Australian Government
Bureau of Rural Sciences

Opportunities for commercial environmental forestry in Australia

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Summary

Commercial environmental forestry (CEF) is an Australian Government initiative to help promote private investment in planting trees for commercial and environmental benefits.

CEF is seen by the Australian Government Department of Agriculture, Fisheries and Forestry as an opportunity to support regional communities and industry in developing regional forestry capabilities in low-to-medium-rainfall zones and at the same time help reduce salinity and land degradation. The Bureau of Rural Sciences was asked to identify regions in Australia, using existing regional information, where farm forestry or plantation developments could provide both salinity benefits and commercially successful outcomes.

The report provides information on potential dryland salinity hazard and stream salinity potential at the subcatchment scale alongside plantation potential or capability. By analysing existing regional-scale information, candidate regions and subcatchments were identified where commercial tree crops could potentially be grown with associated salinity benefits, and the supporting information presented. Results indicate that there are significant potential opportunities for CEF in many regions of Australia. However, to make investment decisions will require further, more-detailed analysis at a localised scale, using finer-scale information and modelling techniques.

Information gaps at a regional scale are evident. The ability to model potential tree growth nationally varies in reliability and with declining accuracy associated with areas outside of Regional Forest Agreement areas. Application of CEF would benefit from regional studies of species and site selection, and growth prediction in drier environments of Australia below the 600 mm isohyet.

Introduction

Around 5.7 million ha of Australian agricultural and pastoral land are currently estimated to have a high potential for developing salinity (HRSCSI 2004). Further, vast tracts of farming land have succumbed to, or are being affected by, salinity. Stream salinity has become a significant issue, particularly within the Murray–Darling River system (MDBMC 2001, HRSCSI 2004). One of Australia's greatest challenges is how to manage natural resources in landscapes that have critical salinity and water-quality problems. The Australian Natural Resources Atlas (Australian Government 2000) provides an overview of salinity issues in Australia.

The National Action Plan for Salinity and Water Quality (NAP) (endorsed by the Council of Australian Governments in November 2000) sets out directions for government, community groups, individual land managers and local businesses to work together to tackle salinity issues and improve water quality. One approach in this plan is to enhance planning capacity within communities to assist in the development and integration of regional and catchment planning.

Within the 500–800 mm/year rainfall region, revegetation can occur to help reduce recharge, thereby helping to lower groundwater levels and ameliorate dryland-salinity effects. Equally, strategically located revegetation can help to reduce the discharge of saline water into catchments and decrease stream salt concentrations (Buffier 2002, CSIRO 2004). Targeted reforestation and revegetation, including the use of commercial tree crops, is seen as a strategic approach to ameliorating dryland and stream salinity in the Murray–Darling Basin (MDB) (MDBMC 2001).

The Commercial Environmental Forestry Programme is an initiative of the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) which aims to support regional communities and industry to help develop and optimise forestry systems in low-to-medium-rainfall zones by providing a commercial benefit while at the same time reducing salinity and land degradation. This concept is known as commercial environmental forestry (CEF). The initiative supports the aims of the National Action Plan for Salinity and Water Quality (NAP) and Natural Heritage Trust (NHT).

The programme aims to develop co-investment (private and public) in forestry to underpin sustainable landuse change for commercial and environmental outcomes in NAP priority regions (see **Figure 1**) and other areas across Australia, such as the NHT zones (see **Figure 2**) Commercial forestry has been proposed as a technically effective and socially acceptable option for dryland and stream salinity management in the 500–800 mm/year zone, where there is likely to be overlap between commercial wood-fibre production and the potential for salinity mitigation. The programme aims to assist regional groups, such as catchment management authorities; private investors, such as landholders; and third-party fund managers to cooperatively develop woody revegetation initiatives, particularly commercial forestry, for consideration in regional catchment investment plans.

The Bureau of Rural Sciences (BRS) was asked to identify, at a catchment scale, those regions in states and territories where farm forestry or plantations are likely to deliver both environmental salinity benefits and commercial gains. Outputs from the project would assist public agencies, catchment management groups and industry. Areas identified would then require more detailed assessments to determine the capability of commercial operations and the expected salinity outcomes.

Figure 1: National Action Plan for Salinity and Water Quality (NAP) zones

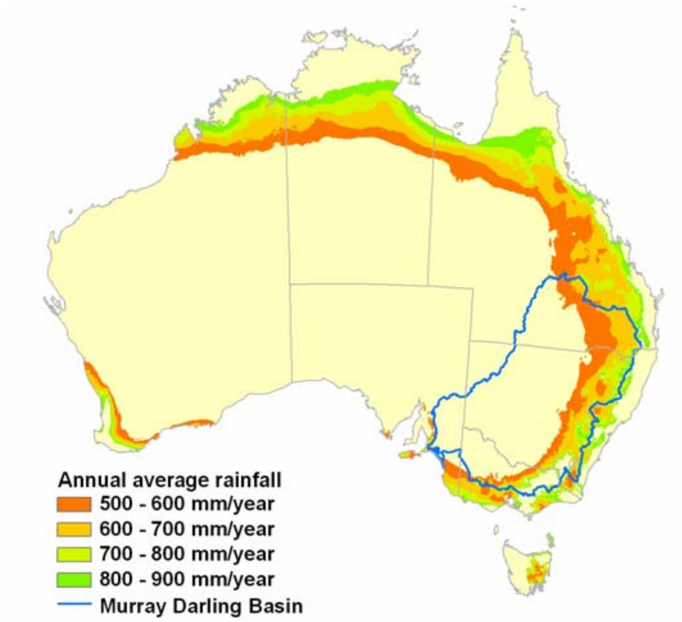
Figure 2: Natural heritage trust zones

Study approach

The project used existing information and knowledge databases available to BRS as well as those available from CSIRO and the Murray–Darling Basin Commission (MDBC). To identify where the CEF concept might apply, a set of CEF decision parameters were developed, based on the work of van Dijk et al (2004). Parameters included:

- Subcatchments should be situated in the low-to-medium-rainfall zone (500–800 mm/year; see Figure 3),
- Prospective areas should be subject to local groundwater flow systems that have potential salinity hazards, as such systems that have an increased likelihood of a salinity benefit (credit) within an economic timeframe,
- Subcatchments that are potentially saline should be a priority, as reducing stream-salinity inputs into catchments would have an increased likelihood of providing a salinity benefit (credit),
- Plantation establishment in low-salinity potential subcatchments should be avoided to allow their relatively higher freshwater runoff to add to total river freshwater flow, compensating for saltier water from other subcatchments,
- Prospective areas include those without native vegetation which were previously cleared for agriculture and have an expected mean annual increment (MAI) for forest growth of more than 9 m^3/ha/year. Areas with identified plantation suitability or near existing plantations would be potential priority areas, and
- Prospective areas should be near existing wood-supply catchments for processing forest products.

Figure 3: Annual average rainfall zones



Information sources and how they were applied

Known CEF catchments or regions and supplementary information

There are several catchments or regions in Australia with known potential for CEF (**Figure 4)**. They include southwest Goulburn–Broken and Upper Loddon catchments in Victoria, and the Little River and Liverpool Plains in New South Wales (NSW) (Herron et al 2004, Sinclair Knight Merz 2004, Walsh et al 2005).

