchment outflows intercepted by plantations. Equations were of the form: (relative to grassland)
1. %catchment outflow intercepted = Plantation area (%).X_1 + C,
2. %catchment outflow intercepted = Runoff/ rainfall (%).X_1 + C, or
3. %catchment outflow intercepted = Plantation area (%).X_1+ Runoff/ rainfall (%).X_2 +C.

	Variable		Coefficients			
Equation number	**X_1**	**X_2**	**X_1**	**X_2**	**C**	**R^2**
1	Plantation area (%)		1.03		-1.02	0.70
2	Runoff/ rainfall (%)		-0.092		0.11	0.002
3	Plantation area (%)	Runoff/ rainfall (%)	1.03	-1.02	1.32	0.94

The relationship is shown graphically in Figure 5 for the raw and log-transformed data. The sign of the coefficients for each independent variable indicate that the percentage of catchment outflow intercepted by plantations: (i) increased with an increase in the percentage area of catchment that was plantation, and (ii) decreased with an increase in the percentage of rainfall that was run-off. This latter term indicates the extent to which rainfall across the catchment is used by vegetation (evapotranspiration).

The percentage of rainfall that becomes run-off is least in low-rainfall areas where there remains a significant cover of native vegetation that intercepts a large proportion of rainfall. Thus, plantation establishment is likely to have the greatest relative impact on catchment outflows in these lower rainfall areas. In an absolute sense, however, the amount of interception (GL per year) increases proportionally with rainfall.

These concepts are also demonstrated in Figure 6 which presents the same data in a slightly different form. Here, the plantation area (%) is divided by the Runoff/ rainfall (%) and the new values compared with the % outflow that is intercepted. The relationship is linear and highly significantly. It again shows that a relatively simple relationship can be used to describe plantation impacts on outflows and the added importance of the over all water balance.

Farley *et al.* (2005) also noted this differential impact of plantations. They reviewed the global data set and concluded that:

'… in a region where natural run-off is less than 10% on mean annual precipitation, afforestation should result in a complete loss of run-off.'

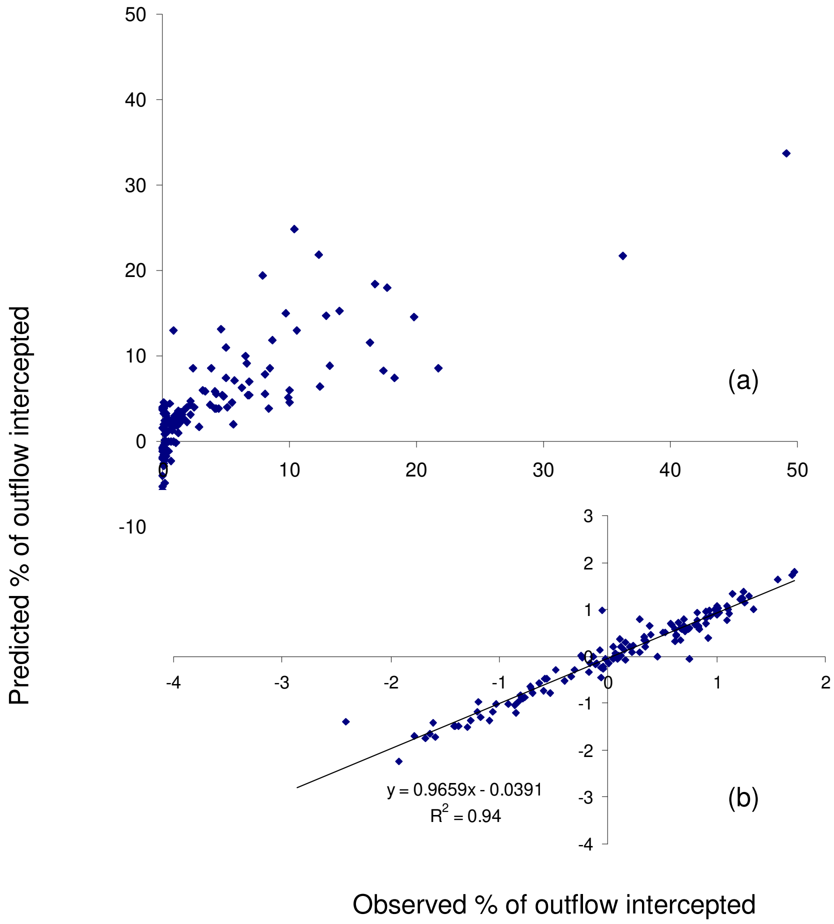

Figure 5. Predicted versus observed values for % of outflow intercepted by plantations (relative to groundwater) for: (a) raw data set, and (b) log transformed data. The regression is of the form:
%catchment outflow intercepted = Plantation area (%).X_1+ Runoff/ rainfall (%).X_2 + C.

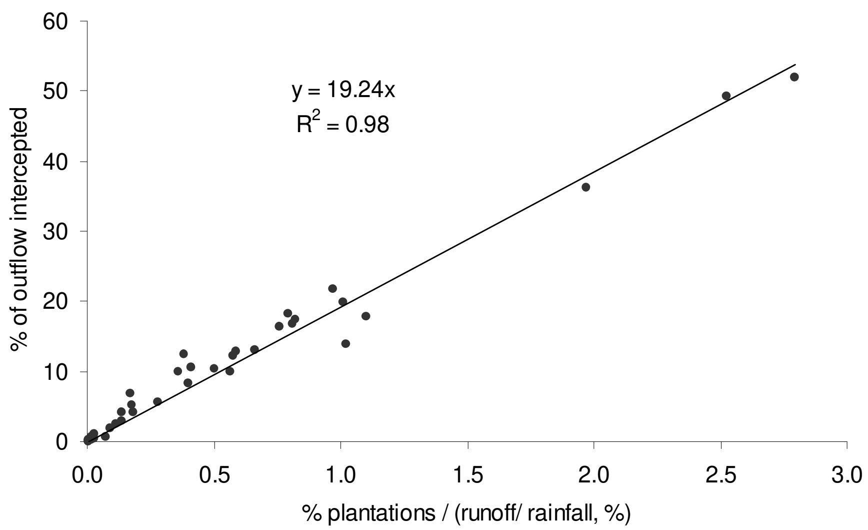

Figure 6. Interception of catchment outflow as a function of the % plantations in the catchment divided by the percentage of rainfall that is run-off.

3. STATE AND TERRITORY REVIEWS

The previous section indicates in which regions and SWMAs there may be issues with plantations and water security. Each State and Territory was interviewed to:

- Further assess where specific issues might lie,
- The state of development and potential direction of policy as it relates to plantations and water interception, and
- Identify specific needs for future research.

Typical questions asked and information included:

- How advanced is policy implementation of the NWI for water interception by plantations?
- Where are the over-allocated or nearly so catchments or units of water management?
- Where are the expected areas of plantation expansion?
- How do the above two points coincide – that is, can the 'hot spots' be identified were plantations and water interception may be an issue?
- What is the unit of water management?
- Can those catchments that are 'approaching full allocation' be identified in which large-scale plantation developments might trigger a threshold being exceeded?
- What tools or other information, if any, are being used to assess the impacts of plantations and other land use change on water interception?
- Could existing plantations be subject to regulation to, for example, eventually release water?
- Is land use change within agriculture as a water intercepting activity also on the policy agenda?
- Are native forests considered important in terms of water interception and potential impacts of climate change and fires?
- Given all of the above, what specific research is needed to help inform and implement policy?

In some cases the jurisdictions did not have enough information to answer all the questions and in most cases policy was not well advanced but was still in the conceptual stage. The discussions were therefore broad ranging to cover most of the issues concerning water security in the context of plantations, other forests and dryland agriculture.

The following sections briefly summarise the State and Territory reviews. South Australia and Victoria are considered in more detail as case studies for groundwater (South Australia) and assessments of change at landscape scale (Victoria).

It should be noted that, except for SA, policy is not yet developed in any jurisdiction. Many of the comments below therefore reflect the current 'thinking' and should not be interpreted as reflecting policy.

3.1 South Australia

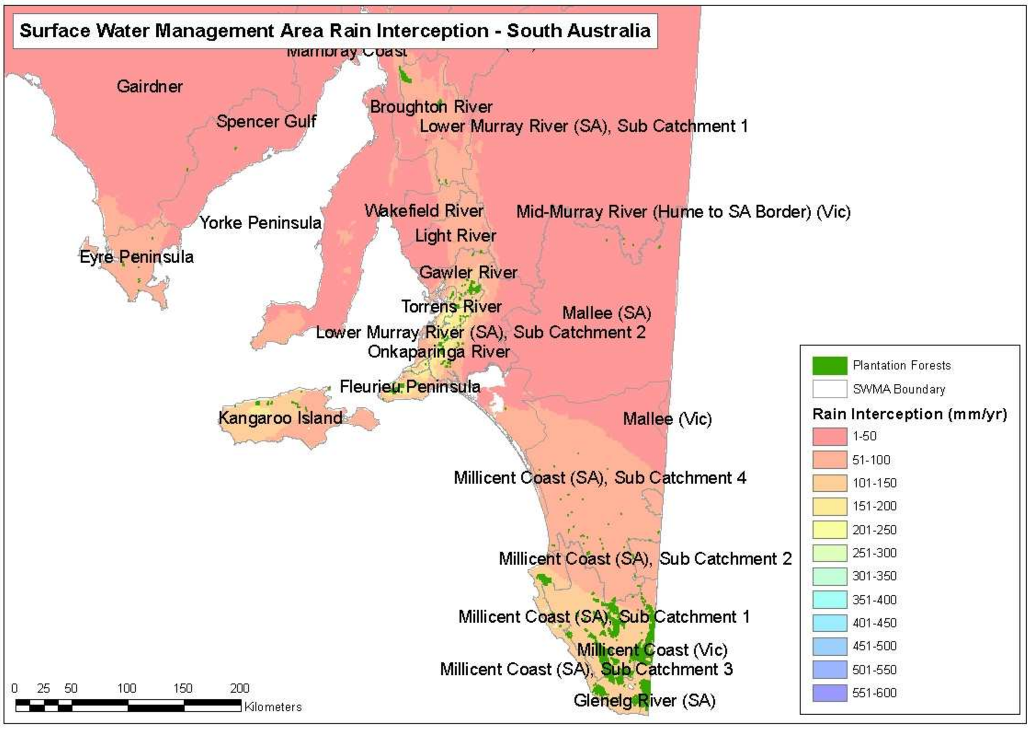

Figure 7. Map of South Australia indicating surface water management areas, the existing plantation areas and the potential for water interception by plantations based on rainfall and the Zhang *et al*. (2001) relationships.

Figure 7 shows the surface water catchments in South Australia and the existing plantations. In the south-east of the state, water resource issues focus on groundwater management. South Australia has the most advanced policies to account for plantation water use, particularly for the impacts of plantations on groundwater. It is important to note that in South Australia, water allocation plan policies are recommended to the responsible Minister by the relevant natural resource management boards, following an extensive mandated community consultation process. These processes are currently being undertaken in a number of management areas where plantation forests are considered to impact significantly upon the local water resources. Consequently a range of issues is, or may be, discussed within the stakeholder community. Therefore, at present, any discussions about policies in those management areas can only be considered as issues of interest. Discussion does not mean they will be become or considered to be a policy in the final water allocation plan.

Water resources are managed under the Natural Resources Management Act 2004. The state is divided into eight Natural Resource Management (NRM) regions, each with its own board. Each board must prepare a water allocation plan for each of the prescribed water resources in its region. Planning involves eight steps:

(i) After consulting with NRM groups and the Minister, prepare a concept statement which sets out the proposed content of the plan.

(ii) Seek comment from the public on the concept statement.

(iii) Amend the concept statement and make it available to the public.

(iv) Prepare a draft plan based on the concept statement.

(v) Seek public comment on the draft plan, including written submissions.

(vi) Submit to the Minister the draft plan and a report on the submissions received from the public.

(vii) The Minister may adopt the draft plan as is or refer it back to the NRM Board for revision, repeating steps iv to vi.

(viii) At least once every five years the NRM boards must review plans.

In the Lower Limestone Coast and the Mount Lofty Ranges NRM regions, prescribed water resources contain commercial forestry plantations. Kangaroo Island, which also has commercial plantations, is not a prescribed water resource, however local councils do take account of potential effects of new plantations on water in assessing planning applications, based on guidelines developed by the South Australian Department for Water, Land and Biodiversity Conservation (DWLBC) (Greenwood 2007).

3.1.1 Lower Limestone Coast

In the current revision of the 5-year water sharing plan for the Lower Limestone Coast (LLC) by the South East NRM Board (SENRMB), the planning process is currently at Step (vii). The draft revised plan includes a proposal to account for water use by the region's plantations using a system of water allocations (SENRMB 2007).

Figure 8 depicts the groundwater management areas of the SENRMB, however plantation forestry only occurs in that area south of line approximately running from Kingston to Naracoorte. This area is currently referred to in forest water legislation as the lower South East. The rainfall in this zone ranges from about 600 mm near Naracoorte to about 850 mm west of Mount Gambier. An estimated average of the mean annual rainfall for the 1 million ha that makes up the lower South East is about 700 mm.

Figure 8. Groundwater management boundaries and prescribed well areas in the Lower Limestone Coast.

The following description of the region was provided by Darryl Harvey from DWLBC. This is an extract from a DWLBC draft report titled *Accounting for plantation forest groundwater impacts in the lower South East of South Australia* (Darryl Harvey, DWLBC, personal communication).

'The topography of the region is relatively flat to gently undulating and has mostly sandy soils. There are over 20 low relief stranded ancient coastal dunes running approximately parallel to the coast. The underlying regional geology is generally karstic limestone and in combination with the surface features, results in no significant surface water streams draining to the marine environment.

The area around Mount Gambier has experienced volcanic activity, with a number of dormant remnant craters evident in the landscape, including the Mount Gambier complex, Mount Schank, and Lake Leake. The Blue Lake crater at Mount Gambier provides a window into the local unconfined aquifer.

The depth from ground to the unconfined aquifer water level ranges from 2-3 metres to about 60 metres in areas of higher relief.

Following early land clearance, and during a significant climatic wet phase, a number of surface water drains were constructed to move excess surface water (could be considered as rejected groundwater recharge) to the coast. This drainage systems should not be confused with the mid and upper South East groundwater drains that have been recently constructed to help mitigate rising groundwater and rising salinity trends in the lower rainfall zone of the mid South East.

There are two main aquifers under formal management in the lower South East; the unconfined limestone aquifer that overlies the confined aquifer which is not always clearly distinguishable, or its water accessible for beneficial use.

The Tertiary unconfined limestone aquifer occurs within fossiliferous marine limestone, with interbeds of marl, calcite and dolomite, and flint horizons. The groundwater is used for a wide range of purposes, ranging from municipal supplies, stock and domestic water supplies, industrial use, and widespread irrigation throughout the region.

Recharge to the unconfined aquifer is largely from locally occurring rainfall which percolates past the root zone of the vegetation. In some areas there are paths of preferential recharge from occasionally occurring surface water. This can be noticed through features locally known as "run away" or "sink holes", which are a characteristic of the lower South East karstic limestone geology.