Figure 4: Catchments identified as suitable for commercial environmental forestry (CEF)

Supplementary information about existing timber mills and export ports (**Figure 5)** informed the potential economic viability of CEF-related operations. It was assumed that if a location was within 200 km of a forest-processing plant, mill or port, then a potential market existed for CEF investment. Potential CEF regions found near existing plantations (**Figure 6)** could share existing forestry support and infrastructure (such as contractors and technical knowledge)

Figure 5: Locations of industries required to support commercial environmental forestry (CEF)

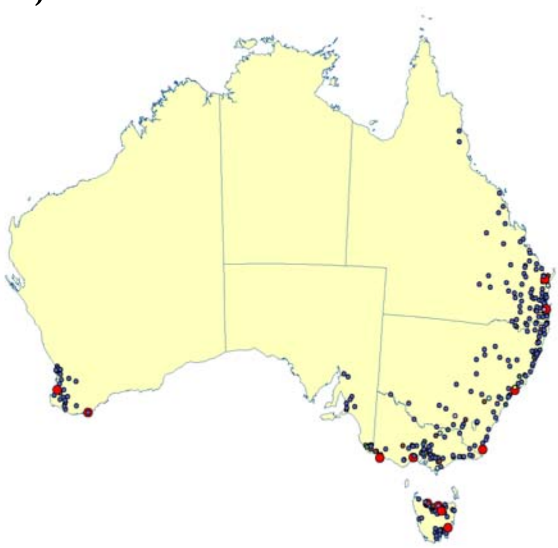
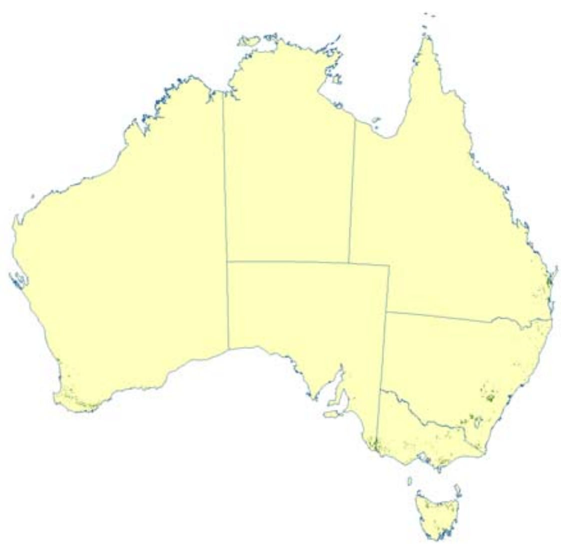


Figure 6: Locations of existing plantations

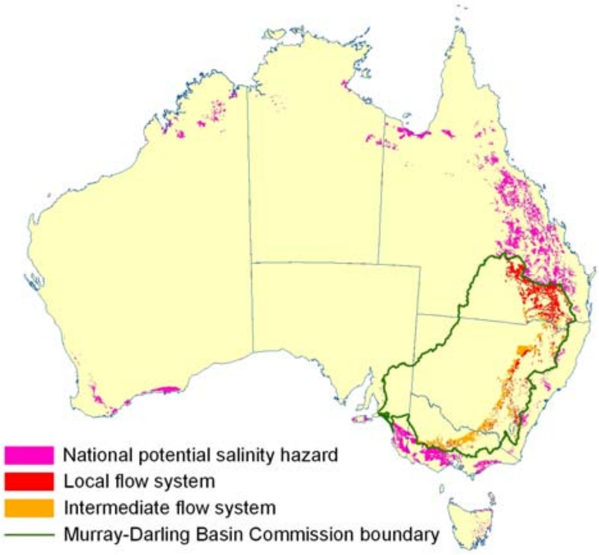


Salinity-hazard areas

Previous research in the MDB (Dowling et al 2004) showed that tree planting is only likely to have a definite effect on environmental salinity levels over an arbitrary timeframe of 50 years, in local-scale groundwater flow systems (GFS). Other work in the mid-Macquarie region of NSW by Baker and Evans (2003) showed that some local GFS can re-equilibrate in less than 10 years and in some cases in less than 5 years. Consequently, tree planting could enhance that timeframe in these systems if they were net salt exporters. As a result, local GFS affected by salinity are candidate areas for planting trees to reduce impacts of salinity. Two maps were used to display salinity hazard. Firstly, a national salinity-hazard map was derived by overlaying areas of saline soils with the 500–850 mm/year rainfall zone. This was then restricted to areas with slopes of less than 2 degrees. The latter was used because analysis of airborne electromagnetics data indicates that the majority of salt stored in the landscape is stored in these flatter areas. This rainfall band was used because salt in areas with rainfall less than 500 mm/year rarely provides sufficient water to mobilise salt in the landscape. Above 850 mm/year, salt has largely been leached out of the landscape.

This method was combined with the MDB GFS map produced by BRS as part of the Catchment Characterisation for Salinity Management project (D9004/D2013) for the MDBC (Coram et al 2000). **Figure 7** indicates which GFS require more focused work to identify which catchments are net salt exporters. Analysis of stream gauging and point stream-salinity data is being used to refine this work.

Figure 7: Potential salinity-hazard data coverage



It should also be noted that salinity-hazard areas are identified largely on the eastern, or recharge, side of regional flow systems, particularly in NSW. These areas are often associated with local GFS overlying larger regional ones and may provide further opportunities for tree planting to ameliorate salinity problems.

In considering using local GFS as the target for tree planting for salinity mitigation, it is important to take climate (rainfall) into account. A groundwater flow system that is a net salt exporter in, for example, a 600–700 mm/year rainfall zone, may produce little salt in a 900 mm/year rainfall zone due to the salt already being leached out. Hence ‘blanket assumptions’ of a particular groundwater flow system being suitable for salinity mitigation should be regarded with caution.

Forest growth and plantation potential

Stephens et al (1998) undertook an assessment of plantation potential studies across Australia. Using the 15 regions from the National Plantation Inventory, they assessed the level of information available about plantation capability or suitability. They found that available information and studies varied widely across Australia. Reliable and accessible information on plantation potential was found for the southwest region of Western Australia, Mt Lofty region of South Australia (SA), northeast Victoria and southeast NSW. Information was less reliable or accessible for Tasmania, the 'Green Triangle' (SA and western Victoria), central Victoria, central Gippsland, the Murray Valley, East Gippsland/Bombala, NSW Southern, Central and Northern Tablelands, NSW North Coast , and southeast and northern Queensland. Limited information on plantation potential was available for the Northern Territory. Since 1998, several regional plantation-potential studies have been carried out, largely associated with Regional Forest Agreements or their outcomes.

Lancefield Consultants (1995) identified around 350 000 ha of land that was suitable for hardwood and softwood plantations in southwest Western Australia. Further work has been undertaken in this region to improve the identification of plantation land, particularly in lower-rainfall sites, to relate plantation potential to soil and groundwater characteristics and survival and growth of tree species (primarily *Pinus pinaster* and *Eucalyptus globulus*). Plantation capability in the lower-rainfall areas of the region are very site-dependent and require field verification of soil and groundwater properties.

Several regional plantation-potential studies were associated with the comprehensive regional assessments (CRAs) for Regional Forest Agreements in Tasmania (Tasmanian Public Land Use Commission 1996), Gippsland, central highland and northeast Victoria (Borschman et al 2000) and southeast Queensland (Spencer et al 1999). The combined outputs of these regional reports are reproduced in **Figure 8**. As well, a national assessment has been undertaken of the potential for commercial timber plantations (Burns et al 1999) based on tree species' environmental profiles (Booth and Jovanovic 1991). Outputs from the national assessment have been used in preliminary assessments of using plantations (see **Figure 9**) for salinity abatement (Bugg et al 2002b).