In addition to local rainfall recharging the unconfined aquifer, there is a natural through flow of groundwater, generally towards the coast, but with a northwest direction in the upper regions. For groundwater management purposes, the extractable volume of water available for allocation from the unconfined aquifer is considered to be a function of the local vertical recharge from rainfall. The quantity of recharge for a groundwater management area is generally reduced by 10 per cent and the balance is referred to as the total available recharge. The 10 per cent reduction is a nominal environmental allowance to ensure the natural lateral through flow and some support for locally occurring groundwater dependant eco-systems.'

About 95% of the region's water resources are derived from the unconfined aquifer. Because this near-surface groundwater system is fed mainly from diffuse local recharge, any land use change that increases evapotranspiration will reduce aquifer recharge. At some locations the water table is present at a shallow enough depth to be accessible by deep-rooted vegetation.

Plantation forestry has been practiced in the region since the late 19th century. By 1990 an estate of approximately 90,000 ha of *P. radiata* plantations had been established, predominantly in the Lower South East, south of Penola. Since 1998 an additional 40,000 ha of *E. globulus* have been established, primarily to the west and north-west of Penola. Plantations now occupy approximately 140,000 ha, or 15% of the agricultural land in the Lower South East.

Groundwater in the LLC is managed and allocated based on long-term ‘sustainable yield’. This means that mean annual groundwater extractions should not exceed the estimated mean annual groundwater recharge, less an allowance to protect water dependent ecosystems (currently 10%). The LLC has been divided into 70 groundwater management units, based largely on the original 100 square mile cadastral units (known locally as ‘Hundreds’). Within each unit, average annual groundwater extraction must not exceed the estimated long-term mean annual recharge, less the 10% allowance for the environment. Within each unit, the rate of groundwater recharge has been estimated based on analysis by Brown *et al*. (2006b). These estimates have subsequently been modified in some areas after refinement of information on depth-to-groundwater.

The draft revised water allocation plan for the LLCPWA includes a proposal that all plantations must have a groundwater allocation based on ‘deemed’ rates of recharge interception and groundwater extraction (SENRMB 2007). Existing plantations would be granted an allocation at no cost but new plantations would need to acquire an allocation. Under the draft proposal, these allocations can be converted to water taking licenses if the land is converted from plantations to agriculture. Taking account of deemed impacts of existing forestry plantations on recharge and extraction.

This proposal is underpinned by considerable research, but there remain substantial knowledge gaps. Three studies in the 1960s using different techniques (soil water balance, groundwater level fluctuations and analysis of environmental tritium in groundwater) indicated plantations were intercepting most or all of the groundwater recharge (Holmes and Colville 1970a and b, Allison and Hughes 1972 Colville and Holmes 1972). This has been confirmed in recent years in plot-scale studies of evapotranspiration (Benyon and Doody 2004, Benyon *et al*. 2006, Benyon *et al*. 2008). The latter studies also demonstrated that at some sites the plantations are a net user of groundwater.

The DWLBC has used this research, and some simple assumptions that were developed in consultation with local forest growers, to develop deemed rates of recharge interception and groundwater extraction by plantations (Brown *et al*. 2006b, SENRMB 2007). At the time of writing, the DWLBC was finalising a report detailing to the process adopted and the models developed, with publication expected in early or mid 2009 (Darryl Harvey, personal communication).

Recharge interception:
- Short rotation (blue gum) = 0.78 x pasture recharge
- Long rotation (pine) = 0.83 x pasture recharge

Groundwater extraction (median depth to water table <6 m):
- Short rotation = 182 mm/year
- Long rotation = 166 mm/year.

The following extract from the draft DWLBC report titled *Accounting for plantation forest groundwater impacts in the lower South East of South Australia* explains some of the rational behind the proposed deemed rates (Darryl Harvey, DWLBC, personal communication). It is important to note this is an extract from the draft report and does not necessarily reflect our views. It is provided for those interested in gaining an understanding of the technical basis for the proposed policy in the lower South East of South Australia.

’It is impractical to commercially measure actual forest water consumption, whether in terms of impacts on surface water yield, groundwater recharge, or by direct extraction from shallow water tables. Based on biophysical principles and assumptions, a

system of forest water models with outputs expressed in annualised deemed values have been developed. They are not point impact measurements, but a characterisation of plantation forests of the same type in the same groundwater management area. They "smooth" the hydrologic impacts of the forest over the full forest rotation period. While appropriate for South East groundwater accounting and management purposes, they may have some application for water accounting in other regions.

The forest water recharge models minimise administrative complexity by managing each forest type as a single class, providing administrative benefit for both forest owners and the water resource manager. While it is a policy issue to be confirmed through the relevant water allocation plan, any change to annualised deemed forest recharge water values should only impact on the water transfer accounting, that is, only of relevance for a business entering or exiting the plantation forest industry, or changing a forest type.

In the case of hardwood plantations, the annualised forest water recharge model indicates plantation forests reduce the groundwater recharge that would normally occur on a forested site to 22 per cent of that occurring if the site were committed to a dryland agricultural land use; representing a loss of recharge on that site of 78 per cent. In the case of softwood forest plantations, the recharge loss to any softwood forest site is 83 per cent of that occurring in a dryland agricultural landscape.

Where the median water table is 6 metres, or less, from ground level, hardwood plantations are deemed to extract 1.82 ML/ha, on an annualised basis, and softwood plantations are considered to extract 1.66 ML/ha.'

These proposed deemed rates are rainfall independent, and are based partly on some as yet unconfirmed assumptions about the amount of recharge occurring prior to canopy closure and after thinning. The DWLBC proposes to undertake some more detailed groundwater modelling and analysis studies, using the proposed deemed rates of groundwater extraction and recharge interception, to verify whether groundwater level responses are consistent with the deemed rates (Darryl Harvey, personal communication).

Assumed recharge rates in each year of the rotation for *P. radiata* and *E. globulus* are shown in Table 5. These were used to calculate the deemed recharge rates shown above. However, they have not yet been confirmed by field measurements. The following extract from the draft DWLBC report titled *Accounting for plantation forest groundwater impacts in the lower South East of South Australia* explains the assumptions used in deriving the proposed deemed rates (Darryl Harvey, DWLBC, personal communication).

'In consultation with the forest industry, the two forest types have been described in terms of forest life (years) from planting to clear felling. In the case of softwood plantations, the number of thinning operations is also included. To assist in "visualising" the characterised plantation, each industry has estimated the productivity, or site quality, of its "average" plantation.

In the case of hardwood plantations, the industry has advised that second rotations will be established by replanting and not by the coppice method.[1]

It should be noted that in the case of softwood plantations, there is considerable variation in how the three main South East forest companies manage and harvest their plantations. During the 2006 review, it was generally agreed plantation rotation length varied from about 28 years to 45 years, with some compartments being harvested at a

[1]Current view of the hardwood industry is higher forest productivity will be gained from improved genetic material that is associated with replanting with seedling stock, rather than continuing by coppicing the existing tree stock. There are also management cost issues in establishing a second rotation by coppicing.

greater age, however, industry agreed on a description that took account of a "weighting" for different plantation management strategies.

In the development of future water allocation plans, a review of silvicultural practices or forest management changes is likely to be undertaken, including a review of the current description of the typical plantation, and hence the annualised water accounting model.

In 2006, the respective plantation industries supported the following basic descriptors for the "average" plantation forest:[2]

<u>*Hardwood (short rotation) plantation forest*</u>

- *Planting to harvest, the time period is ten years;*
- *Expectation of a site index of 14 with an annual productivity of 220 cubic metres by year ten; and*
- *Establishment of next rotation is one year after clear felling and by planting new seedlings (no coppicing).*

<u>*Softwood (long rotation) plantation forest*</u>

- *Planting to harvest, the time period is 35 years;*
- *Four thinning operations, where the object is to approximately halve the tree density existing at the time of commencing the thinning;*
- *Plantations expected to be site quality 3; and*
- *Establishment of next rotation is one year after clear felling.'*

Recent studies at three field sites indicate recharge in the early part of the rotation is higher than the assumed rates for years 1 and 2 shown in Table 5 (Benyon *et al.* 2008). Recharge rates in the first two years of a *P. radiata* rotation appear to be about 200% of the deemed pasture recharge rate. However, recent data from one *P. radiata* field site also indicates the amount of recharge after thinning may be less than the assumed rates. On balance, with more recharge in the first 2 years, but less after thinning, the rotation average may not be substantially different from the deemed rates.

There is perhaps greater uncertainty in the deemed rotation average recharge interception for *E. globulus*. If recharge in the first 2 years averages 200% of pasture recharge and not 100% as assumed, this would reduce net recharge interception over the whole rotation for *E. globulus* from 78% to approximately 60%. However this will depend partly on how quickly recharge declines after year 2 and partly on whether the plantation in each subsequent rotation is re-established from seedlings or coppice and the effectiveness of weed control. In the recent CSIRO studies, regeneration was from seedlings and weed control was effective.

Table 5. Assumed recharge rates (mm/year) under plantations in the LLC as a percentage of recharge under pasture.

Year of rotation	*P. radiata*	*E. globulus*
1	120	120
2	100	80
3	80	60
4	60	0
5	40	0
6	20	0
7+	0	0
Year after thinning	50	N/A

[2] Determined and agreed by industry representatives in consultation with the South East Natural Resources Management Board in October 2006.

For groundwater extraction the deemed rates are based on detailed CSIRO studies of groundwater use by plantations in the region. An alternative to the deemed rates could be a recently developed simple empirical model based on rainfall and potential evapotranspiration (Benyon *et al*. 2008). This could be applied in each groundwater management area to give a more precise estimate of groundwater extraction. The analysis of data from 22 plantation sites with closed-canopies in the Green Triangle indicated mean annual evapotranspiration in the region is largely determined by annual rainfall, accessibility of groundwater and potential evaporation (Benyon *et al*. 2008). Closed-canopy plantations without access to groundwater used all of the rainfall, while closed-canopy plantations with < 6 m median depth to groundwater, and no root impeding layers, used water at a rate equivalent to about 90% of the theoretical potential maximum evapotranspiration determined by available energy. An empirical relationship accounted for 94% of the between-site variation in closed-canopy mean annual water use.

DWLBC has advised that policy makers in South Australia 'are receptive to using new or improved science to refine management values, however at this stage of developing the relevant water allocation plans, there is a commitment to the current model, version 2006. However, new approaches should be considered for the future. A key attribute of the current approach is that the annualised approach for a "typical" plantation negates the need for considerable administration and compliance costs to all parties' (Darryl Harvey, personal communication).

Research needs

South-east South Australia is the plantation region with the most comprehensive set of field measurements of evapotranspiration from commercial plantations in Australia. Given that the precautionary principle applies to management of water resources in South Australia, we consider the underlying science to be of sufficient rigor to form the basis for estimating plantation water use for the purposes of developing policy. There are still knowledge gaps which, if filled, could potentially improve the accuracy of regional estimates of groundwater recharge and net groundwater uptake under plantation land by the order of 10 to 20%. Given the draft LLCPWA water allocation plan would allocate about 200,000 ML $year^{-1}$ to plantations for recharge interception and about 100,000 ML $year^{-1}$ for groundwater extraction, a 10 to 20% improvement in accuracy of these deemed rates equates to 30,000-60,000 ML.

Additional research needs include:

1) Improved understanding of needs of water dependant ecosystems, in terms of quantification and description of the water regime (for example flow duration or inundation).
2) Improved estimates of water use and recharge for determining:
    a) Water use of plantations aged 2 to 5 years in *P. radiata* and *E. globulus*.
    b) Effects of early rotation management (longer/shorter fallow, more/less weed control).
    c) Water use post-first thinning in *P. radiata* with groundwater at 4 to 8 m depths.
    d) Whether plantation water use various over time in response to rising or falling groundwater levels.
    e) Effect of thinning on water use in *P. radiata.*
3) Improved prediction and modelling of water use by plantations.
4) Monitoring (for example, remote sensing) to verify regional-scale extrapolation of estimates of water use based on plot-scale measurements.
5) Assessment of the impact of groundwater salinity on groundwater uptake by plantations and the resulting wood productivity.

6) Impact of plantation forest groundwater extraction on residual groundwater salinity, after two consecutive plantation rotations (at a large scale, say 50,000 ha).
7) DWLBC anticipates that review of its deemed values (as mentioned above) will drive the need for investing in items (5) and (6).
8) Monitoring (for example, remote sensing) to verify regional-scale extrapolation of estimates of water use based on plot-scale measurements.

3.1.2 Mount Lofty Ranges and Kangaroo Island

Smaller areas of commercial plantations have been established in the Mount Lofty Ranges to the east and southeast of Adelaide, on the Fleurieu Peninsula to the South of Adelaide and on Kangaroo Island. The Mount Lofty Ranges (MLR) is a prescribed water resource, requiring a formal water allocation plan, whereas Kangaroo Island is not. A water allocation plan is currently being drafted for the MLR. It may include a proposal to manage the impacts of plantations on water resources and water dependent ecosystems.

The MLR provides 60% of Adelaide's water supplies and there is currently a moratorium on new water using activities until the water allocation plan has been approved. All that can be said at this time is that the water allocation plan is currently in preparation for community consultation. Additional information, including details of any policy proposal, may become available in 2009.

On Kangaroo Island, water resources are not prescribed but the Council does take account of DWLBC technical guidelines on likely hydrological impacts of plantations when assessing applications for plantation developments.

Research needs

- These regions are complex with respect to hydrology, particularly the Mount Lofty Ranges. There is a need to provide more transparency in water accounting to enable quantification and qualification of environmental water needs. This is important where groundwater provides base flown to streams and the flow duration may be an important factor.
- Local measurements of water use will enable more accurate comparison between plantations and other land uses and will enable local-scale predictions of impacts of land use change on water interception.
- In the case of Kangaroo Island, plantation forestry could provide an important environmental service if located in areas that are considered to be at risk of dryland salinity. Research relevant to local conditions is needed to quantify the impacts of plantations on salinity.
- The potential carbon and biodiversity benefits of plantations in the lower rainfall zones need to be quantified and the impacts of such plantations on water resource sustainability assessed.

3.2 Victoria

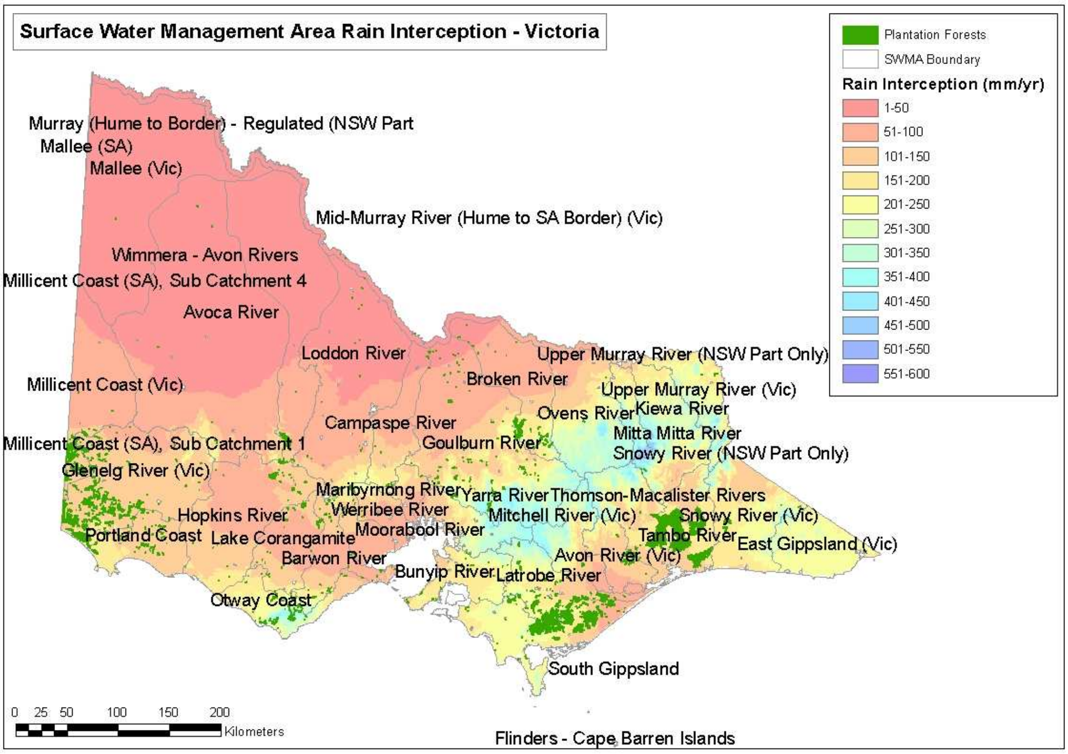

Figure 9. Map of Victoria indicating surface water management areas, the existing plantation areas and the potential for water interception by plantations based on rainfall and the Zhang *et al*. (2001) relationships.

Victoria's surface water management areas and estimated potential interception predicted by the Zhang *et al*. (2001) relationships are shown in Figure 9. A draft policy on intercepting activities is currently being developed. Alternatives to a water licensing arrangement are being considered and could include a full market-based system such as cap and trade amongst other instruments.

Victoria published a policy White Paper (Vic. Government 2004) setting out a plan for management of Victoria's water resources. Action 2:20 of the White Paper recognises the potential for land use changes, including plantations, to intercept water and commits the Victorian government to assessing these impacts and developing a state-wide approach to their management. To address Action 2:20 the Victorian government has:

- Developed a bio-physical understanding of intercepting activities and used this to conduct a state-wide assessment to identify high, medium or low impact hydrologic impact zones for new land use change.
- Commissioned an independent policy research project to identify a range of potential policy instruments that could be used. This work will inform a subsequent phase of developing a Victorian policy position on addressing land use change interception.
- Commenced development of a policy approach. Until the new arrangements take place, existing planning arrangements will apply.

The main areas of interest are in south-western Victoria and Gippsland where there has been rapid land use change to blue-gum plantations since about 1995. In south-western Victoria the area of hardwood plantations has increased by more than 154,000 ha in the Green Triangle region and by 30,000 ha in central Victoria. Change in agricultural land use has also been significant in south-west Victoria. For example it is estimated that between 1990 and 2001, the area of cropping expanded by about 120,000 ha and dairy by about 250,000 ha (SKM 2005). In Gippsland, the area of plantations increased by about 60,000 ha between 1995 and 2005. The effect of plantations on water resources is also a local issue in a few northeast Victorian catchments, but plantation expansion in this region in the past decade has been somewhat less than in the south-west and Gippsland. Historically, most of the softwood estate had replaced native forest.

Water planning and licensing is the responsibility of Gippsland and Southern Rural Water in rural southern Victoria. However, various other stakeholders, particularly Catchment Management Authorities (CMAs), also have an interest in water resources and over the past six years have sponsored several studies examining the effects of land use change on water.

3.2.1 South-west Victoria

South-west Victoria includes the areas managed by the Glenelg Hopkins and Corangamite CMAs. The region of about 40,000 km^2 (17% of Victoria) includes the Otway groundwater basin (Australia's eighth largest groundwater basin) and various surface water catchments. The climate and hydrology is more complex and diverse than on the SA side of the border. Dalhaus *et al*. (2002a and b) identified 27 groundwater flow systems in the Glenelg Hopkins CMA (GHCMA) and Corangamite CMA (CCMA) areas. These range from small local systems to large regional systems. Total groundwater recharge and discharge has not been well quantified across the region. Surface water systems in the GHCMA and CCMA generate mean annual flows totalling 8,376 GL. Mean annual rainfall is as low as 550 mm around Geelong to >1900 mm in the higher parts of the Otways (SKM 2005).

Land use in the region in 2003 was 65% livestock grazing, 17% native vegetation, 7% cropping, and 5% forestry plantations. Transport, water bodies and urban areas made up most of the remainder (SKM 2005). Since 1990 there has been a consistent trend away from broad acre grazing to dairy, cropping and plantation forestry. There has also been growth in rural residential areas, but still <1% of the total land area (SKM 2005). Based on analysis of recent trends and discussions with various stakeholder groups, in 2005, SKM predicted that between 1990 and 2030 the area of broad acre grazing will decrease by about 1.1 Mha, dairying and cropping will increase by about 730,000 ha, plantation forestry by about 175,000 ha, native revegetation by about 150,000 ha and various other land uses by smaller amounts.

Using a one-dimensional water balance model, 'SoilFlux', SKM has undertaken various studies to predict the impacts of these land use changes on water resources. Their 2005 regional analysis estimated that by 2030, total surface water will have decreased by 6% to 9% compared to 1990 flows and groundwater recharge by <1%.

This modelling approach has recently been extended by SKM to all of Victoria on a 1 km^2 grid. By overlaying expected changes in water resources and assessments of current stress, hot spot areas have been identified.

One such hot spot area is the Hawkesdale Groundwater Management Area. In 2007, Southern Rural Water commissioned an analysis by SKM of the groundwater budget for the Hawkesdale GMA (SKM 2007). There is a local issue of over allocation of groundwater. Based on CSIRO observations of groundwater use by plantations in the Green Triangle, and the area of plantations in Hawkesdale GMA established with depth to groundwater <5 m, SKM (2007) estimated these plantations could be extracting between 12,000 and 20,000 GL of groundwater per annum. This means that in some parts of the Hawkesdale GMA, groundwater is effectively over-allocated.

CSIRO has recently completed a report on plantation water use in the region (Benyon *et al.* 2008). This includes analysis of annual water use from six plantation sites in south-west Victoria and 16 in south-east SA in relation to various site factors. An empirical relationship between mean annual water use, climate and depth to groundwater was derived which accounts for 94% of the between-site variation in mean annual water use. The report also evaluates the performance of three models of plantation water use: SKM's SoilFlux model, a version of the 3-PG model and CABALA. The three models were reasonably accurate in predicting annual water use of plantations not using groundwater but had poor accuracy for sites with access to groundwater.

3.2.2 Gippsland

Some stakeholders are concerned about the potential impacts of new plantations on water resources in Gippsland. Between 1995 and 2005 about 60,000 ha of new plantations were established, with continued expansion likely. The Victorian DPI has used their Catchment Analysis Tool (CAT) to predict effects of land use change on water resources and salinity. The CAT model estimates water use, recharge, flows of water, salt and nutrients to streams, depth to water table, erosion, and carbon store at 1 ha resolution for a range of land uses. It uses 3PG for modelling tree growth and water use. CAT has also been applied in the Corangamite CMA and will be rolled out across the rest of Victoria.

Predictions from the CAT model need to be verified through long-term monitoring of vegetation water use, streams and groundwater.

Research needs
Victorian policy makers identified the following priority research needs:

- Plot-scale studies of plantation water use and long-term monitoring of groundwater levels to verify estimates of groundwater use by plantations.
- Long-term monitoring and analysis of stream flows in sub-catchments with and without recent land use change to verify predictions of declining stream flows in catchments subjected to recent land use change.
- Understanding impacts of land use change on seasonal stream flow patterns in addition to impacts on mean annual flows.
- Regional-scale verification and extrapolation of plot-based measurements of evapotranspiration, for example using a remote sensing method.
- The impacts of land use change under different climate change scenarios.
- Maximising the value of plantation product per unit of water used.
- Measurements of water use by other land uses to enable more accurate comparisons between various grazing and cropping systems, plantations and native vegetation.
- Understanding the impact of different agricultural management practices (for example, raised bed cropping, stubble mulching, minimum tillage and other biomass conservation practices) on recharge and runoff.
- Assessing the trade-offs between water interception and other economic, environmental and social impacts, including research on policy to identify ways of managing water resources to ensure that the highest value (greatest societal benefit) is derived from the resource across competing interception / extraction / environmental demands.
- The impacts of forest management (silviculture) on water use and productivity (not necessarily a high priority).
- Assessing the interactions between groundwater and surface flows (not necessarily a high priority).
- Impacts of native forest management on forest water use and streamflow.

3.3 Queensland

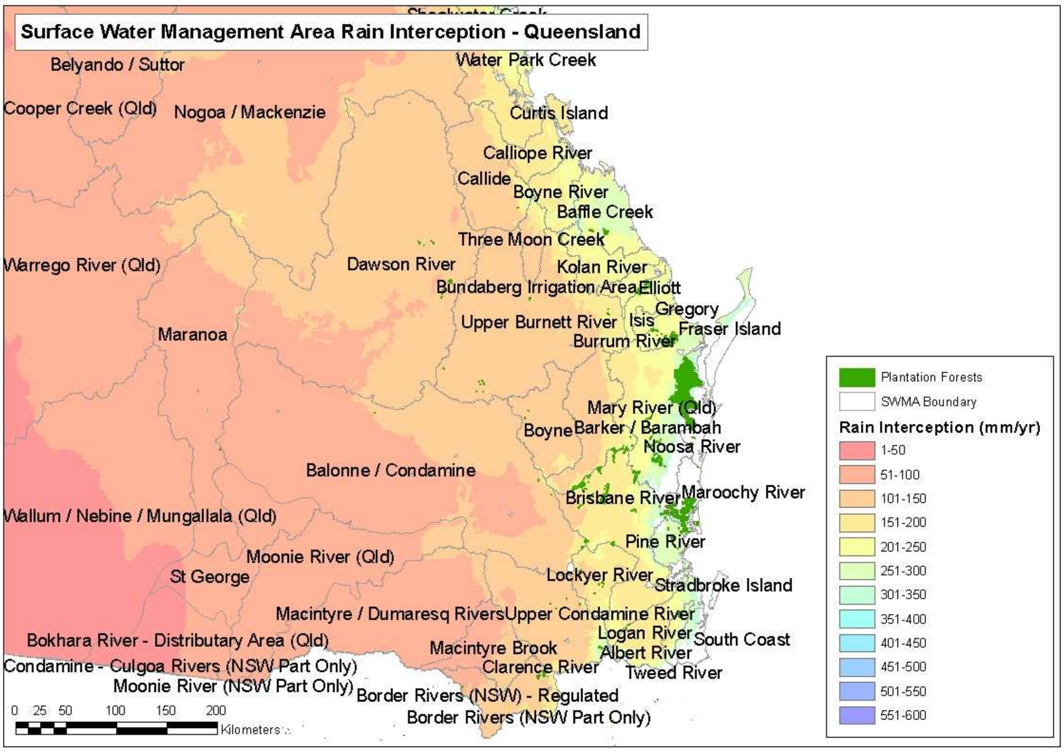

Figure 10. Map of south-east Queensland indicating surface water management areas, the existing plantation areas and the potential for water interception by plantations based on rainfall and the Zhang *et al*. (2001) relationships.

Queensland is yet to develop a policy on the management of the water impact of plantations and it is not presently a high priority. The majority of plantations are located in catchments where there is either an abundance of water or limited development so the competition for water supplies is minimal (Figure 10). A qualitative risk assessment is underway to determine if future plantation development will be a threat to water security and so far this has determined that there is no need to increase the management of the impacts of plantations on water availability. It is recognised that this will be an issue that will have to be dealt with in the future and the development of a national approach will help to guide this.

The majority of plantation development has occurred in the south-east of the state with some smaller developments in the coastal north. There is little plantation development in inland (Murray-Darling Basin) areas of Queensland.

Management of forestry activities is controlled by different legislation and development codes managed at both state and local Government level. Establishment of plantations is primarily guided by local councils' planning provisions which will vary between local councils.

The Risk Strategy of the MDB (MDBC 2008) provides the process for assessing the impact on water supplies of any projected growth in plantations and applies to the whole of the Murray-Darling Basin. The likelihood of a significant growth in plantations in the Queensland Murray-Darling Basin is considered to be negligible due to the climatic conditions and soil types. This assessment is supported by the Murray-Darling Basin Sustainable Yields project (CSIRO 2008a) which also concluded that plantations are not considered a significant risk to water security.

In the rest of the state there is a high probability that there will be an increase in the area of hardwood plantations in the future as the harvesting of native forests will be progressively replaced with plantation timber. In south-east Queensland, native forest harvesting will be phased out by 2025 (under the South-East Queensland Forests Agreement) and as a consequence there is a government imperative to develop more plantation timbers (hardwood and softwood) to replace native forest. It is likely that under the State-wide Forest Process (which is being developed and will cover the remainder of the state), similar transitional arrangements will be introduced on non-cypress resources in the south-west in the near future. No final decision has been made on this issue at present.

The State-wide Forest Process has set an initial target of 20,000 ha of hardwood plantations across the state and active sourcing of suitable sites has been a priority for Forestry Plantations Queensland (who manage the Queensland Government's plantation estate). Trial plantations of hardwoods are established in the region indicating that there may be additional plantations in the future.

Other relevant points included:

- The possible impacts that a carbon trading market might have on new forest plantings is of interest.
- The impacts of change in agricultural land use are considered to be potentially important but are not an issue at present due to the low level of change in this land use.
- The role of native forests is of interest and the potential for management (thinning for example) to release water.
- The potential for climate change impacts is considered very important.

Research needs

Queensland identified the following priority research needs:

- Better estimates of plantation water use, especially at fine scales of time and space.
- Estimates of the impacts of plantations on down-stream users and at specific points in space.
- Methods to translate water use into water access entitlement. For example, should everything try to be predicted and measured or should default values be used?
- Potential for the area of carbon plantings to expand and intercept water.
- Cost: benefit analysis of the benefits and trade-offs of new plantations for the range of social, economic and environmental impacts.