Figure 8: Combined data from regional plantation-potential studies undertaken for comprehensive regional assessments

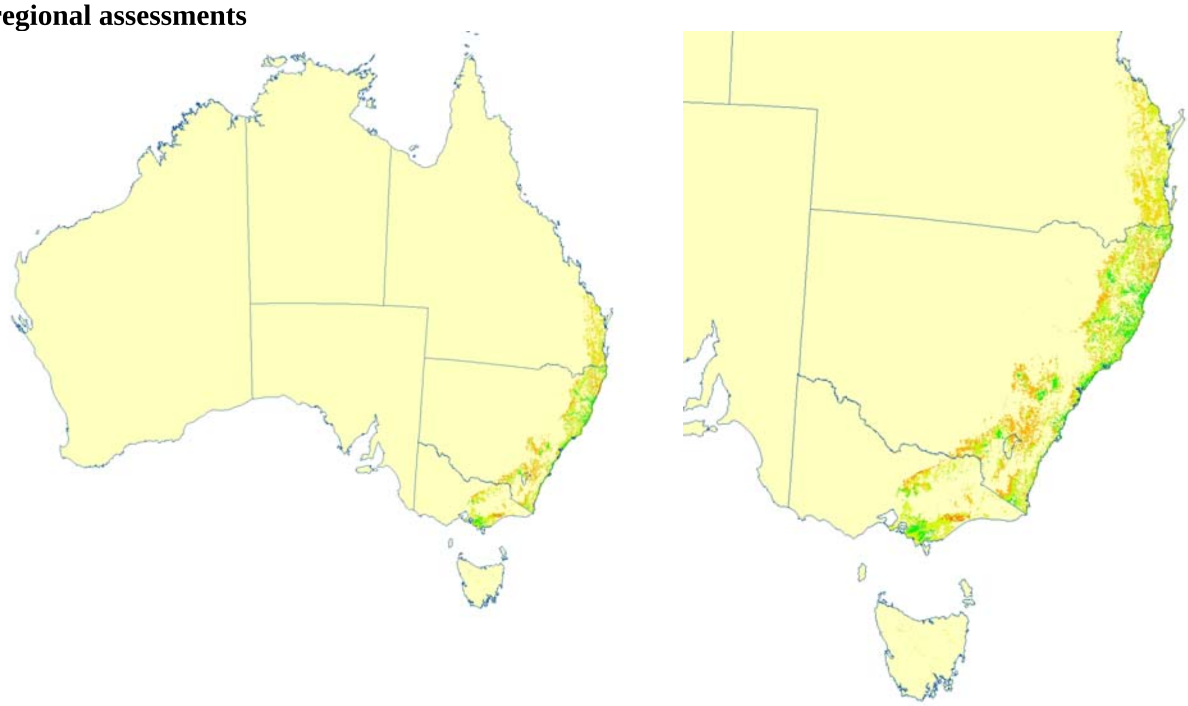
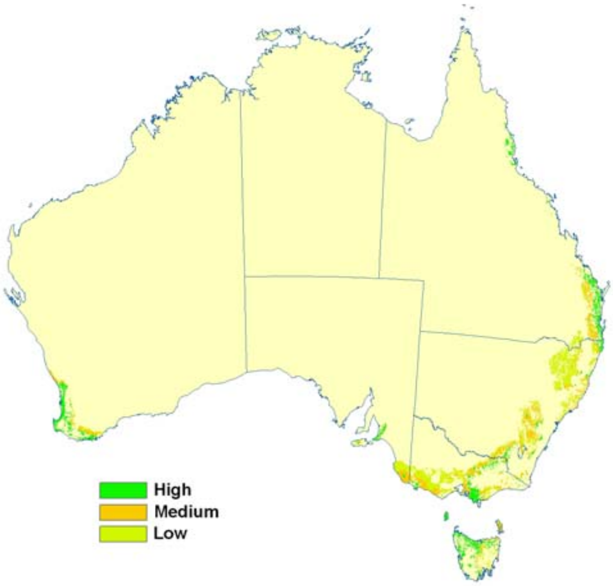


Figure 9: National plantation capability for 'Pinus radiata'



The Australian Bureau of Agricultural and Resource Economics (ABARE) and BRS (2001) undertook a strategic assessment of plantation capability and suitability across NSW. This project integrated previous studies undertaken in NSW CRAs (BRS et al 1998, 2000ab) and extended them into less-conventional timber-plantation areas. As well, the study incorporated assessment of potential benefits from growing plantations for a range of purposes, including salinity abatement, land rehabilitation, biomass production and carbon sequestration (Bugg et al 2002a). Tree-growth predictions in these studies were based on the spatial model 3-PG [3PG-SPATIAL] described in Tickle et al (2001) and information available from previous NSW regional plantation studies. Bugg et al (2002a) described the method used in the NSW study. A generic tree-growth model was developed based on *Pinus radiata*. Softwood and hardwood MAI (at age 20) was mapped after calibration using field measurements. *P. radiata* (softwood) was used throughout the state, *Eucalyptus nitens* (hardwood) for southern NSW and tablelands and *Eucalyptus grandis*, *Eucalyptus pilularis* and *Corymbia variegata* (hardwoods) for the NSW North Coast. The outputs for hardwood (**Figure 10)** and softwood (**Figure 11)** plantations and land degradation (**Figure 12)** are used in the current CEF assessment.

Figure 10: Hardwood plantation capability across New South Wales

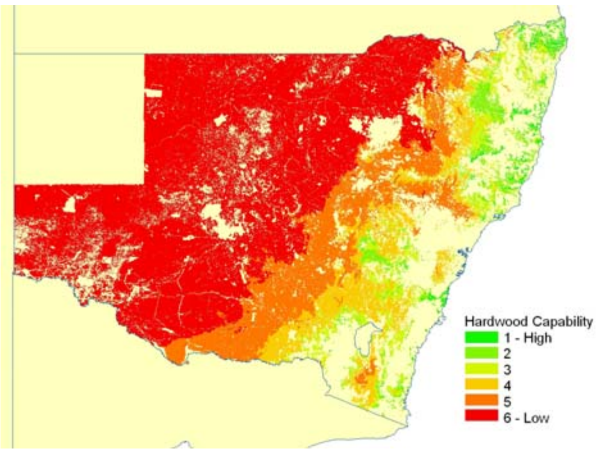


Figure 11: Softwood plantation capability across New South Wales

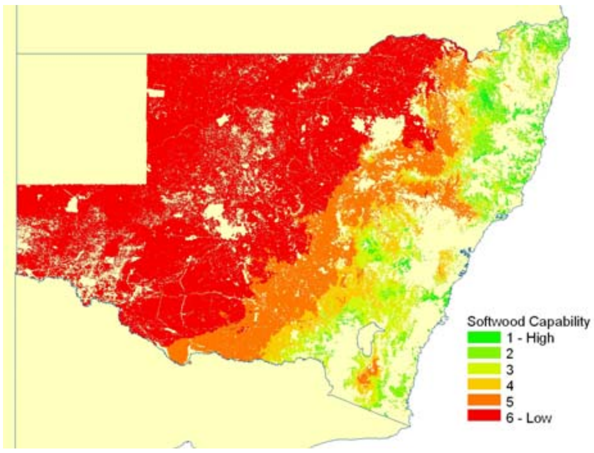
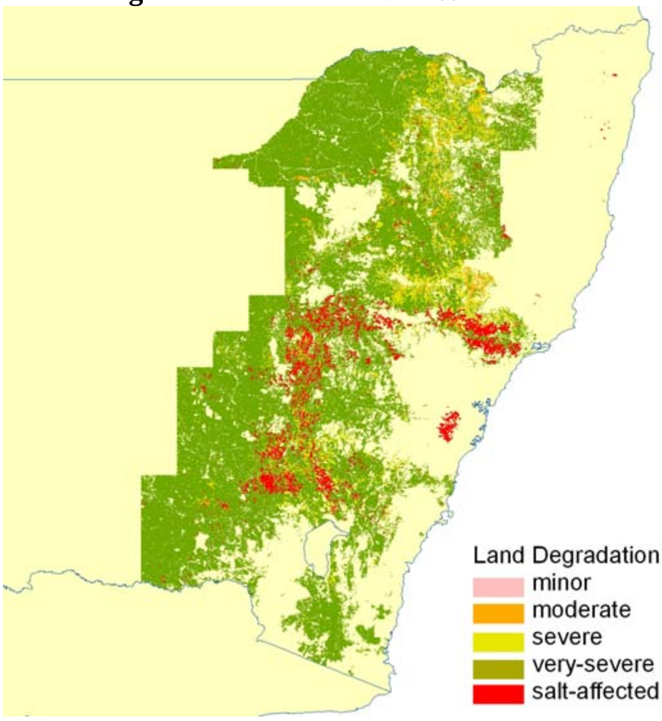
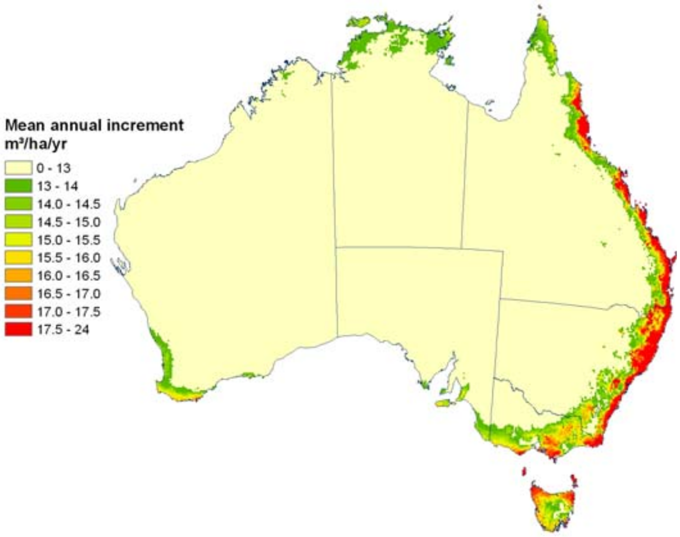


Figure 12: Severity of land degradation in New South Wales



The calibrated generic tree model devised using 3PG-SPATIAL was used by BRS to map potential tree growth nationally. The 3PG growth model predicts the growth rate of a forest or plantation in MAI (m^3/ha/year at age 20). A MAI below 10 indicates generally a non-commercial area, 10–15 low commerciality, 15–20 medium commerciality and above 20 high commerciality. For assessing CEF potential, MAI intervals of <9, 9–10, 10–12, 12–14 and >14 were identified (see **Figure 13**)

Figure 13: National generic mean annual increment (MAI) map of potential tree growth



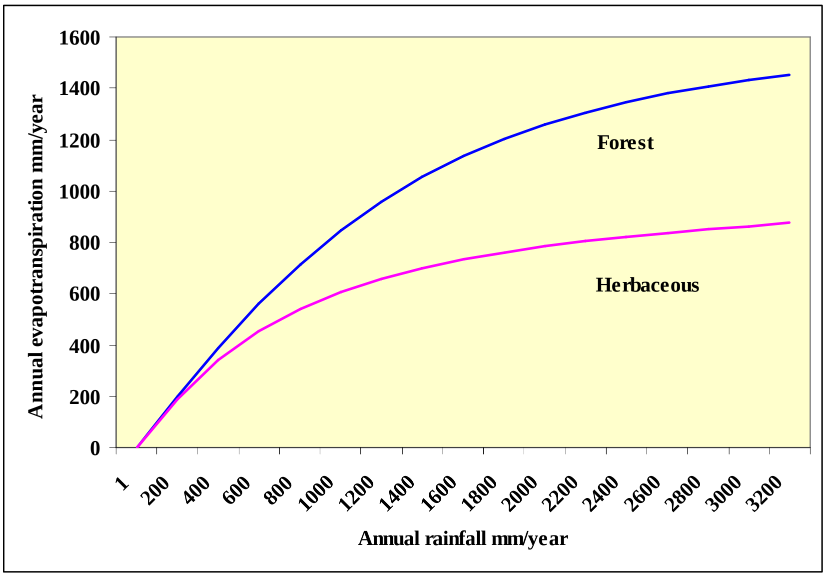
Catchment hydrology and stream salinity

The quality and quantity of groundwater and stream flow is a result of complex interaction between rainfall, climate, soils, geology, land practices and vegetation cover (Keenan et al 2004) Information regarding catchment hydrology and stream salinity is generally limited in both the regional and national context. Information is better for the MDB but its quality varies across the Basin (Smitt et al 2002). Dowling et al (2004) examined the case for the conversion of cleared land to native vegetation in terms of the change made to salt generation and river salinity in the MDB.

The work of Dowling and co-workers prioritised MDB catchments with respect to salinity and hydrological benefits from different management options. While Dowling et al (2004) recognised that there were significant limitations in their work and that it was ‘work in progress’, significant lessons can be learnt from their results. One lesson was the use of models developed by Zhang et al (2001) and their application in geographic information systems (GISs). Consequently, this study applied Zhang et al’s models to databases available within BRS.

The models of Zhang et al (2001) work on the premise that the most important factors controlling evapotranspiration (*ET*) are precipitation (*P*), potential evapotranspiration (E_o) and vegetation type. Zhang et al (2001) developed a simple two-parameter model that relates mean annual evapotranspiration to rainfall, potential evapotranspiration and plant-available water capacity that can be used for estimating water yield. The model uses the difference between annual evapotranspiration in herbaceous communities and forests (Figure 14).

Figure 14: The relationship between annual rainfall and annual evapotranspiration for forests and herbaceous cover as predicted by Zhang et al’s (2001) model



Zhang’s evapotranspiration model is described in Equation 1:

Equation 1

$$ET = \left(f \frac{1 + w_f \frac{E_{of}}{P}}{1 + w_f \frac{E_{of}}{P} + \frac{P}{E_{of}}} + (1 - f) \frac{1 + w_h \frac{E_{oh}}{P}}{1 + w_h \frac{E_{oh}}{P} + \frac{P}{E_{oh}}} \right) P.$$

where:

- *ET* = total annual evapotranspiration for the catchment in mm,
- *f* = the proportion of the catchment that is forested (>70% canopy cover),
- *w* = the plant-available water coefficient (which Zhang et al (2001) determined as 2.0 for forests and 0.5 for short grasses and crops),
- E_o = annual potential evapotranspiration for forested and non-forested areas, Zhang assumed E_o to be constant and determined a value of 1410 for trees and 1100 for herbaceous plants in mm, and
- *P* = annual precipitation in mm.

Equation 2 can be applied for calculating a pixel of uniform vegetation cover:

$$ET = \left(\frac{1 + w\frac{E_o}{P}}{1 + w\frac{E_o}{P} + \frac{P}{E_o}} \right) P$$

Equation 2

Stream flow (Q) may be estimated, assuming no change in soil or groundwater storage, using Equation 3:

$$Q = P - ET$$

Equation 3

The value of Q would be equivalent to the water discharge into a combination of stream and groundwater flows.

Zhang et al's model was based on empirical measurements from catchments with the following characteristics:

- rainfall is the dominant form of precipitation,
- slopes of catchments are gentle,
- soil depth is relatively thick (>2 m), and
- data from 250 catchments worldwide with 96 from Australia and covering a wide range of soil and climate types.

Zhang et al (2001) conclude that the model should be robust and scientifically justifiable. The curves fit well with the curves of Holmes and Sinclair (1986) and Turner (1991) in rainfall areas of 500–1500 mm/year. The equation gives a long-term average of annual *ET* (and stream flow), with no seasonality or water quality.

Zhang et al's models appear to be relatively robust when used at a geographically coarse scale where combinations of soil, climate and landuse types are smoothed out in regional estimates (Dowling et al 2004). Discrepancies with Zhang et al's estimates and observations do begin to occur when models are applied at finer resolutions and under certain soil, landuse and climate characteristics. Evans et al (2004) identify these discrepancies but conclude that Zhang et al's models are an appropriate estimator of catchment yield. The model assumes that *ET* is a linear function of forest cover; however, this may not be the case. The effect of tree cover may be non-linear and a threshold may exist below which no change in *ET* between forest and non-forest catchments could be observed. This may mean that when only a small proportion of a catchment is forested, the Zhang curves may not be applicable. These curves may be better in calculating water-yield impacts where the proportions of plantations and forests are higher than 20% or where catchments are larger than 1000 ha in size (CSIRO Land and Water et al 2003). As well, when only part of a catchment is forested, the location and pattern of the trees in the catchment may have an important effect that should be considered (Aryal et al 2003, CSIRO Land and Water et al 2003, Vertessey et al 2003).