3.4 New South Wales

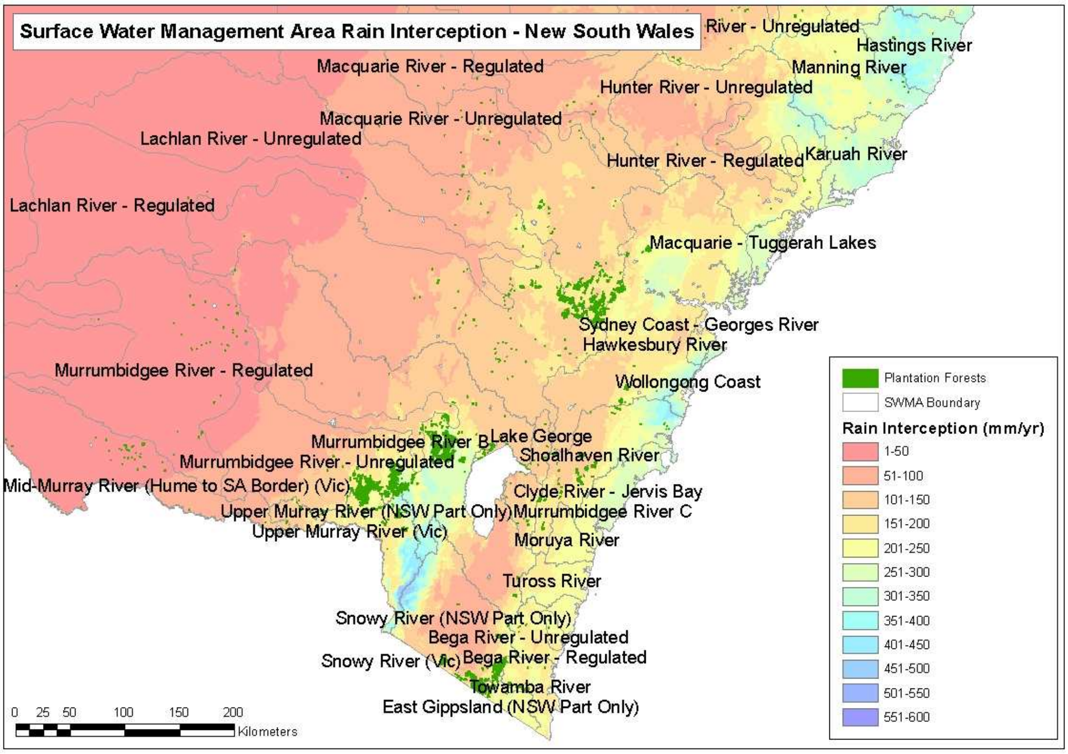

Figure 10. Map of New South Wales indicating surface water management areas, the existing plantation areas and the potential for water interception by plantations based on rainfall and the Zhang *et al.* (2001) relationships.

A draft policy is yet to be developed for NSW. For the most part, the regions of interest are within the MDB and are surface water issues (Figure 11). All of the inland regulated rivers in NSW are over-allocated. NSW is benchmarking plantation water use for all catchments for 2004, the year in which Water Sharing Plans were gazetted. Under that framework, water use by existing (pre-2004) plantations would be considered part of the 'consumptive pool'. In over-allocated catchments, only plantations established since 2004 would then need a water access entitlement. This is a tradable commodity so that if the plantations were converted back to agricultural land use, the water could be sold.

Recent estimates by BRS indicate that there could be an additional 50,000 ha planted in NSW by 2020 (Murrumbidgee and Murray regions). It also noted that plantations are being established in the Richmond catchment.

Assessments under the Murray Darling Basin Sustainable Yields (MDBSY) project (CSIRO 2008a) have been completed for NSW and, as for all catchments in the basin, plantations are not considered a significant risk to water security at regional scale. For example, for the Murrumbidgee catchment it was assumed that there would be 17,000 ha of new plantations. This was assessed as having negligible impact on run-off for the region but potentially significant local impacts depending on where the plantations were established.

Climate change impacts are considered important. This is illustrated well in the MDBSY project. Although estimates of climate change impacts include a good deal of uncertainty it is calculated that availability of surface water could decrease by 11% across the whole of the basin. The impacts are exacerbated in dry years. For example, in an average 2030 climate, water diversions would decease by 20% in the Murrumbidgee and by more than 50% in some regions of Victoria. The impacts would be even more severe in the 'drought years' of a 2030 climate.

Other relevant points included:

- How to treat existing plantations was an open question with a range of options needed.
- Definitions of ‘significance’ and ‘large-scale plantations’ are important in terms of differentiating between impacts at local and regional scales.
- Assessing the impacts of plantations on down-stream users is important, rather than just on streamflow.
- Regional bodies, such as Catchments Management Authorities, are promoting shifts to perenniality and so land use change in the agricultural sector could be an important issue.
- Carbon plantings could be an issue.
- The role of fires in native forests as it affects water supplies is critically important.

Research needs

NSW identified the following priority research needs:

- Predicting plantation water use at local scales.
- The impacts of plantations on down-stream water use at local scale.
- Climate change impacts.
- Potential impacts of carbon plantings.
- Impacts of native forest fires on water supplies.

3.5 Western Australia

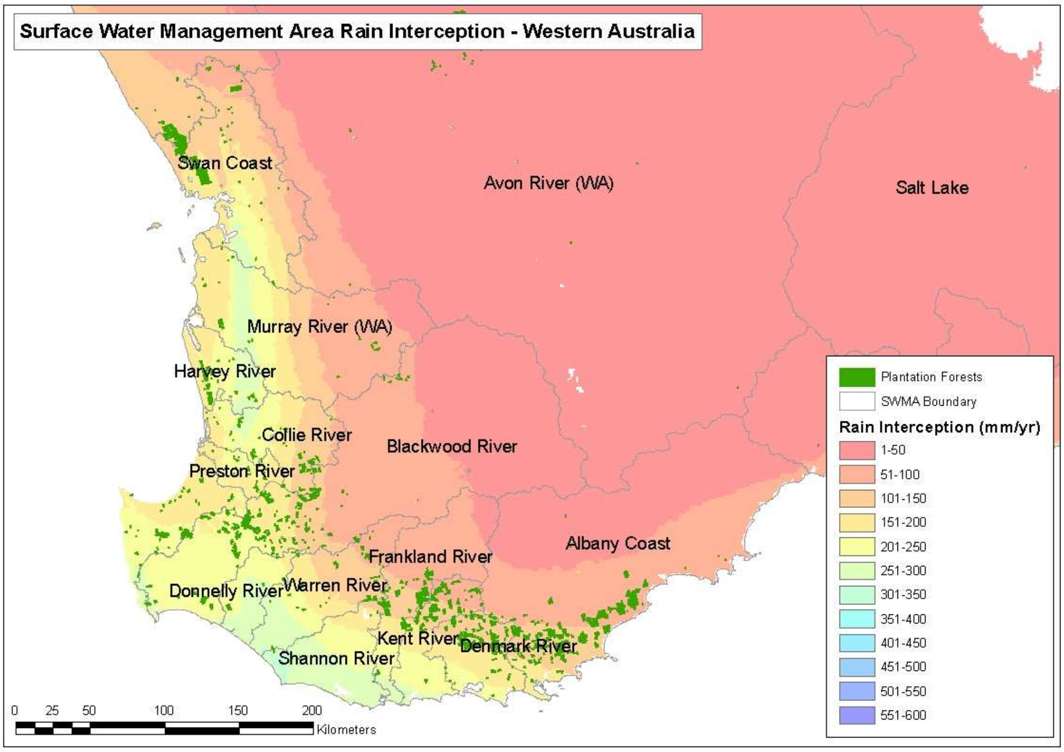

Figure 12. Map of south-west Western Australia indicating surface water management areas, the existing plantation areas and the potential for water interception by plantations based on rainfall and the Zhang *et al.* (2001) relationships.

A draft policy is yet to be developed for WA. The Government has prepared 'A Blueprint for Water Reform in Western Australia' (DoW 2006, 2007). Groundwater areas (to the west) and surface water areas (to the east) have been proclaimed. It recommends that interception of water by plantation forestry will be accounted for in the management of water resources and that water management plans may require that water used by plantations be licensed where there is a significant impact. It also notes that in lower rainfall areas, plantations may have a positive impact in controlling dryland salinity and thus would not require water licenses.

South-west WA is an area of recent plantation expansion with nearly 300,000 ha established between 1991 and 2005 (Figure 4). Much of that expansion has been in the southern most parts such as the Albany Coast, Denmark River and Kent River. However, regions of main interest to the WA government are the Swan Coastal Plain and the Scott Costal Plain (Figure 12). These are areas of sedimentary material and significant groundwater resources.

Analysis by WA and using BRS figures for plantation area indicates that, as a percentage of management units (surface water subarea) in the south-west, plantations cover between <1% and 20% of individual subareas with only one subarea at 31%. The situation is similar for groundwater subareas. The main concern therefore for WA is the potential for plantation expansion in subareas where there is available land.

Although policy is yet to be developed, current thinking is that:

- All land use change activities should be subject to some form of planning and regulation, but only in areas where the land use activities impact on Water Access Entitlements or environmental values. In parts of WA, plantations may have a positive environmental impact in saline-prone areas by lowering water tables.

There are no consumptive pools in these areas hence plantations may not be regulated as they are achieving environmental objectives, whereas in areas of shallow water tables and potential acid sulphate soils, plantations may be restricted.

- *Existing* plantations could be licensed for their estimated maximum water use; this water would not be included as part of the consumptive pool because the plantation existed before setting the amount of the consumptive pool. If the land use changed to a non-plantation state, the 'new' water would be made available to the consumptive pool (assuming the new land use takes less water and accounting for climate change impacts).
- *New* plantations would be subject to considerations of water availability based on the current land use and water balance. Once all existing plantations are accounted for in this way, any new plantation applications after an agreed date (probably the date the new Act is gazetted) would be treated as new water users subject to the standard licensing rules. It is yet to be debated in WA whether the allocation to an existing plantation remains for the entire period of land use, or only to the end of the next rotation.
- Once a methodology to determine plantation water use is established and agreed to by the stakeholders, determining the significance of that water use should be possible. For a plantation development in an area where there is a consumptive pool, and there is water available from the consumptive pool to satisfy the plantation, an allocation may be granted based on the agreed understanding of the plantation maximum water requirements. If insufficient water is available, the plantation owner may purchase the allocation from the market or decrease the area of plantation.
- If plantations owners are given a Water Access Entitlement for the maximum amount of water interception for the life of the plantation, they would be able to trade it only at the end of the rotation, or during the rotation if the plantation reduces in size. The key research question for WA is the maximum water use by a particular plantation taking into consideration site factors.

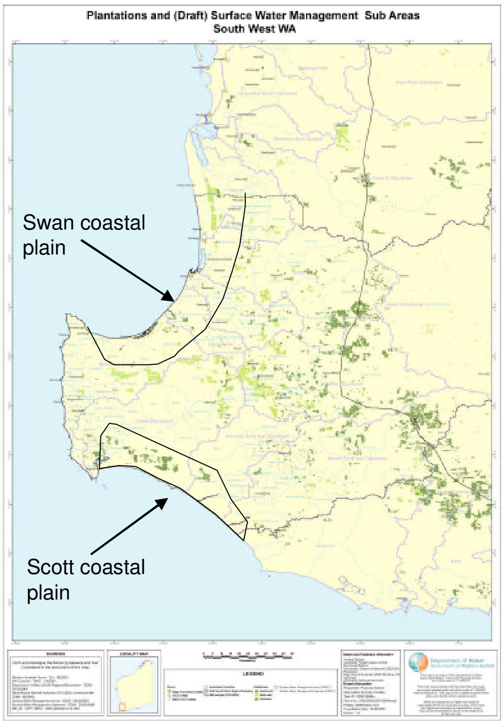

Figure 13. Location of the Swan Coastal Plain and Scott Coastal Plain where the main issue is groundwater impacts of plantations.

WA is generally following the Lower Limestone Coast policy of SA to inform policy development to protect groundwater. Unlike SA, it may propose to license plantations with an amount of water that is the maximum throughout the rotation period – rather than using the rotation average water balance as SA has proposed. This would have the benefit of giving plantation owners rights to the maximum amount of water, whether or not it was used in reality. It would allow them to trade that water if needed at the end of the land use, but conversely would impose an additional economic penalty for new developments. The maximum water use would also prevent potential over-allocation of the water resource if other water users fully allocate the resource before the plantation reached maximum water use. Current WA thinking considers that licensing water interception at the maximum level would create a 'risk buffer' and avoid potential over-allocation.

'No go' zones could be regulated such as the Scott River plain where there are acid sulphate soils and pose an environmental problem if the soils, currently submerged, are exposed to air through drying.

WA has developed and applied the LUCICAT model (Bari and Smettem 2003, Bari and Smettem 2005, 2006) to predict the impacts of land use and climate change on streamflow and salinity at a catchment scale. Different land use scenarios can be run once the model is calibrated to predict the impacts of changing the area of native forests, pastures and plantations in a catchment. It incorporates surface to groundwater interactions needed to model runoff in WA successfully. The model has been applied to various scenarios in WA such as prediction of the impacts of dams, recovery of salinised catchments by large-scale afforestation, climate change, and changes in water availability under multiple rotations of plantations (Bari and Berti 2005, Dixon and Bari 2008).

Management of native forests to increase water yield is of interest to WA. The forested catchments in the hills near and south of Perth currently provide 40% of the city's public water supply. This is a decline from 80-90% in the early 1970s, associated with a decrease in streamflows of about 60-80% due to lower rainfall and increased population and utilisation of groundwater resources. Thinning forests provides a cost-effective option to release water and experiments are underway to determine the relationship between levels of thinning and changes in water availability.

WA is currently funding a major experiment in The Wungong Catchment, about 60 km south-east of Perth and which covers 12,845 ha. The thinning trial is being undertaken across 7,900 ha. It is thought that an average of 4 to 6 GL of streamflow can be released annually due to thinning, depending on rainfall.

With the decline in surface runoff to reservoirs in Perth's catchments, associated with markedly lower rainfall since the 1970s, the city has become increasingly dependent on groundwater. The Gnangara groundwater mound is now regarded as a critical water supply for Perth, supplying 60% of the city's needs. To increase groundwater recharge, approximately 25,000 ha of *P. pinaster* plantations will be removed from the recharge areas over the next 20 years. Current research is also examining the potential to increase recharge through the use of controlled burning in areas covered with native vegetation.

Research needs

WA identified the following priority research needs:

- Determination or agreed estimation of the maximum water use by a particular plantation taking into consideration the rotation requirements, rainfall changes over the rotation period and other site factors.
- Prediction of water use across large areas including the ability to scale up from plot measurements to 'sub-area' scale.
- Defining an appropriate baseline condition against which water interception due to plantations can be compared.

- Climate change impacts.
- How to determine ‘significance’.
- Monitoring actual water use.

3.6 Tasmania

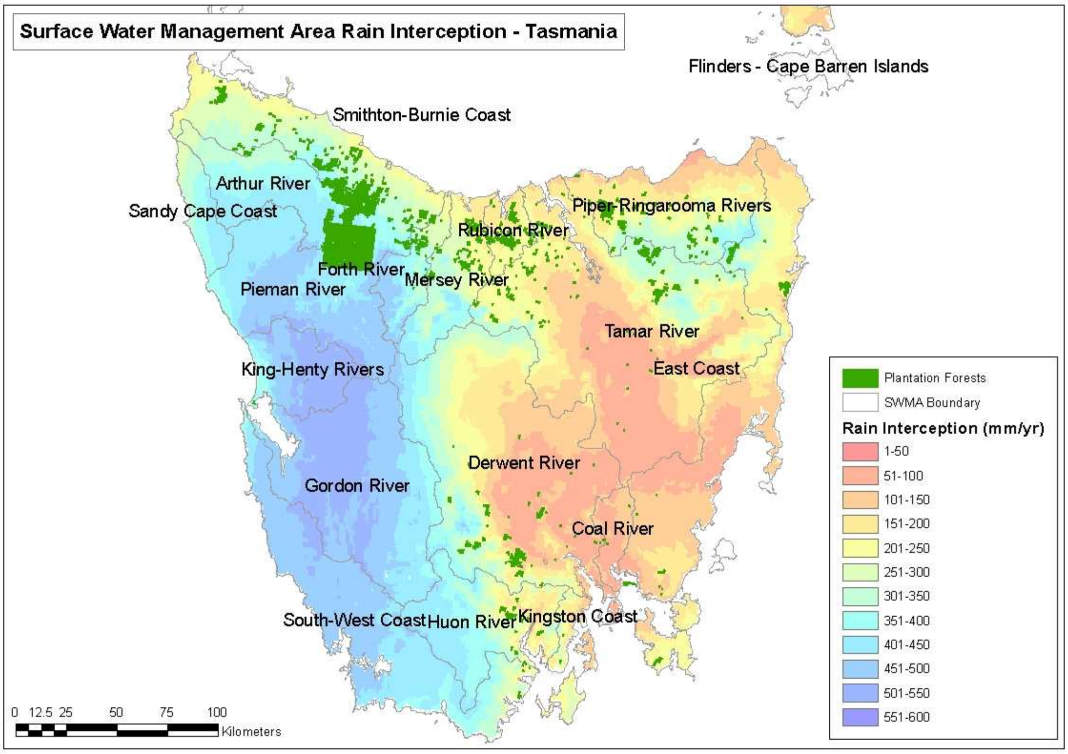

Figure 14. Map of Tasmania indicating surface water management areas, the existing plantation areas and the potential for water interception by plantations based on rainfall and the Zhang *et al.* (2001) relationships.

Tasmania is still to determine how to fully implement the NWI, as is the case with most of the other jurisdictions. An implementation plan in response to the NWI has been developed and is being progressively worked through (DPIW 2006). The potential impacts of large-scale plantation forestry are recognised. Tasmania has developed the 'Water Availability and Forest Landuse Planning Tool' tool to assess the impacts of land use change on seasonal flows and identified where there are risks that may need to be managed (DPIW 2008). The planning tool has been tested in the Ringarooma catchment for possible application statewide.

Most new plantations are expected to be established in the north-east of the state (Figure 14). None of the catchments are thought to be over-allocated on an annual basis but there may be issues with seasonal flows, particularly in summer and localised impacts on downstream users. The results of the Ringarooma study (DPIW, 2008) suggest that a 25% increase in plantation area reduces yields in the sub-catchment by about 3%. If the plantation area is increased by 50% then an 8% decrease in water yield is predicted, which was considered significant. It was also noted that the results apply at sub-catchment scale and not at a local scale of say less than 5 km^2.

This local scale issue is considered important and there is interest in getting better hillslope scale predictions (for example, 100 ha) of the impacts of plantation development on local down stream users.

Because catchments are not considered to be over-allocated, Tasmania is exploring the option of applying a planning and management framework where there are identified risks which can be mitigated, rather than necessarily regulating plantations through the issuing of water access entitlements.

The best way to monitor plantation water use is an issue. Forestry Tasmania prefers a method that is based on measurements of basal area rather than wholly predictive models that require substantial amounts of input data, including soil topographic and physical information that is difficult to obtain for Tasmania.

The impacts of logging and fire on water availability are considered important.

Research needs

Tasmania identified the following priority research needs:

- Better estimates of plantation water use, especially at fine scales of time (including seasonal differences) and space.
- Climate change impacts.
- Impacts of native forest management.

3.7 Northern Territory

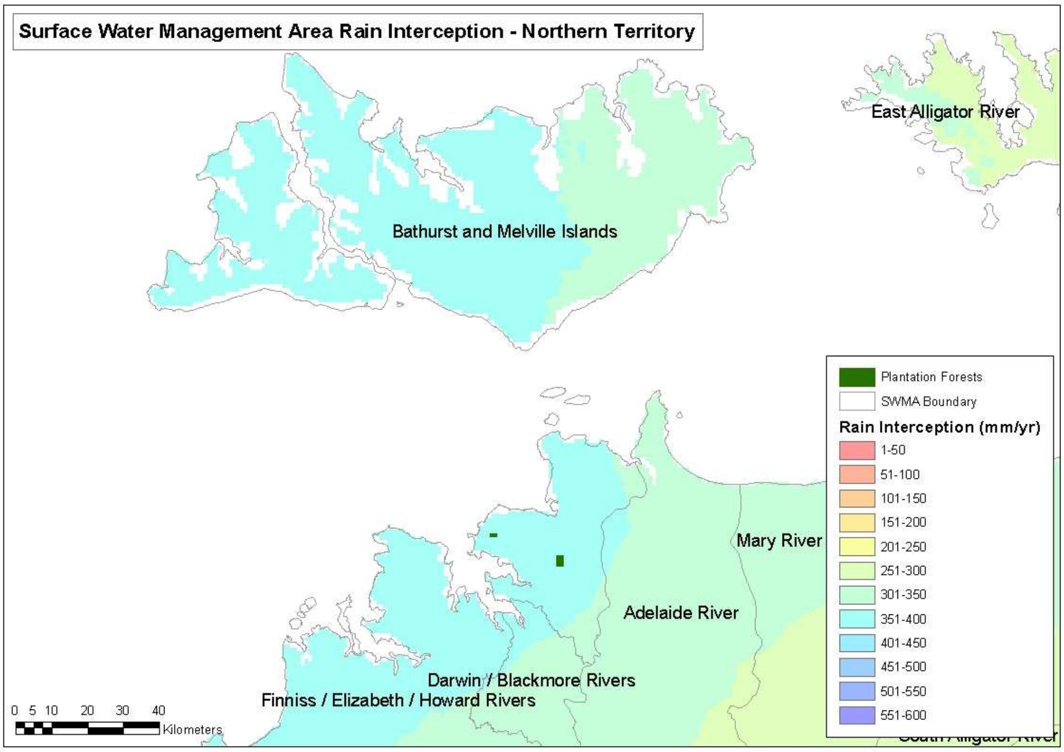

Figure 15. Map of Northern Territory indicating surface water management areas, the existing plantation areas and the potential for water interception by plantations based on rainfall and the Zhang *et al.* (2001) relationships. New plantations on the Tiwi islands are not shown.

A draft policy is yet to be developed for the Northern Territory and there are relatively few plantations currently established (Figure 15). The main areas of interest are:

1. ***Tiwi islands***. There are now about 30,000 ha of plantation, mostly *Acacia mangium* and this could expand to 100,000 ha. The plantations are established on ex-native forest land. A Code-of-Practice is being developed that will require measurement of water by plantations in comparison to native vegetation to assess any impacts on water availability.

2. ***Douglas Daly***. This region is about 160 km south of Darwin and overlies the Daly Basin aquifer. This feeds the Daly River that provides water to indigenous communities. Of the 100,000 ha of freehold land available in the region, 50,000 ha have been purchased by four plantation companies with about 10,000 ha planted to date with African Mahogany (*Khaya senegalensis*). The concern is potential interception by plantations of groundwater and reduction in summer flows of the Daly River. The Government may consider, depending on the availability of information, capping the amount of water extraction and issuing water licenses to plantations companies for future developments.

   Information on tree water use is considered the greatest knowledge gap including the extent to which plantations would directly access groundwater.

Research needs

The Northern Territory identified the following priority research needs:

- Methods to predict and monitor tree water use.
- Groundwater extraction by plantations.
- Groundwater and surface water connectivity.
- How to determine levels of sustainable allocation.

3.8 Australian Capital Territory

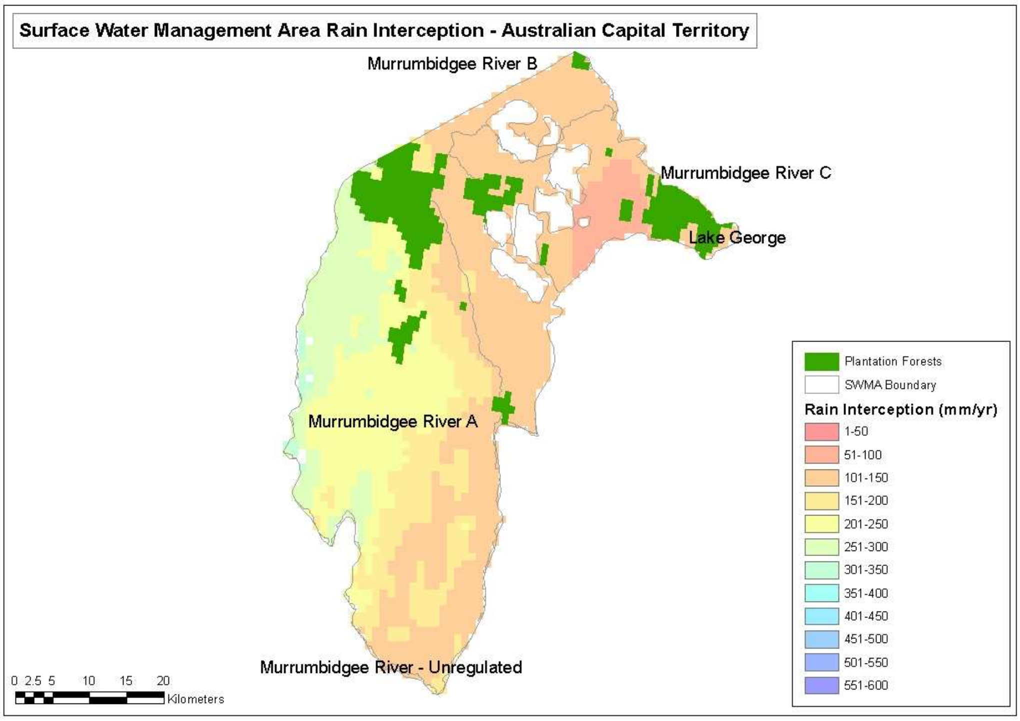

Figure 16. Map of Australian Capital Territory indicating surface water management areas, the existing plantation areas and the potential for water interception by plantations based on rainfall and the Zhang *et al*. (2001) relationships.

A draft policy is yet to be developed for the Australian Capital Territory. Although plantations covered a reasonable proportion of the Territory (Figure 16), many of these were burnt by bushfire in 2003. Some of these areas were replanted for insurance reasons and plantations may be converted to other land uses in the future. Generally, plantations are not considered an issue in the context of impacts on water security.

Research needs

The ACT identified the following priority research needs:

- Climate change is the overwhelming concern.

4. PLANTATION MANAGEMENT AND WATER USE

A key objective of the plantation industry is to grow as much product (usually wood volume) as possible at the least cost. Should plantation companies need to purchase water access entitlements then consideration may need to be given as to how to maximise the volume of wood production per unit volume of water used for the most economic outcome.

Two recent reports are highly relevant here: (i) Benyon *et al*. (2007) who reviewed some of the management impacts that can affect plantation water use, and (ii) White *et al.* (2007) who reviewed the management impacts on the water use efficiency of wood production. This section summarises some of the more salient points from those reports.

Table 6. Factors that affect plantation water use in a rainfall zone of 700 mm/yr and where the baseline water use is 610 mm/year, compared to grassland water use of 520 mm/yr (from Benyon *et al*., 2007).

Component or management practice	Water use or change in water use (mm)
Mean annual rainfall	**700**
Plantation water use ET	**610**
Grassland ET	**520**
Average difference in water use (plantation – grassland)	**90**
1. Plant available water	
• Deep soil	+50
• Shallow soil	-60
2. Rainfall season	
• Summer	+50
• Winter	-20
3. Aspect with greater slope (assuming same soil)	
• Northerly	+50
• Southerly	0
4. Soil nutrient status	
• High	+40
• Low	-40?
5. Rotation length	
• Longer	+30
• Shorter	-30
6. Spacing	
• Close	+?
• Wide	-?
7. Thinning	
• Unthinned	0
• Thinned	-40?
8. Forest health	
• Good	0
• Poor	-40
9. Landscape position (assuming same soil)	
• Bottom of slope (groundwater access)	+450
• Top of hill (no groundwater access)	0

Table 6 summarises potential maximum impacts of various site and plantation management factors on plantation water use (Benyon *et al*. 2007) for *E. globulus* growing in a 700 mm rainfall zone. The values are indicative only and should be treated with caution. In many cases there are few data upon which to base estimations. Nonetheless, they serve to indicate the magnitude and direction of responses that might be possible.

Not surprisingly, in rainfall zones where annual rainfall is less than annual potential evapotranspiration, the main determinant of water use by plantations is the availability of water. Any site or management factor that alters the amount of water available to trees will likewise change their water use. Site factors that could substantially affect water use include soil depth, landscape position including access to groundwater and soil fertility. Important management impacts could include spacing, pruning, thinning, rotation length and fertiliser application. The rationale for these responses and example data are detailed in Benyon *et al*. (2007). These and other plantation management strategies also affect stand growth, the size of trees within the stand and the cost of management and harvesting.

The review of White *et al*. (2007) summarised in detail available evidence for site and management impacts on the water use efficiency of wood production. Their main conclusions included:

- The water use efficiency of wood production varied from 1 to 5 m^3 ML^{-1} for *E. globulus*, *E. nitens* and *P. radiata* plantations from across south-eastern and south-western Australia.
- For plantations in climates characterised by winter dominant rainfall and summer drought, any management activity that increases leaf area index will increase water use during the early part of the growing season and thereby maximise plantation growth and the water use efficiency of wood production.
- In low rainfall environments, on shallow soils or even in unusually dry years at wetter sites, maximising leaf area to improve water use efficiency of wood production may expose the plantation to potentially lethal water stress. Decreasing the stocking density to as low as 600 stems per hectare minimises the risk of drought death without decreasing wood yield. This substantially reduces the harvesting cost per unit volume and thus increases the financial returns per unit water used.
- On responsive sites, fertiliser addition can increase the water use efficiency of wood production.
- Establishing plantations where trees can access shallow, fresh groundwater may increase the water use efficiency of wood production.

These concepts are encapsulated in Figure 16. The results are outputs from the CABALA model of growth for a plantation of *E. globulus* growing in mean annual rainfall of 840 mm. Although results were derived from a model, they are consistent with data presented by White *et al*. (2007) and upon which the model is based. In this example, we have simulated stem volume production and water use for a reference case of a plantation established at 1200 stems per ha growing on soil 2 m deep and with low fertility. The impacts are then tested of: (i) increasing soil depth to 8 m, (ii) decreasing the stocking to 600 stems per ha, and (iii) adding nitrogen fertiliser to increase soil fertiliser. The main results are:

- Increasing soil depth and hence the volume of soil water available to roots substantially increased stem volume (Figure 17a). Increasing soil fertility also increased volume growth but to a lesser extent.
- Increases in water use were proportionately less than those for volume increments (Figure. 17b).
- Water use efficiency of stem production was substantially higher for the 8 m soil depth and high fertility treatments compared with the reference case.
- Decreasing initial spacing from 1220 to 600 stem per ha had only a marginal influence on stem volume production and water use efficiency. However, the results of White *et al*. (2007) demonstrate that planting at densities such as 1200 sph (stems per hectare) in low rainfall environments run a severe risk of drought death and especially when fertiliser is applied. This management practice increases leaf area index and so causes soil water to be depleted to an extent that exacerbates drought conditions, leading to tree mortality.