Keenan et al (2004) reported considerable variation in water use within the broad vegetation class of forests and herbaceous vegetation. Rather than having generalised values for *w* (plant-available water capacity co-efficient) for forests and herbaceous cover, the study of Keenan et al (2004) showed a potentially greater range in *w* for various vegetation types, including different types of forests (eg pine compared with eucalypt), different stages of forests development (eg very young forests with low *ET* versus forests with full canopy closure and higher *ET*), and different types of herbaceous vegetation (eg perennial compared with non-perennial). Following discussions with L Zhang (pers comm 2004), Zhang et al's models could be applied using integrated vegetation and landuse information and the following values of *w*:

- 2 for plantations, native forests and woodland,
- 1 for native shrub lands and heathlands, horticultural trees and shrubs, and perennial crops,

- 0.5 for annual crops, pasture and native grasslands, and
- 0.1 for bare ground and built-up areas.

The model was run in ArcMap, as described in Annex 1. Subcatchment freshwater and stream salinity runoff were also estimated based on what proportion of the catchment was affected by salinity hazard (saline soils). Flows of fresh water and saline water were estimated within the area of subcatchments. Noting the relationship between salt load and water yield reported in Dowling et al (2004) based on the work of Zhang et al (2001), subcatchments were ranked based on fresh water and predicted stream salinity. **Figure 15** (saline water) and **Figure 16** (fresh water) show the predicted discharge of saline and fresh water from subcatchments falling into the 500–800 mm/year rainfall bands across Australia; the higher the index, the higher the predicted quantity of saline or fresh water discharged from the subcatchment. **Figure 17** and **Figure 18** show the predicted discharge of saline and fresh water, respectively, from subcatchments in the MDB.

Figure 15: Predicted national saline-water discharge

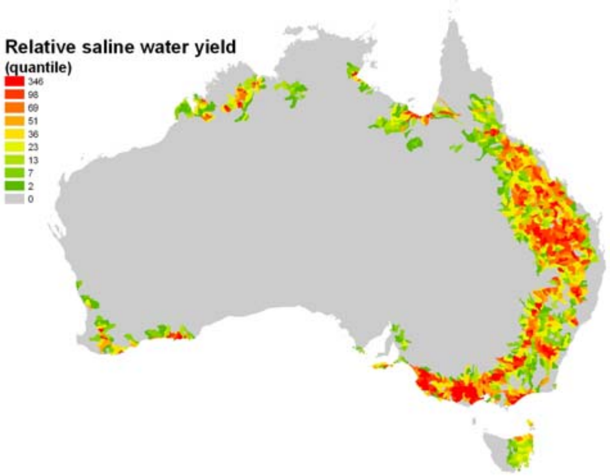


Figure 16: Predicted national freshwater discharge

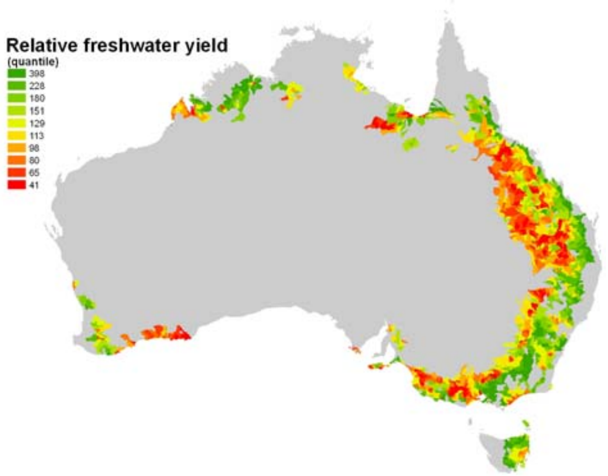


Figure 17: Predicted discharge of saline water in the Murray–Darling Basin (MDB)

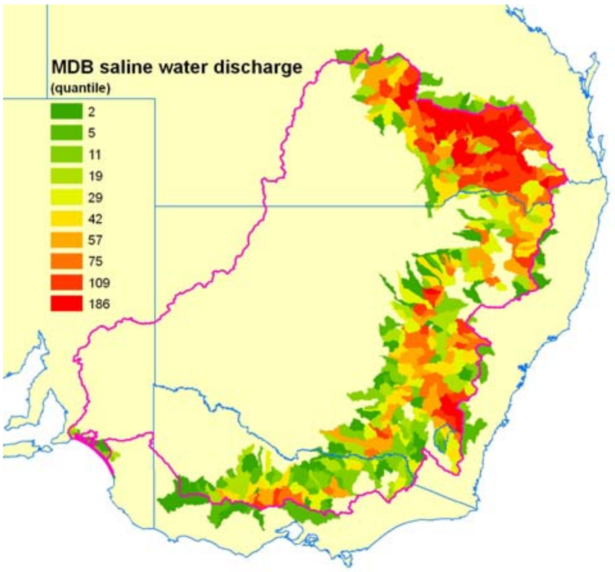
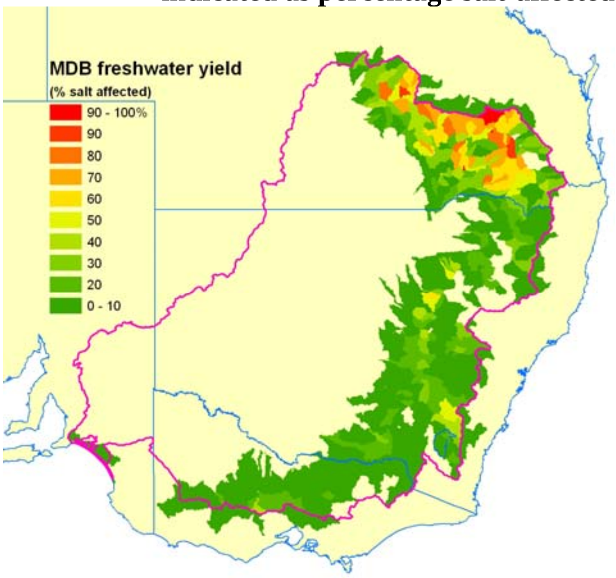


Figure 18: Predicted discharge of fresh water yield in the Murray–Darling Basin (MDB) indicated as percentage salt-affected

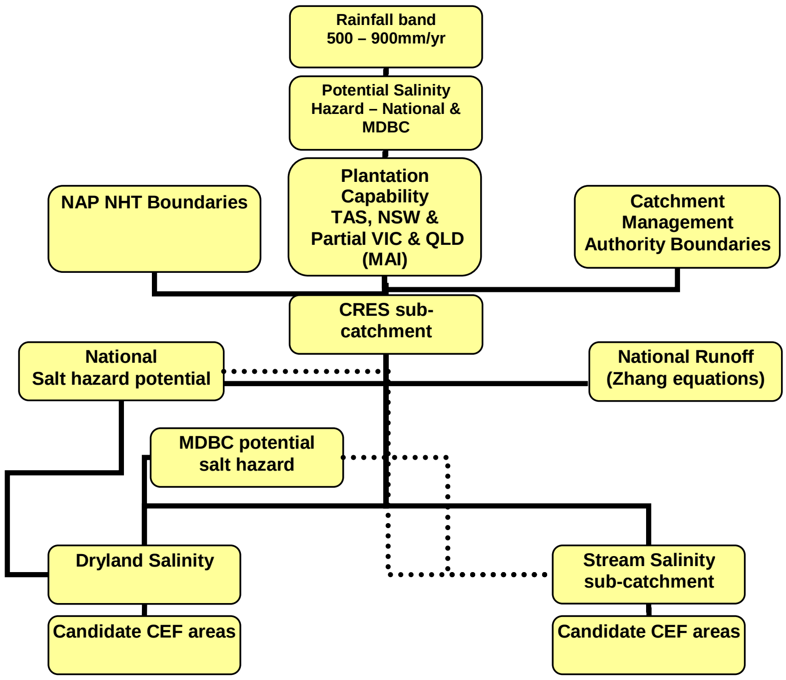


Results

Prospective CEF target areas

Areas to be targeted for CEF can be split into those associated with dryland salinity and those associated with control of stream salinity. Both approaches were undertaken in a GIS environment using ArcInfo and ArcMap. **Figure 19** provides a diagrammatic presentation of the approach to identify candidate CEF areas for addressing dryland and stream salinity.