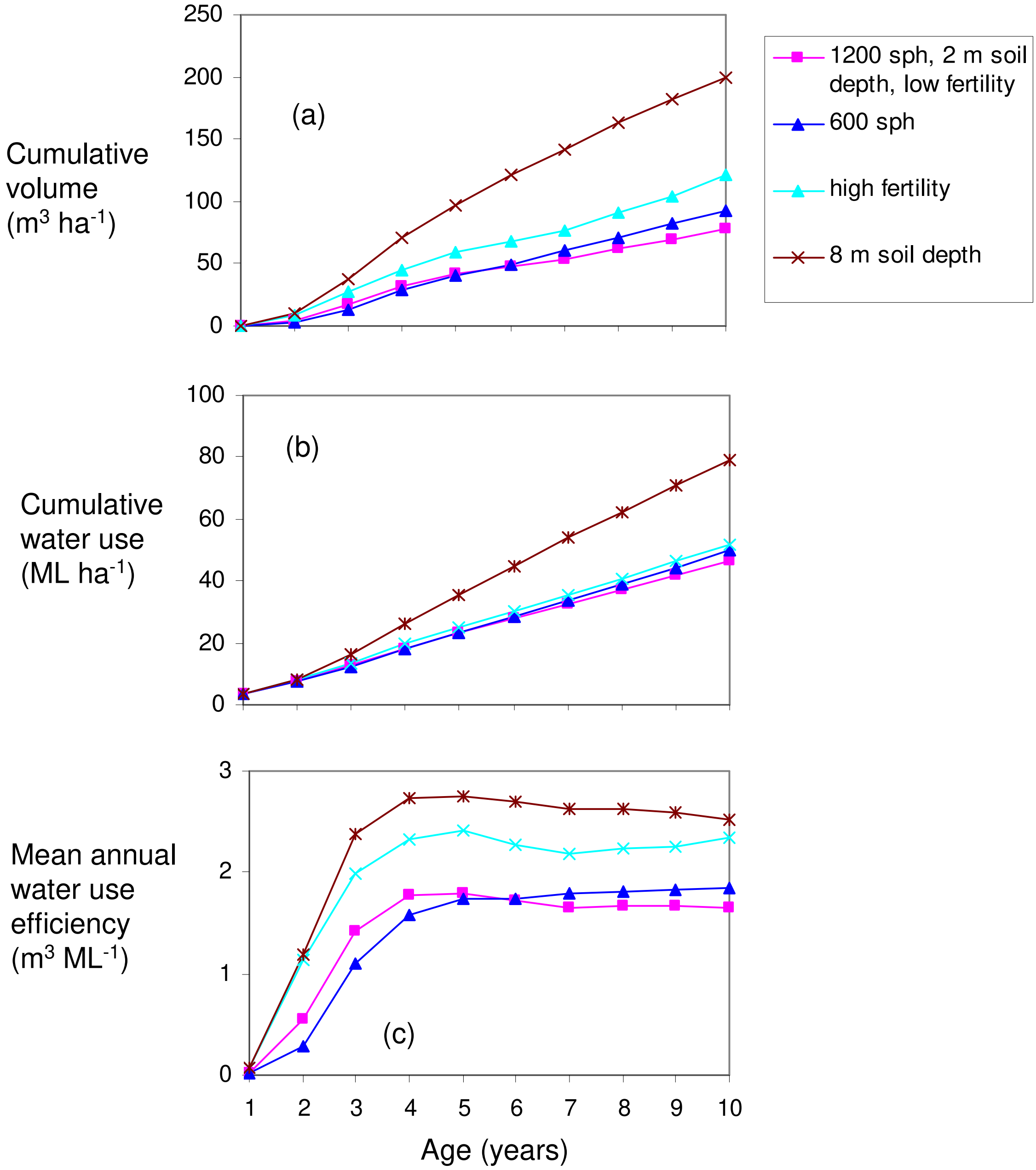

Figure 17. Outputs from the CABALA model of forest growth and water use showing the impacts of spacing, fertility and soil depth on various site and management scenarios on: (a) cumulative volume, (b) cumulative water use, and (c) mean annual water use efficiency (volume increment).

Figure 18 shows for the base case scenario, 1,200 sph, 2m soil depth and low fertility, the estimated contribution of tree transpiration, evaporation from soil and canopy interception of rainfall to total evapotranspiration. Although it might be intuitive to suppose that tree transpiration is the pathway through which most water is lost, evaporation from soil is often the dominant component. This reinforces the need to consider all components of the water balance in such studies and that management practices that can reduce direct evaporative losses from soil and litter surfaces may retain and save considerable amounts of water.

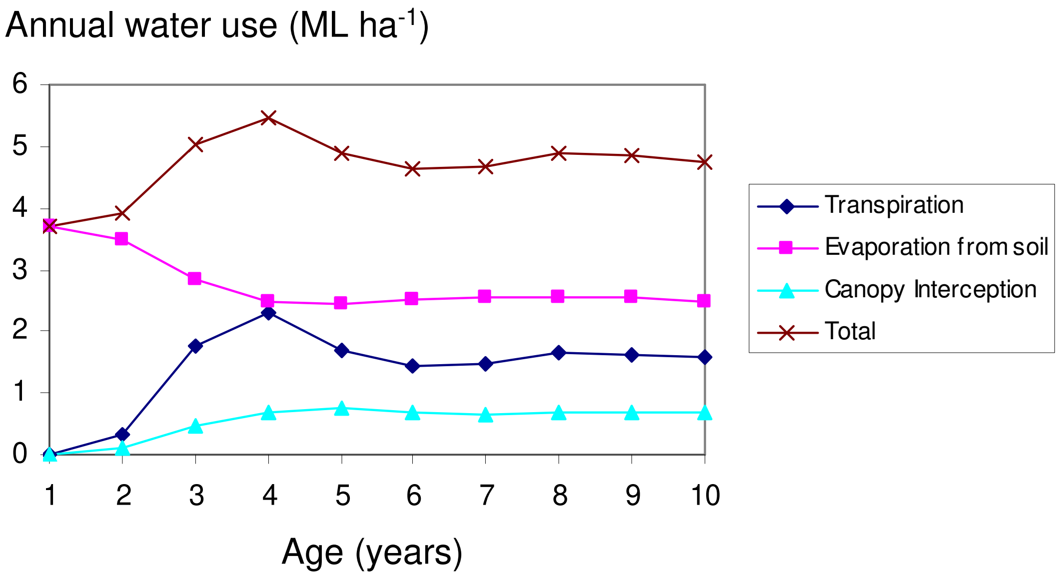

Figure 18. CABALA model output showing the contributions of components of the water balance for the reference case of 1200 sph, 2 m soil depth and low fertility.

5. NATIVE FORESTS

Although the focus of the NWI has been on plantations, native forests have a much greater influence on water availability. They contribute large amounts of water to the main urban and irrigation water storages and their importance has been vastly under-appreciated to date. Run-off from forested catchments supplies 40 to 90% of water to Melbourne, Sydney and Perth and to smaller cities such as Hobart and Canberra. Some 40% of Adelaide's water is also derived from the Murray River, a substantial proportion of which flows from forested upland catchments.

The amount of water used by the forests (evapotranspiration) is by far the largest component of the total water balance. Typically, more than 80% of total rainfall is lost back to the atmosphere through evapotranspiration, the residual amount being available for run-off. Small changes in the evaporative component, therefore, have a large effect on catchment yields.

This concept was recently well illustrated by Marcar *et al*. (2006) for the Murray-Uplands region which extends from about Canberra (ACT) to Creswick (Victoria) (Figure 19). Native forests occupy about 3.3 Mha of the region with mean annual rainfall greater than 600 mm – about 47% of the total area and far greater than the about 0.2 Mha of plantation. There are nearly 2 Mha of native forest in rainfall zones above 1000 mm.

Marcar *et al*. (2006) estimate that in the native forest area above 600 mm:

- Forest water use is 32,000 GL.
- 8,000 GL is delivered as streamflow.
- A 5% change in forest water use from these forests would translate into a 20% change in streamflow or 1600 GL (= 5% x 32,000 GL).
- For comparison, this change would have the same impact on water availability as a change of 1.3 Mha in the area of plantations in the Murray Uplands region.

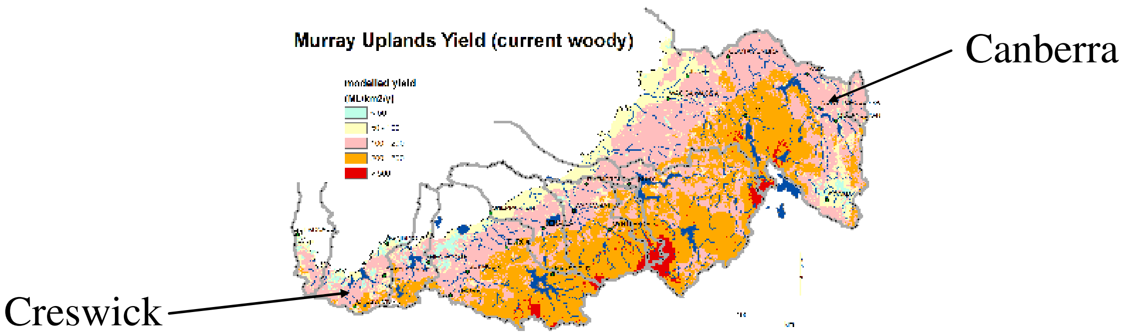

Figure 19. Area of the Murray Uplands region.

The numbers given above are large and especially so in the context of plantation impacts. The example of a 5% change in water use by native forests across the region is well within the realms of possibility under an increasingly variable and changing climate and the impacts of fire.

Assessing the influence of native forests on water availability, its interaction with biosphere and possible adaptive and management strategies is a greatly under-explored and challenging area, the outcomes from which may have profound implications for water managers.

This section discusses the impacts of fire and climate change on water use and catchment yield in native forests.

5.1 Fire

The water balance of some native eucalypt forest ecosystems changes substantially during the life of the dominant trees as the stand matures and opens up. The ecological response of eucalypt forests to fire, and hence impacts on catchment water yield, depend on the intensity of the fire and the species of trees. Eucalypt trees can generally be categorised into 'seeders' which are killed by fire and subsequently regenerate from seed, or 'sprouters', which are resistant to fire and resprout from epicormic buds buried in the bark or from lignotubers.

In the high rainfall (>1200 mm $year^{-1}$) catchments of southern Australia eucalypt forests are dominated by the 'seeder' category. This has important implications for patterns of water use after fire and most research has been undertaken in these forests.

The patterns of streamflow following bushfires of sufficient intensity to kill trees and stimulate regeneration of the forest by a dense cover of eucalypt seedlings, are typically characterised by three distinct stages (Figure 19, Marcar *et al*. 2006):

(i) An immediate and short-term increase in streamflow which may last for 2 to 5 years. All vegetation is killed by the fire, essentially reducing transpiration and canopy interception losses to zero. The soil is exposed and it is during this time that erosion loses and impacts on water quality are greatest.

(ii) A decrease in streamflow to a minimum about 20 to 40 years after the fire. Seedling regeneration can be extremely dense, of the order of several hundred thousand stem per ha, and vigorous. Stand water use is at a maximum thereby decreasing streamflows.

(iii) A gradual increase in streamflow as trees mature, die, and total forest water use decreases.

An example for the Melbourne water catchments illustrates the impacts on fire on water yield. On 13 January 1939, wildfires swept the forests of eastern Victoria that supply much of Melbourne's water, converting about 65,000 ha of mature mountain ash forests to regrowth. From Figure 20, it is estimated that 25 years after the fire, streamflows had decreased by about 400 GL per year due to increased forest water use compared to the pre-fire levels – equivalent to about 90% of Melbourne's water use.

Moreover, the prognosis for severe fire conditions is likely to get worse. Climate change is likely to increase fire frequencies and intensities in south eastern Australia. Climate change affects not only the weather and number of extreme fire weather days, but also rates of vegetation growth rates, fuel loads and fuel moisture content. For example, it has been predicted that the number of extreme fire danger days in Australia could increase by up to 300% by 2050 compared with 1990 levels (Lucas *et al*. 2007). The kinds of megafires experienced in southern Australia in 2002/03 and 2006/07 may only be a portent of things to come with potentially serious consequences for biodiversity, catchment water yields and greenhouse gas emissions.

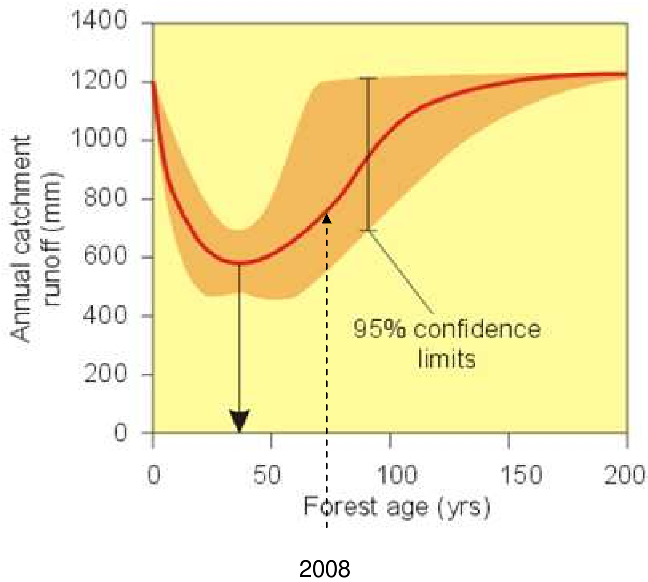

Figure 20. The estimated change in catchment run-off from 65,000 ha of Victoria's forests after the 1939 Black Friday bushfires. The starting point (0 years) was mostly mature forest, of which there are few areas today.

5.2 Climate variability and change

The direct impacts of changes in climate and atmospheric conditions on forest water use and hence catchment water yields may be profound.

Some of these are summarised in Table 7 although there currently is large uncertainty in estimation of the effects. This is compounded by the fact that there will many complex interactions and feedbacks between the impacts of climate change on forest growth and water use.

Changes in rainfall obviously have the greatest impacts on water yield and also on forest water use. However, increases in concentrations of atmospheric CO_2 may also have significant impacts. This is a very uncertain area of science because the way in which eucalypt species will respond to increased CO_2 is unknown. At a global level, there is already some indication that past increases in CO_2 have lead to greater run-off (Gedney *et al*. 2006). Increased CO_2 causes partial closure of leaf stomata though which water is lost. Polglase *et al*. (2007) calculated possible responses by eucalypt forests to increased CO_2 using a physiological model and suggested that, at an atmospheric concentration of 570 ppm CO_2 (the year 2060 according to one scenario of the IPCC), decreases in forest transpiration could increase streamflow from the Murray Uplands by as much as 40%. This would largely off-set decreases caused by changes in rainfall. Although the numbers are highly uncertain, they do serve to indicate the importance of native forests in controlling water supply and the potential impacts of climate change.

Table 7. Expected magnitude and direction of change in rainfall, temperature and radiation and atmospheric CO_2, and their potential impact on water availability (from Marcar *et al.* 2006).