Figure 19: Process used to identify commercial environmental forestry (CEF) candidate areas



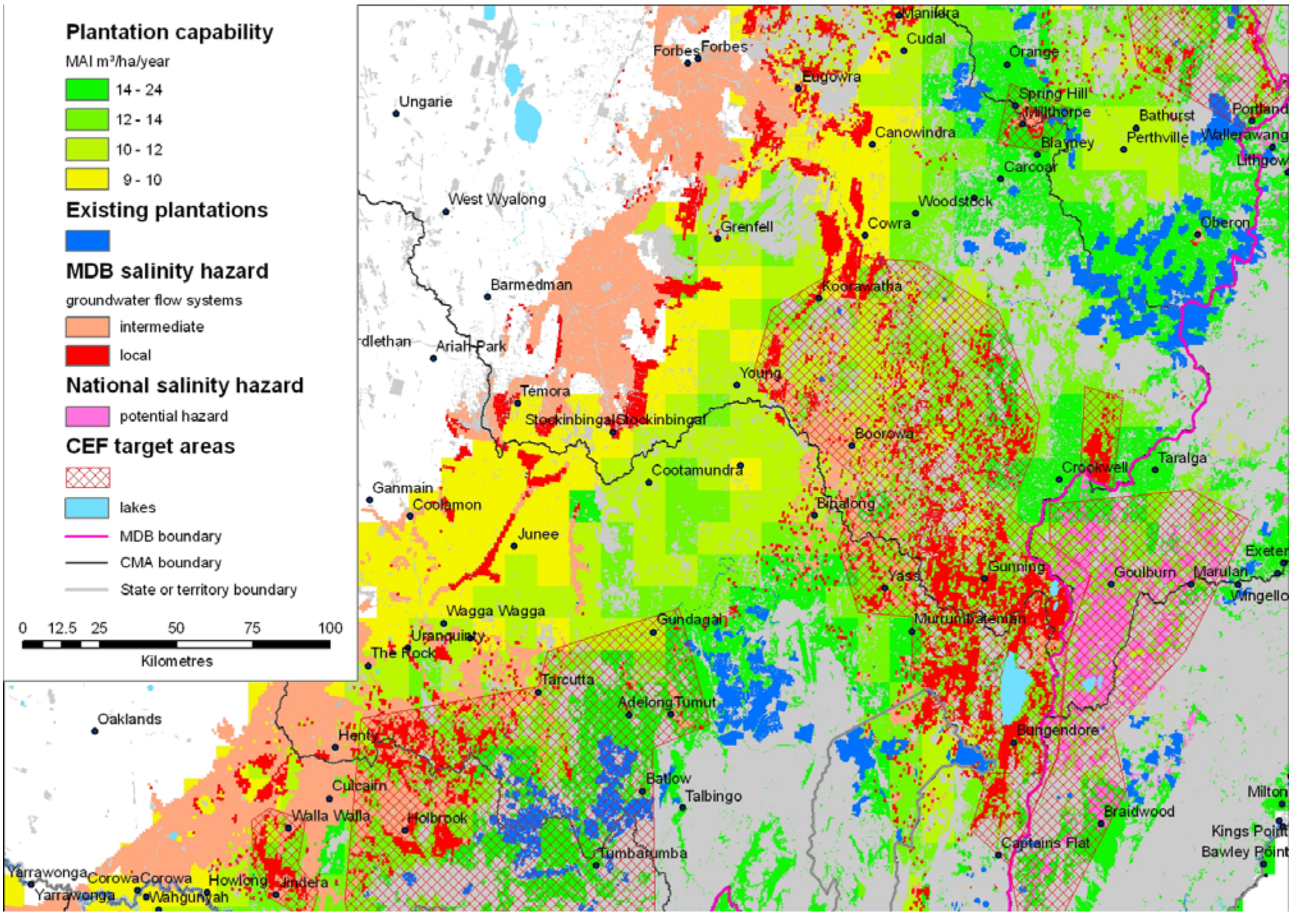
CRES: Centre for Resource and Environmental Studies, Australian National University
MAI: Mean Annual Increment (a measure of forest growth potential)
MDBC: Murray Darling Basin Commission
NAP: National Action Plan for salinity and water quality
NHT: Natural Heritage Trust
Zhang refers to the models of Zhang et al 2001

A composite of GIS coverages and masks were used to identify CEF candidate areas for dryland and stream salinity. Land subject to salinity hazard in the 500–850 mm/year rainfall zone, which was not native vegetation and had acceptable mean annual increments, was to be targeted for dryland salinity. Cleared agricultural land suitable for growing commercial trees in catchments with high discharge of saline water was targeted to ameliorate stream salinity.

Dryland salinity

National and MDB coverages that identified land potentially subject to salinity hazard in the 500–850 mm/year rainfall zone were used. A native-vegetation coverage map comprising vegetation types labelled as native forests, woodlands, open woodlands, shrublands and heathlands was used as a mask to identify land that was not native vegetation. Such land was a combination of cleared agricultural land, hardwood and softwood plantation, water bodies and urban areas. Areas that were built up (urban centres) or water bodies were identified and excluded from the analyses. Existing softwood and hardwood plantation resources were used to provide a regional context to the viability of CEF enterprises. Plantation-capability maps covering NSW, Tasmania, southeast Queensland and parts of Victoria were also incorporated into the geographical database to help identify potential suitability of land. The MAI coverage with MAI intervals of 9–10, 10–12, 12–14 and >14 colour-differentiated was incorporated into the database to provide information on anticipated growth rates. Catchment-management authority, NAP and NHT regions were included to provide administrative boundaries. The data were incorporated into the GIS as a series of overlays. **Figure 20** illustrates a selected example of the coverage.

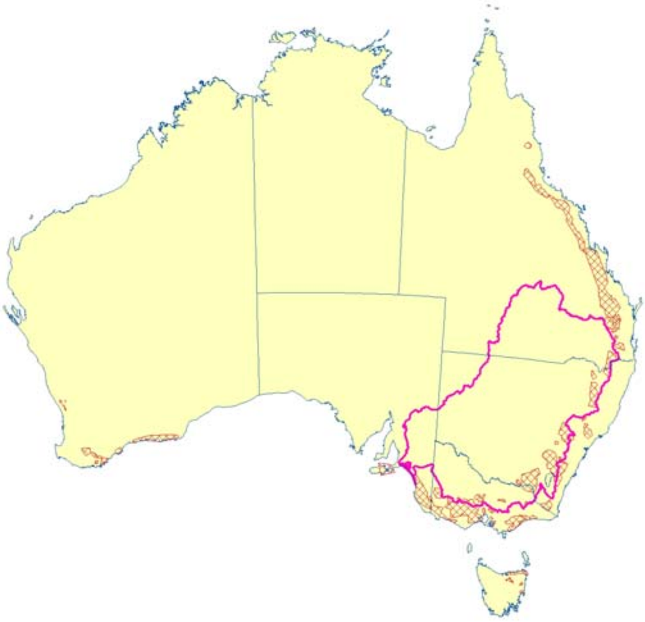
Figure 20: Example of map generated for an area targeted for commercial environmental forestry (CEF)



CMA: Catchment Management Authority
MAI: Mean Annual Increment (a measure of forest growth potential)
MDBC: Murray Darling Basin Commission

Areas of clumped or significantly speckled salinity hazard with suitable MAI were identified by eye and tagged to be included into a coverage of prospective CEF areas for dryland salinity. The proportion and pattern of speckling of hazard within a local area determined whether an area was included or excluded. As density of speckling declined, the likelihood of exclusion increased. Areas were also weighted for inclusion if they had salinity hazard present and were near existing plantation resources or within an area identified as having plantation capability. The CEF coverage distinguished between areas within the MDB and outside because of the better information available for the MDB. This is illustrated in **Figure 21** with Local and Intermediate GFS for areas outside the MDB shaded purple and within the MDB Local GFS indicated in red and Intermediate shaded pink.

Figure 21: National commercial environmental forestry (CEF) target coverage Highlighted area indicates the Murray Darling Basin Commission boundary.

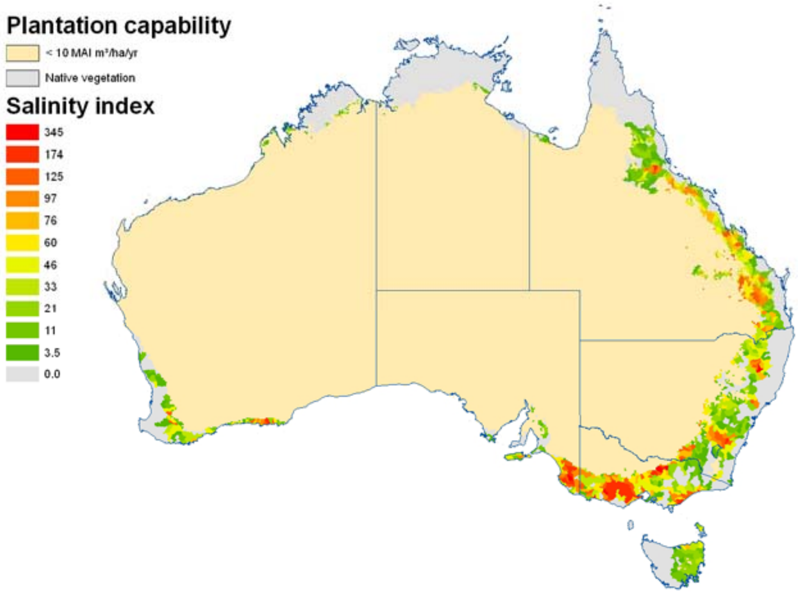


Stream salinity

Stream salinity in catchment systems can be managed and controlled through targeted afforestation programmes in those subcatchments contributing higher-salinity water yields or tributary inflows and controlling afforestation of those subcatchments contributing predominately fresh water to the catchment system. Inputs of saline water in catchment systems are diluted through lower inputs of saline water and higher inputs of fresh water. The index described above ranks subcatchments on their proportional contributions of saline and fresh water. The higher the subcatchment's salinity index, the higher the expected salt load being contributed to the catchment. As the index of fresh water of a subcatchment increases, the contribution to salinity dilution in stream water increases.

Coverages of national and MDB saline and fresh water (**Figure 20**), MAI and native vegetation were used to determine candidate subcatchments for commercial environmental projects in a geodatabase. The freshwater coverages were used to help interpret the saline-water index in the saline-water coverages. National and MDB saline water at a subcatchment level were gradationally colour-differentiated by salinity index from low (greens), moderate (yellow) to high (reds). A native-vegetation coverage map comprising vegetation types labelled as native forests, woodlands, open woodlands, shrublands and heathlands was used as a mask to identify land that was not native vegetation. The MAI coverage was used to mask land with a predicted MAI of less than or equal to 9 out of the analysis. Land with predicted MAI greater than 9 was used as a transparent mask such that the colour-differentiated subcatchments based on stream salinity were displayed. Areas within subcatchments shown in red are candidate CEF areas (**Figure 22**).

Figure 22: Subcatchment stream salinity-hazard map of Australia
MAI: Mean Annual Increment (a measure of forest growth potential)



Discussion and conclusion

Outputs of the current study are an interim product based on current information available to the BRS. They are incorporated and presented in catchment management authority, NAP and NHT regions to provide administrative contexts.

Caveats need to be placed on the information presented in this report as the information is generally coarse and its reliability varies spatially depending upon the source information and assumptions used in data compilation or modelling. Annex 1 and 2 explain how various maps were produced or the source of the data used. In general, the methodologies employed have been reviewed and referenced. The principal aim of the present study was to help identify potential areas where CEF could be considered using existing regional information.

For the purpose of making investment decisions, further analyses of areas are required using finer-level data. These would include improved site information, data on species' selection, subcatchment modelling analysis on the viability of plantings and salinity benefits, as well as the economics and commercial risks of such ventures. Appropriate tools for localised analyses include those being developed in CSIRO under the CEF Programme.[1]

While compiling information for this study, information gaps became evident which need to be remedied through future work. The generic tree model used for predicting MAI in this study varies in its reliability. The model has a further expected decline in accuracy from areas that are not associated with Regional Forest Agreements. This is largely because reliable growth information is limited and plantation-capability assessments have not been undertaken in areas outside of these Agreement regions. Accuracy in MAI is also likely to decline in northern Australia compared with southern Australia. Plantation-capability assessments are warranted in areas not covered by Regional Forest Agreements.

[1] http://www.ffp.csiro.au/KI-CEFResearch.asp (Accessed 2 May 2006)

The CEF concept would benefit through a study of species and site selection, and growth prediction in the drier environments of Australia below 600 mm. The concept of commerciality in the current study has been limited to consideration of current commercial sawlog and pulpwood species that are associated with isohyets of greater than 600 mm rainfall. However, there are commercial species associated with drier environments below the 600 mm isohyet that need to be investigated in the context of commercial environmental forestry concept; these include using Callitris (native cyprus pine), oil mallees and sandlewood in dryland afforestation programmes (Forests Products Commission 2003, National Forest Inventory 2003, Wildy et al 2003). These species that grow in low rainfall zones (300–600 mm) have commercial application and are known to have benefits in reducing groundwater tables associated with salinity. Based on current research within Australia, a national study of the application of low-rainfall species to controlling dryland salinity from a CEF perspective may be warranted.

Ongoing research looking at water-balance effects of afforestation and salinity amelioration is being undertaken by CSIRO, MDBC and various state agencies, some of which are sourced in the References. Such research will be important in understanding, within landscapes and catchments, how afforestation or environmental plantings influence and change salinity (dryland and stream). Such understanding will be important from a commercial perspective if salinity-credit markets are established and include afforestation and environmental plantings.

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Annex 1 Application of the models of Zhang et al (2001) in ArcMap to derive average annual water discharge and subcatchment flow of saline and fresh water

The Zhang et al (2001) water-use model (see main paper) was used to estimate subcatchment runoff by subtracting evapotranspiration from rainfall for each point in that subcatchment implemented in ESRI ArcMap 8.3 using the Spatial Analyst extension.

The datasets used were:

- Bureau of Rural Sciences (BRS) integrated vegetation cover 2003, version 1 [**veg_cov_v1** ~100 m grid],
- average annual precipitation [**ann_ppn** ~1 km grid] modelled using the Australian National University's Centre for Resource and Environmental Studies (CRES) Anuclim, version 5,
- national subcatchment polygon shapefile [**cres250**] also modelled using CRES, ANUDEM using the 9-second digital elevation model,
- national potential salinity hazard map [**haz_poss1** ~1km grid] derived from parent geology and groundwater flow-system maps, and
- Murray–Darling Basin (MDB) salinity hazard map [**gfs_salt_haz** ~1 km grid].

All datasets were transformed to the Geocentric Datum of Australia (GDA, adopted in 1994) , Australian Albers projection.

The vegetation grid was reclassified into zhang_w using the 5-category lookup table as described in Table 1.