Parameter	Change or possible change by 2070	Possible responses
Rainfall	Decrease by up to 45%, at least in Spring	Less water available for evapotranspiration
Droughts	Increased frequency	Increased tree death, incursion of pests and diseases, temporarily reducing leaf area and potential for evapotranspiration. More frequent and more intense fires. Change in forest type.
Temperature	Increase by 0.5-6.2 ^{o}C	Increased growth and evaporative demand, leading to increased water loss from interception and transpiration, but perhaps offset in winter by increased streamflow due to less snow cover.
Radiation	Possible increase or decrease resulting from changed cloud cover	Increased radiation will lead to increased growth and evaporative demand, leading to increased water loss from interception, transpiration and evaporation.
Atmospheric CO_2	CO_2 concentrations in the atmosphere will increase by 20-50%	Increased growth and canopy expansion due to CO_2-fertilisation effect, leading to increased losses from interception and transpiration. This will be offset by reduced stomatal conductance, leading to less transpiration and increased water yields.

6. DRYLAND AGRICULTURE AS AN INTERCEPTOR OF WATER

In the context of the NWI, any large scale change in land use that intercepts water should be subject to licensing in over-allocated catchments or in catchments approaching full allocation and where the change in land use would exceed thresholds and thus bring the catchment into over-allocation. Plantations have been the focus of most jurisdictions but other forms of dryland agriculture may be of interest for two main reasons:

(i) The extent to which plantations intercept water depends on the base case, that is, the form of agriculture prior to plantation establishment and the amount of water it used. The emphasis of much of the recent literature has been on assessing factors that control water use by plantations. However, as Benyon *et al*. (2007) point out, the change in water use after plantation establishment may depend as much on the water use of the preceding agricultural phase as it does on subsequent plantation water use. And like plantations, the amount of water used by the agricultural system will depend on a host of site and management factors.

(ii) Some jurisdictions are paying attention to changes in land use other than plantations which also intercept water (that is, increase water use). Some parts of Australian agriculture have undergone a significant transformation in the past 10 years or so. For example, between 1990 and 2001 in south-west Victoria, about 370,000 ha of broad acre grazing was replaced by dairy and dryland cropping (SKM 2005).

There is good evidence that perennial pastures such as lucerne and phalaris use more water than annual crops and pastures (see reviews by Benyon *et al*. 2007 and Keenan *et al*. 2004). This is thought to result from deeper rooting in perennials and longer growing season. However, the difference in rooting depth and water use between perennial grass species and annuals will be site specific; deeper soils without impeding layers allowing greater root penetration whereas shallow soils will tend to converge the rates of water use.

Rainfall also has an impact, the extensive reviews of Petheram *et al*. (2002) and Walker *et al*. (1999) determined that recharge beneath annual plant systems was greater than under perennial plants and that the difference increased with rainfall.

Keating *et al*. (2002) used a modelling approach to assess the impacts of various forms of cropping and grazing on water use. Table 8 shows an example from their assessments, comparing the 'annual excess water' which is that available for run-off or deep drainage. It compares lucerne (perennial pasture) with wheat (annual crop) for two rainfall zones and shows that lucerne can use substantially more water than a wheat crop used in this example. The reduction in run-off (that is, the difference in the annual water excess between the two systems) is predicted to be 75 mm at 600 mm mean annual rainfall and 250 mm at 800 mm rainfall. For comparison, the run-off reduction between generic forest and grassland is shown for the same rainfall as calculated from the generalised equations of Zhang *et al*. (2001) which have been widely cited and applied in Australia. The reduction in run-off when forests are established on grassland also increases with rainfall. The results from Keating *et al.* (2002) and Zhang *et al.* (2001) are not strictly comparable, using an annual crop (wheat) and grassland, respectively, as the reference agricultural system, but they do serve to illustrate the magnitude of the responses that are possible under various land use changes.

Table 8. Comparison of estimates of mean annual water excess (calculated as rainfall – total evapotranspiration) and the reduction in run-off after land use changed from either wheat to lucerne, or grass to forest.

Mean annual rainfall (mm)	**600**	**800**
Crop	**Mean annual water excess, or Run-off reduction (mm)**	
Keating et al (2002)		
	Mean annual water excess	
Lucerne	25	50
Wheat	100	300
	Run-off reduction	
(Lucerne – wheat)	**75**	**250**
Zhang et al. (1999)	**Mean annual water excess**	
'Forest'	42	89
'Grass'	133	241
	Run-off reduction	
(Forest – grass)	**91**	**152**

Clifton *et al*. (2006) used detailed catchment modelling to estimate the impacts of land use change on water availability in catchments of south-west Victoria. They related the proportion of various types of land use to catchment run-off and found that:

Run-off (mm/yr) = 4 – 201.nf – 28.ppng + 257.urb + 349.com $R^2 = 0.94$

where:

nf = proportion of sub-catchment under plantation, native forest or woodland

ppng = proportion of sub-catchment under perennial pastures or native perennial grassland.

urb = proportion of sub-catchment under urban use

com = proportion of sub-catchment under commercial use.

The coefficients of each independent variable indicate the contribution of that form of land use in controlling run-off. For example, a 10% increase in the proportion of forests or perennial pasture indicates a decrease in catchment yield of 20 mm or 2.8 mm respectively. That is, each unit increase in forests causes a reduction in catchment water yield about 7 times greater than each unit increase in perennial pasture.

It is difficult to verify such modelling results. As Petheram *et al*. (2002) point out, there have been very few studies that have directly compared water use or recharge from pastures or annual crops with those of plantations or native forest, and particularly rainfall zones greater than 600 mm $year^{-1}$. In one of the few studies, Dunin (2002) measured water use and drainage below woody perennials, herbaceous perennials and annual crops and pasture. Water use by woody perennials (tree belts) was greater than for herbaceous perennial plants (lucerne) which had greater water use than annual crops and pasture.

As with tree plantations, management of agricultural crops and pastures can exert an important influence of rates of water use and hence catchment yields. Benyon *et al*. (2007) summarised some of the factors controlling water use in agricultural systems (Table 9). The magnitude of management impacts can be potentially large and factors that promote the health and vigour of plants are likely to increase water use.

The implication of such an analysis is that the net impacts of plantation establishment on water use will depend on the preceding type of crop or pasture as well as the condition of that agricultural phase as determined by site and management factors.

Table 9. Summary of factors affecting water use by agricultural systems. In this example the indicative changes in water use indicated (110 mm decrease or 150 mm increase) are for 700 mm MAR and with annual water use of 520 mm (from Benyon *et al*. 2007).

Factors likely to <u>decrease</u> water use – by up to 110 mm	Factors likely to <u>increase</u> water use – by up to 150 mm
• *Poor nutrition*	• *Perennial crop/pasture*
• *Waterlogging*	• *Good nutrition*
• *Late sowing*	• *Early sowing*
• *Low seeding rate*	• *Crop established after fallow*
• *Poor establishment*	• *High seeding rate*
• *Fallow*	• *Deep ripping*
• *High stocking rates*	• *Deep lime/gypsum applications*
• *Intensive grazing*	• *Deeper rooting*
• *Surface soil compaction*	• *Mounding waterlogged sites*
• *Soil salinity/sodicity*	• *Rotational grazing*
• *Poor subsoil chemical properties*	• *Irrigation*
• *Poor subsoil physical properties*	
• *Crop established after perennial pasture*	

7. SYNTHESIS

The following discussion summarises the main points emerging from the preceding analyses.

In recent times the literature has placed a heavy emphasis on the impacts of plantations on streamflows. This seems to have emanated from earlier papers such as Vertessy *et al*. (1999) and subsequently reports such as by Keenan *et al*. (2004) and the Risks to Shared Water Resources for the MDBC (Van Dijk *et al*. 2006). Our review of State and Territories suggests that the impacts of plantations on groundwater should take at least equal, if not higher, precedence. This issue is well known in the south-east of South Australia where policy development has been well advanced for some years. Proposals there include issuing some existing plantations with a water license and in some cases may require the land to be cleared at the end of the next rotation. The Swan and Scott Coastal plains in the south-west of WA are also regions where groundwater impact is the main issue, and where policy similar to the South Australian example may be followed. On Perth's critically important Gnangara groundwater mound, existing plantations will be removed over the next two decades to increase recharge. In the Hawkesdale GMA of southwest Victoria, applications for new irrigation licenses have been denied in areas where groundwater is now considered to be over-allocated due in part to water use by plantations established over the past decade. In the Douglas Daly region of the NT, interception of groundwater is an issue but the area is yet to be developed to plantations. South-west WA and the Green Triangle are regions where there are already high concentrations of plantations in some water management units or where there has been a large expansion of the plantation estate recently which could possibly continue into the future.

Of the regions where surface water is of main interest, plantation impacts are not considered a problem in Qld and the ACT. In Tasmania, the south-east region could be an area of significant plantation expansion. Those catchments are not considered to be over-allocated on an annual time scale but there may be issues with seasonal water availability. Tasmania is thus exploring the option of applying a risk-based planning and management framework where there may be competition for water.

Many inland catchments in the MDB are severely water stressed and over-allocated, including in NSW and Victoria. However, plantation expansion in these regions is expected to be limited. It is predicted that there may be an additional 50,000 ha established in NSW by 2020, mostly in the Murrumbidgee and Murray catchments. In Victoria, areas of expansion are expected to be confined largely to the south-west and Gippsland regions, both of which are outside the MDB and subject to varying levels of water stress. Both NSW and Victoria are still developing policy. In the NT, apart from the Douglas Daly region, potential water impacts are an issue in the Tiwi Islands where there has been a significant level of plantation development on cleared native forests.

Considerations of scale and the unit of water management are key concepts. At regional scale (the area of a whole catchment) the impacts of plantations on water availability are minor because plantations occupy a small proportion of the land surface and thus intercept small amounts of water compared to end-of-valley flows (Table 2, CSIRO 2008a, Brown *et al*. 2007. For example, it is estimated that an additional 17,000 ha of plantation in the Murrumbidgee catchment (*c.f.* 1.4 mill ha of native forest) would decrease inflows by 6 GL by 2030, or 0.1% of the system total (CSIRO 2008b). The corollary of this argument is that, if the current 136,000 ha of plantation currently in the Murrumbidgee were all cleared and converted to pasture, it would increase inflows by about 48 GL or 0.8% of the system total (although the existing plantation estate is in rainfall zones slightly higher than would be any new plantation developments). By comparison, it was estimated that the combined effects of climate change and farm dams would decrease run-off by about 10%. However, impacts of plantations may be significant at local scale, whether on surface or groundwater resources.

Furthermore, much of the recent emphasis has been on plantation impacts on annual streamflows and for forests at maturity (e.g. Zhang *et al*. 2001, Keenan *et al*. 2004). Such assessments are a useful first approximation but at local scale the real issue is the level of interception as it affects other consumptive users or environmental flows. This will depend on the types of user, for example whether summer irrigation is the main demand for water and whether the river system is regulated or not which affects the quantity and timing of flows.

The NWI explicitly states that there should be no retrospectivity when developing policy that concerns land use change. But it also requires that over-allocated catchments be brought back into full allocation. This presents policy with something of a dilemma where small, over-allocated units of water management are largely occupied by plantations. The options available to bring the catchment back into full allocation need to be identified and may be limited. In the Lower limestone Coast example of SA, plantation forests account for about 32% of all manageable impacts (including stock and domestic use, all licensees and plantations) and can be as high as 78% of the total in at least one of the groundwater management areas. For those groundwater management areas that are over-allocated, it is proposed that all licensed allocations be reduced in proportion to the 'total available recharge' under that land use, in essence requiring that all land uses such as irrigated crops and plantations be moved on an equitable basis according to their water interception. An added complication is the groundwater management units, or 'Hundreds' are not hydrological boundaries. In recognition of that, the SA policy would allow water allocations to be transferred between some of the groundwater units and thus provide a wider perspective of the hydrological balance.

The potential impacts of carbon plantings on water resources is difficult to predict. Forestry has been included as an eligible activity in Australia's Carbon Pollution Reduction Scheme. Polglase *et al*. (2008) recently assessed opportunities for different forms of forestry across Australia. From an economic perspective, carbon plantings are able to be dispersed around the landscape because they do not need to be concentrated around ports and processing facilities. Concerns have been raised by some political and farming sectors that carbon plantings will compete for food and water including in high rainfall zones where water impacts would be greatest. In over-allocated catchments or catchments approaching full allocation, any new, large, block plantings would be subject to the same regulation as industrial plantations. This is where the test of 'significance' again comes into play. Most jurisdictions do not propose to regulate plantings such as agroforestry or farm forestry where the trees occupy say less than 10% of the farm (for example, as is proposed in the Lower Limestone Coast). That provides a strong incentive to disperse trees across the landscape for carbon sequestration and would also spread the risk of plantings to fire, pest and disease. In WA, the environmental benefits of trees in the lower rainfall, salinised landscapes of the wheat/sheet zone are recognised and no water licensing for any form of forestry is proposed.

The States and Territories were asked to nominate priority areas for research to help them better inform and apply policy. There was an overwhelming consensus from this survey that better estimation of water use by plantations at local scale was the highest priority for research. It was a high priority for all jurisdictions except the ACT, where plantation impacts are not considered an issue. Most States have their own hydrogeological models that describe the flows of water across and through the landscape into waterways. They also include an evapotranspiration component but have varying degrees of sophistication, ranging from simple evaporation models such as is used in LUCICAT in WA to explicit description of water balances calibrated to individual tree species, agricultural crops and pastures and management practices. However, even the more complex models need to be tested and verified against robust data. Components of the water balance are sensitive to a range of factors including species, soil depth and texture, presence of groundwater and impeding layers, site preparation climate, spacing, weed control, thinning and rotation length (Table 6). This imposes a great challenge for models to accurately capture the effects of these factors, some of which vary across the landscape. It cannot be emphasised enough that even models with explicit description of water balances under trees and agriculture need to be tested and verified to demonstrate they are giving sensible results. For example, Benyon *et al.* (2008) recently tested three models at 22 closed-canopy plantation sites in the Green Triangle. Predictions of mean annual water use were reasonably good for sites without access to groundwater but poor at sites with access to groundwater. Two of the models also gave poor predictions of seasonal variation in water use and the two models which predicted plantation productivity only gave poor to moderately good predictions of growth rates.

Most jurisdictions considered that improved modelling of water use and water balances at local scales was needed. Simple, equilibrium models of forest water use can and have been used successfully to predict the impact of large-scale expansion of forests on streamflows (for example using the method of Zhang *et al.* 2001). However, it is a far more difficult task to predict the impacts of a plantation at hillslope scale (say 100 ha) on local, down-stream users and at particular times of the year (for example, summer). It is even more complicated when trying to estimate the changing impacts across the rotation, from pre-planting to harvest. The water balance can change markedly and all components need to be considered, including canopy interception of rainfall, tree transpiration and evaporation from soil (Figure 18). At present we do not have this generic modelling capability that can be applied across all regions, site conditions, species and management practices.