Table A1 Plant-available water coefficients (*w*) allocated to vegetation cover categories

w	Vegetation identification	Description
2.0	1	'Native forests and woodlands (adheres to the Australian definition of)'
1.0	2	'Native shrublands, heathlands and open woodlands (non-forest woody vegetation)'
0.5	3	'Native grasslands or vegetation used for grazing/pastures not explicitly labelled as improved or modified'
1.0	4	'Horticultural trees and shrubs (eg orchards)'
1.0	5	'Perennial cropping (eg sugarcane, grapes etc)'
0.5	6	'Annual crops (eg cereals), grazing/pastures explicitly labelled as improved or modified'
2.0	7	'Hardwood plantation forests'
2.0	8	'Softwood plantation forests or plantations of mixed/unknown composition'
1.0	9	'Non-vegetated not elsewhere classified'
0.0	10	'Lakes, wetlands, water courses and reservoirs'
0.1	11	'Urban areas, transport services etc'
0.0	**99**	**'Vegetation cover unknown or unable to be inferred from input data'**

The Zhang spatial algebraic equations were executed stepwise on the grid datasets. In our implementation, the *w* values were multiplied by 10 to create an integer grid required for spatial calculations in ArcMap (in raster form).

Estimation of evapotranspiration coefficient E_o in mm

[Eo] = con([zhang_w] >= 10 1410 1100)

Estimation of Runoff

[E02] = (1 + [zhang_w] / 10 * [Eo] / [ann_ppn_p])

[PE] = ([ann_ppn_p] / [Eo])

[ET] = ([E02] / ([E02] + [PE])) * [ann_ppn_p]

[RO] = [ann_ppn_p] - [ET]

The average runoff per subcatchment

This was estimated as the average of all cells in the calculated runoff grid [RO] intersecting a subcatchment boundary.

The proportion of runoff potentially affected by salt

This was estimated to be proportional to the area of a subcatchment potentially affected by salinity in the salinity-hazard grids [**haz_poss1**; national] and [**gfs_salt_haz**; MDB]. It was estimated as the ratio of cells affected to all cells intersecting a subcatchment polygon, and stored in the subcatchment polygon. The estimated runoff was weighted by this hazard proportion to derive a saline-water yield estimator. The values for fresh water and saline water were then derived.

Annex 2 List and description of data used in this study

Summary

The data used were:

- potential salinity hazard
- subcatchment boundaries
- average annual rainfall
- modelled catchment runoff
- forest productivity potential
- various boundary datasets
- National Forest Inventory, plantation locations.

Explanatory notes

Potential salinity hazard

The Bureau of Rural Sciences (BRS) derived two potential salinity-hazard maps based on underlying geology and groundwater flow systems; a national map and a more detailed Murray–Darling Basin map. These maps only show potential salinity hazard; other local contributing factors must be present before land actually becomes salt-affected.

Groundwater flow systems (GFS)

Groundwater flow systems (GFS) have been developed in the National Land and Water Audit (NLWRA) as a framework for dryland salinity management in Australia. They ‘characterise similar landscapes in which similar groundwater processes contribute to similar salinity issues, and where similar salinity management options apply’ (Coram et al 2001, page 12).

GFS have been identified on the basis of nationally distinctive geological and geomorphological character. Local, intermediate and regional GFS are described by their response rate to hydrological change caused by alteration to the natural environment. The underlying assumption is that salinity is caused by increased recharge leading to rising groundwater tables, which have resulted from changes in land management over the past 200 years.

- Local flow systems respond rapidly to increased groundwater recharge. Watertables rise rapidly and saline discharge typically occurs within 20–30 years of agricultural development. These systems can also respond relatively rapidly to salinity-management practices, and afford opportunities for dryland salinity mitigation through alternative land-management practices.
- Intermediate flow systems have a greater storage capacity and permeability than local systems and take longer to ‘fill’ in response to increased recharge. Saline discharge typically occurs within 50–100 years after agricultural development. The extent and responsiveness of these groundwater systems offer much greater challenges for dryland salinity control.
- Regional groundwater flow systems have a high storage capacity and high permeability, and take a much longer time period to develop groundwater discharge than local or intermediate flow systems. Saline groundwater discharge may not occur for more than 100 years after agricultural development. Regional systems occur on a scale that is so large as to make farm-based catchment-management options impractical. Salinity mitigation in these systems will require widespread community action related to issues of common concern, as well as

engineering measures to protect high-value assets and infrastructure, together with the adoption of living with salt strategies.

National potential salinity hazard (flosys)

A national map derived from soil chemical and physical limitations related to salinity, combined with a mean annual rainfall range of between 500 and 800 mm and a land-surface slope of less than 2 %.

Derivation

The coverage is the intersection of the following data sources:

Soils with potential salinity hazard

- Derived from the digital version of the Atlas of Australian Soils, compiled by KH Northcote et al and published by CSIRO between 1960 and 1968 at 1:2 million scale. Linked to properties of soils affecting land management — an interpretation based on the categories established in The Atlas of Australian Resources, volume 1, Soils and Landuse, Natmap, 1980; (compiled for BRS by G Yapp and S Veitch). The following classes are classified as soils with potential salinity hazard:
  - chemical limitations: saline soils — salinity high throughout the profile,
  - physical limitations: hard-setting soils with dispersible clay subsoils,
  - physical limitations: soils with periodic subsurface waterlogging,
  - mean annual rainfall between 500 and 800 mm,
  - derived from the ANUCLIM grid of long-term mean annual rainfall (version 1.8),
  - land-surface slope less than 2%, and
  - derived from the national 9-second Digital Elevation Model (version 2).

Subcatchment boundaries (cres250g)

The Australian National University's Centre for Resource and Environmental Studies (CRES) modelled subcatchment boundaries: 'A nested set of subcatchments and catchments for Australia. The catchments have been determined from the version 2 of the 9-second continental Digital Elevation Model (DEM) produced by CRES for AUSLIG.'

Average annual rainfall (ann_ppn)

BRS maintains an enhanced national annual rainfall surface, representing the annual rainfall for each 1-km square grid. From these data, we mapped the 600 to 900 mm/year rainfall band, considered to be suitable for growing trees — not too dry for growing trees, but avoiding areas of high rainfall more likely to have existing native forest cover.

These climate data are sourced from the ANUCLIM[2] software enhanced with a Digital Elevation Model.

Modelled catchment runoff (zhang_w, ro_5param)

Calculated for this project, a simple evapotranspiration model was developed by Lu Zhang from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to estimate runoff

[2] http://cres.anu.edu.au/outputs/anuclim.php (Accessed 1 May 2006)

from each subcatchment. The average annual rainfall, minus transpiration from five categories of vegetation, was used to estimate mean subcatchment runoff. This was multiplied by the proportion of the subcatchment potentially affected by salinity to compute a proxy for salt mobilisation.

Forest productivity potential (maialb1, soft0613, hard0613)

Data compiled from the Regional Forest Agreement process on potential plantation productivity showing likely mean annual increment (MAI), a measure of forest growth potential. Separate datasets from Tasmania, Victoria, New South Wales (NSW) and Queensland were used. Areas with MAI less than 10 are considered marginal investment quality and less than 9 unviable economically. Datasets developed for NSW through the Regional Forest Agreements were used for the Murray–Darling Basin component.

Various boundary datasets (alig5mg, nht_alb, nap_alb, bound_lmdb)

Data from Australian states and territories, Natural Heritage Trust regions, National Action Plan zones and the Murray–Darling Basin were used for the final production of maps.

National Forest Inventory (ausfor250, plant_2001)

This study used the National Forest Inventory forest type and plantation type locations, and used the native vegetation attributes in this coverage to mask areas of native forest or shrubland where local regulations prevent replacement of native forest with plantation forest. The latest plantation-location data were used to qualify potential salinity-hazard areas within subcatchments with established large plantation estates and associated industries, making them more attractive for plantation investment.