Other common priority research areas cited were monitoring plantation water use, assessing tests of ‘significance’ and ‘thresholds’, and climate change impacts. Monitoring can be an extension of prediction, in that the same models used for prediction can be used for monitoring but with the benefit that if the trees are well established, various attributes can be used for calibration and validation, such as tree size and leaf area. In some cases it will be possible to directly measure tree transpiration through sap flow sensors, but these are not practical to apply across large areas and we again note that canopy interception and evaporation from soil can be equally, if not more important than transpiration. For both prediction and monitoring of water use it is important to have a reference point: the water use of the preceding agricultural enterprise. Recently, the focus has been mostly on amounts of water used by plantations using models such as those of Zhang *et al.* (2001). As Benyon *et al.* (2007) have pointed out, estimating water use of the agriculture phase is equally important as estimation of plantation water use and depends on a range of factors. The past decade or so has seen a marked change in agricultural land use and management with a significant shift towards more perenniality and management that aims to retain and use more soil water for increased productivity. It is the difference between plantation and agricultural water use that matters. Water use of agricultural plants may differ by 100 mm or more for the same site depending upon type of crop or pasture (Benyon *et al.* 2007). The extent of interception, and hence run-off, will therefore depend on the type of crop or pasture on which the plantation is established.

Monitoring ideally needs to be cheap, cover large scales, be temporally sensitive so that at least seasonal changes in water use can be detected and account for total stand water use that includes canopy interception and evaporation for soil as well as tree transpiration. Methods have been developed using remote sensing to quantify the spatial variation in water use across large areas. Some satellites (for example MODIS and Landsat) sense emissions of various thermal wavelengths of radiation from the Earth’s surface. At any one instant, there is a balance between the incoming shortwave radiation, the outgoing long-wave radiation (sensible heat), the storage of energy in the soil and the loss of energy due to evaporation (latent heat loss). For a given incoming net radiation, higher latent heat loss due to evaporation (for example high water use by vegetation) results in a relatively cooler surface temperature. Net incoming radiation and the change in heat storage in the soil can be measured or modelled on the ground, and sensible heat loss can be measured using satellites, enabling latent heat loss to be inferred by difference. That is, on a particular satellite image on a cloud-free day, the spatial variation in surface temperature across the image is a function of the spatial variation in the current rate of water use or water loss from the surface. Daily evapotranspiration can be estimated if the relationship between instantaneous latent heat loss and daily evapotranspiration is known. By obtaining such estimates periodically through the year, seasonal or annual evapotranspiration can be estimated. The 'Surface Energy Balance Algorithm for the Land' (SEBAL) method, developed by a Dutch company (Waterwatch), is currently being tested in parts of south-eastern Australia. To date, the results for plantations in the Green Triangle have not been promising, but if the method can be modified to give reliable estimates, it may prove useful in enabling regional-scale verification of current plot-based estimates of water use by plantations and other land uses.

Research needs are often regionally specific. An example is the Lower Limestone Coast where it is proposed to license plantations based on a thorough understanding of the changing water balance throughout the plantation. By definition, that requires detailed research on pathways for water and loss under fallow and as the stands grow through to harvest. As Figure 18 indicates, for example, evaporation from soil during and soon after the fallow period can be significant.

Tests of 'significance' and 'thresholds' and how to apply them to plantation development were a common concern among the jurisdictions. Duggan *et al*. (2008) summarised the various approaches and clearly they are in the formative stages. In the plantation context, significance may need to take into account scale and concentration of plantings as it affects local versus regional water users. Industrial plantations are usually concentrated in relatively large, contiguous blocks and so are more likely to have local rather than regional impacts. But when considered as a proportion of the total consumptive pool of water, plantations are usually a small component.

'Thresholds' apply to catchments that are approaching full water allocation and new developments would send them into over-allocation. The NWI indicates that considerations other than just water interception may be taken into account. Because environmental impacts will be regionally-specific it is up to jurisdictions to make those assessments. Impacts on values such as river salinity and biodiversity could be taken into account and, as for water, they are far more likely to have local than regional impacts.

An important question for the plantation industry may be the cost:benefit ratio of having to pay for water versus the volume of wood produced. Figure 17 showed that site selection and silviculture (for example, spacing and nutritional management) can increase wood production with a proportionately lower increase in water use – the result being that more wood is produced per unit of water used. Generally, the best silviculture that maximises productivity also increases water use efficiency. In the case of initial tree spacing, it has been shown that in lower rainfall areas it is preferable to plant trees at 600 than 1200 sph. Volume production is essentially the same and the risk of drought death is greatly mitigated at the lower planting density.

Finally, the dominant role of native forests in controlling water availability is yet to be widely appreciated. Over the next few decades, climate change will potentially have enormous impacts on Australia's water supplies. The majority of Australia's large cities draw some or most (up to 90%) of their water from forested catchments in which the amount of water used by the forests (evapotranspiration) is by far the largest component of the total water balance. Typically, more than 80% of the total rainfall is lost back to the atmosphere through evapotranspiration and small changes, therefore, have a large effect on catchment yields. For example, it was shown for the Murray Uplands region that a 5% reduction in evapotranspiration could lead to a 20% increase in streamflow, or 1,600 GL. This is far greater than the influence that plantations exert on water resources. Quantifying the many interactions and feedbacks as they apply to an increasingly variable and changing climate is a greatly under-explored and challenging area, the outcomes from which may have profound implications for water managers.

Water use of native forests can be altered substantially by fire and climatic changes that affect forest physiology including rainfall, temperature, humidity and CO_2. The impact of CO_2, in particular, could be of extreme importance but the scientific evidence is limited at present.

We conclude that, at regional and national scale, the impacts of plantations on water security have received an unwarranted emphasis. This is especially so when the amount of water intercepted by plantations compared with downstream users and other components of the water balance is considered at whole-of-catchment scale. Local scale impacts may be important, however, and especially where plantations occupy a majority of the unit of water management. At regional scale and for many of the important catchments suppling drinking water and environmental flows, native forests exert the overwhelming control on water availability. Together with the impacts of climate change, far more national focus needs to be applied to research areas to better understand and prepare for future water resources.

8. RECOMMENDATIONS FOR RESEARCH

On the basis of this review and synthesis we have developed a short list of recommendations for future research. As far as possible we have listed areas of national relevance. Inevitably, there will be some local issues that require particular research to advance policy and the participation of the forest industry (some of these have been identified in Section 3 for South Australia and Victoria). Wherever possible we have made the recommendations specific to indicate the types of research that might be undertaken, the reasons for them and the outcomes that would be derived. The recommendations are not intended to be exhaustive; rather, we have focussed on those that we consider to be the highest priority to advance knowledge of water interception by plantations in the policy and forest industry domains. The recommendations are described below.

Recommendation 1. Consolidate national data sets to further develop and test process-based models and improve prediction of plantation water use.

The most common research need cited by State agencies was better prediction of forest water use. This includes three main components: tree transpiration, rainfall interception and evaporation from soil. Many State agencies have well developed hydrogeological models of water flows within catchments but it was often stated that the greatest weakness in those models is prediction of forest water use. Vegetation often uses the majority of incoming rainfall and yet site water use is difficult to predict for the range of site, species and management conditions. In particular, there is a need to be able to predict changes on water use and the impacts on recharge and streamflow at relatively fine spatial and temporal scales of resolution, including at 'hillslope' scale and at least annual, if not seasonal.

To date, the focus of policy has been very much on plantation water use but, as discussed in the preceding sections, the previous land use is also an important determinant of how conversion to plantation will affect water use. Small percentage errors in predicting water use of different land uses translate to large percentage errors in estimating effects of land use change on water yield.

As far as possible, models also need to be able to account for site and management impacts such as position in the landscape, species, age of plantation and stage of development, spacing, thinning and harvesting impacts. That is an ambitious list and in reality, it will be impossible to achieve for all the combination of site and management factors possible.

Nonetheless, CSIRO and State agencies collectively have an extensive data base of water use for at least a range of species and sites. For the most part, tree transpiration is the main component of the water balance measured using sap flow sensors, and in some cases they are complemented by measurements of rainfall interception and evaporation from soil. Rainfall and the prevailing climate have often been monitored by an on-site weather station. Regular, such as monthly, changes in soil water content have also been monitored in some sites and the soil profile has been well described at most sites. There is thus an extensive national data base for components of the water balance in plantation forests which would benefit from consolidation and interpretation.

Similarly, models of plantation water use are well advanced in Australia, the two most commonly used being CABALA and 3-PG. CABALA is a detailed physiological model that has been extensively tested for particularly blue gum plantations. It is suitable for exploring the impacts of forest silviculture, such as spacing, thinning and harvesting, on site water balances. 3-PG is a simpler model and thus lends itself well to spatial applications. Both models explicitly describe the components of the water balance and are sensitive to soil, climatic and management parameters.

Groundwater uptake by plantations represents a special case and is particularly important given that some of the immediate issues with water interception by plantations are overlying groundwater regions in the green triangle, south-west Western Australia and the Northern Territory. Groundwater uptake depends upon, among other things, soil type, depth to groundwater and presence of an impeding layer and plantation age. The CABALA and 3-PG models have been modified to include groundwater uptake. However, recent testing of these modified models using a data set of 22 plantation sites in the Green Triangle has shown that improvements are needed in the way groundwater uptake is simulated. Across ten plantation sites with access to groundwater, CABALA over-estimated water use by an average of 17%, whereas 3-PG underestimated annual water use by an average of 37% (Benyon *et al.* 2008). Further analysis of the reasons why these models performed poorly on these sites should lead to worthwhile improvements in model capability. The fact that one model over-predicted while the other under-predicted indicates it should be possible to get it right.

Once models are well tested and verified against a national database they could be run spatially across the regions of interest for various scenarios incorporating species, management and climatic combinations. The improved models of water use can also be linked to those of catchment water flows used by the various state agencies or the Commonwealth to predict the impacts of plantation establishment on in-stream water supplies and availability.

The outcomes would be policy and forest management informed by verified model(s) of plantation water use and model outputs to estimate the impacts of plantation establishment on water interception.

Recommendation 2. Identify cost effective and practical methods to monitor plantation water use and impacts.

Process-based models can be used to predict stand-level water use by plantations but continued monitoring provides a means of verifying such predictions. It is relatively straightforward to measure all components of the water balance directly but it is limited to relatively small areas with uniform soil, climate and plantations species, age and condition. It will be important to continue, and perhaps increase, monitoring of streamflows and groundwater levels. In future, monitoring might also include remote sensing of water use across regions and large catchments.

If land use change is having real impacts on water availability, there should be some evidence of changes in streamflows and groundwater levels. Because of the relatively low water use at the beginning of the rotation, impacts of recent plantation developments may not yet be evident as reduced streamflows or falling groundwater levels. Streamflows and groundwater levels are also strongly influenced by rainfall and many parts of southern Australia have experienced below average rainfalls in recent years. To confirm whether expected long-term impacts of land use change are occurring, good quality, long-term monitoring of streamflows and groundwater levels is required.

Remote sensing methods may offer ways to extrapolate from site-scale to whole catchments and regions and to better monitor seasonal and spatial variation in water use. To date attempts to use remote sensing for plantations in the Green Triangle have been unsuccessful, but further investment in this area might result in development of useful monitoring methods.

It might also be possible to gain indications of potential impacts of recent forestry developments and changes in forest management practices using forest inventory data already being routinely collected by forest managers. Further analysis is required to determine whether variables such as basal area, height and stand volume can provide useful indicators of forest water use.

Recommendation 3. Develop and apply methods to determine 'significance' and 'thresholds'.

Definitions of 'significance' and 'thresholds' are ultimately policy questions. The role of scientific research is to provide data or methods to provide enough information upon which policy can be based. 'Significance' relates to net impacts – on other users of water, environmental flows and also on other social, environmental and economic values. 'Thresholds' relate to volumes of water and will apply to new plantations and those catchments approaching full allocation. Determination of significance and thresholds needs to be consider, among other factors:

- The impact of water interception on other consumptive users, including environmental flows. This is the over riding consideration. In the policy sense, how much water a plantation uses is irrelevant if there is little impact on other consumptive users or environmental flows.
- Definition of scale and the unit of water management. In most cases, plantations have little impact on end-of-catchment flows but they may have significant impacts on local streams, for example drying streams during summer flows and affecting only a few irrigators.
- The extent to which plantations are distributed across the landscape. Many jurisdictions suggest excluding low density plantings, such as agroforestry that occupies less than 10% of a farm, on the assumption that they will have less impact on water availability. In reality, if there are enough of the plantings spread across the landscape they may have the same affect on end-of-catchment flows as a single contiguous block. The latter, however, may have impacts on local water availability as discussed above.
- A level of 'significance' that will cause under-allocated catchments to come into full allocation and therefore exceed a 'threshold'. Furthermore, there may be a need to account for the effects of a variable and changing climate on water use, interception and streamflows.
- Plantation water use within the context of other forms of land use and land use change, an understanding of the cumulative water impacts and the ability of policy to account for and regulate intercepting activities.

The impacts of new plantation developments on water availability can be assessed by spatially explicit, biophysical models of plantation water use and seasonal and annual catchment water flows. The modelling would enable exploration of the relative effects of various site-scale factors to be evaluated, including position in the catchment, soil type, species and management. The same models should be applied in demonstration catchments in all states to enable direct comparison and cross-checking of the various different methods currently being used to evaluate plantation impacts. Case study catchments will need to have reasonably long-term, good quality streamflow data available to enable verification of model predictions.

This analysis would provide a well-tested set of models (or sub-models) that could be applied consistently across the country. It would help policy makers quantify the impacts associated with various levels of development to enable them to assess their significance.

Recommendation 4. Investigate and apply methods to assess the net benefits and impacts of plantations on economic, environmental and social values.

In some cases, jurisdictions may wish to take account of social, economic and other environmental impacts of plantations in catchments when developing and applying tests of significance. The net benefits and trade-offs will vary from region to region and depend on the particular issues considered to be of importance. In some cases the benefits will not have a market value (biodiversity enhancement) and not all benefits and trade-offs may assume equal weighting. Because of this variation it is unlikely that a single method for impacts assessment can be developed and applied across Australia.

It would be beneficial to undertake select case studies to assess the net impacts of existing (and possibly future) plantations according to a set of regionally appropriate criteria. As far as possible the impacts should be quantifiable and presentable in terms of economic costs or returns, although externalities that have no market value should also be considered. Other land uses and their net impacts should also be considered for comparison. Such a balance sheet would help place plantations into a whole-of-catchment context and ascribe an overall value for land uses per unit volume of water used ($\$ ML^{-1}$).

Recommendation 5. Investigate climate change and management impacts on native forests and catchment water flows.

To ensure long-term security of water supplies for most of the capital cities and the MDB, far more needs to be invested in research to quantify the impacts on water use, water yield and water quality resulting from rising CO_2 levels, climate change and associated other changes in native forests (for example increased bushfire frequency or intensity).

This research could include:

- Studies of hydrological processes in common native forest types in water supply catchments and associated studies of streamflow to determine how disturbances such as fires influence water use and streamflow.
- Modelling studies to simulate impacts of management interventions (for example, thinning, planned burning) on forest water use and water yield.
- Physiological studies to identify the theoretical basis for the extent to which trees acclimate to increasing levels of for incorporation into predictive models.
- Analysis of historical Landsat data sets in conjunction with other vegetation cover, climate and streamflow data to determine whether there is any evidence of changing forest cover and streamflow attributable to rising CO_2 levels. For the period Landsat data are available, CO_2 levels have increased by about 10%.
- Long-term controlled experiments to examine physiological responses of common eucalypt species to elevated CO_2 and changing climate.

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