FINAL REPORT

Afforestation Risks to Water Resources in the Murray-Darling Basin

Contract: MD1537-CP1

Ref: 3001821

November 2010

AUSTRALIA | ASIA | MIDDLE EAST | AFRICA | PACIFIC

ACKNOWLEDGEMENTS

SMEC wishes to acknowledge the valuable time and insights of the people interviewed for the purpose of this project. Their industry experience and technical expertise have been instrumental in the development of the synthesis presented by this document. Specifically, we would like to thank:

- Professor Damian Barrett, University of Queensland
- Assoc Prof Leon Bren, University of Melbourne
- Kevin Burns, ABARE
- David Bush, CSIRO Plant Industry
- Mark Cotter, Goulburn-Broken Catchment Management Authority
- Professor David Ellsworth, University of Western Sydney
- Ahmed Hafi, ABARE
- Kenton Lawson, ABARE
- Greg Lundstrom, River Murray CMA
- Gavin Matthew, A3P
- Geoff Minchin, Lachlan CMA
- Dr Nick O'Brien, New Forests
- Dr Phil Polglase, CSIRO Sustainable Ecosystems
- Warwick Ragg, Australian Forest Growers Association
- Rhonda Toms-Morgan, QMDC
- Dr Narendra Tuteja, Bureau of Meteorology
- Dr Albert van Dijk, CSIRO Land and Water

The approach to this project was developed in consultation with the Murray-Darling Basin Authority. We appreciate the advice received from Dr Mathew Maliel, Jason Alexandra, Alice Shields, Phil Price, Ian Burns and Gavin Pryde. Land use and rainfall maps were produced by Rob Chatfield.

Published by Murray-Darling Basin Authority
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This report may be cited as: SMEC 2010, *Afforestation risks to water resources in the Murray-Darling Basin,* Murray-Darling Basin Authority, Canberra.

MDBA Publication No. 131/11

ISBN 978-1-921783-90-6

EXECUTIVE SUMMARY

Plantation forests established on previously cleared land have potential to intercept significant quantities of water, resulting in possible adverse effects on catchment water yields and stream flow. The looming prospect of climate change, with expectations for a drier climate in the Murray-Darling Basin, also has potential to reduce water availability in the Basin. The potential for large-scale expansion of forestry plantations therefore poses a risk that the combined effects of climate change and increased water use by forests may significantly reduce the availability of water for environmental and consumptive use within the Murray-Darling Basin.

This project was initiated to assess the risks presented by afforestation to water supply in the Murray-Darling Basin, within the context of climate change. The overarching objective of the project was to synthesise existing knowledge, and to identify knowledge gaps and options for future planning and program development in relation to traditional forest plantations in high rainfall areas, and carbon sequestration afforestation throughout the Basin, and their associated potential impacts and benefits within the MDB.

In the context of this study, traditional forest plantations refer to plantations established for the purpose of commercial harvest for wood products. This practice is distinct from plantations that are established primarily for the purpose of carbon sequestration, and which may or may not be operated on a commercial basis.

The effects of afforestation on catchment water yields are driven by hydrological processes at multiple scales. The Risk Assessment program conducted by the MDBA has initiated a number of inter-related projects to address these different scales. This project, CP1 addresses the issues arising from changes in area of plantation forestry, drawing on existing information on forest water use, anticipated changes in plantation area, economic drivers, and effects of climate change scenarios adopted by the MDBA. The effects of plantation management on water use by forests and resulting impacts on catchment water yields are addressed in project CP2. Physiological water use by trees at scales ranging from individual plants to forest ecosystems, and the influence of environmental factors on forest water use are the focus of project CP3.

The project was undertaken in two parts to reflect the different drivers for traditional afforestation activities in the higher rainfall areas of the Basin, and for plantings specifically for carbon sequestration throughout the Basin. High rainfall areas are considered to represent regions which receive at least 600 mm y^{-1} average rainfall. These requirements are addressed in separate sections of the report.

Specific objectives with regard to traditional forestry plantations were to:

1. Collate and synthesise current scientific knowledge on the impact traditional plantations have on catchment water balances, including surface and groundwater, with a focus on high rainfall areas; and

2. Analyse the information in terms of the significance of the water yield impacts to MDB catchments and stream flow, using three climate change scenarios and taking into account growth projections for the increased establishment of plantations in high rainfall areas.

Objectives for assessing potential effects of carbon sequestration plantations were to:

1. Achieve a clear understanding of the current scientific knowledge and gaps on the impacts of afforestation for carbon sequestration benefits and the impacts on catchment water balances;

2. Identify current legislation and policies in each jurisdiction relating to afforestation for carbon sequestration, with a focus on the water use impacts of these policies;

3. Identify current and proposed rates of increase or decline in afforestation types across the MDB, areas which may be most impacted and associated land use changes;

4. Design a framework and undertake an assessment of the potential impacts, both positive and negative, that afforestation for carbon sequestration is having or will have on a catchment and basin wide scale, under three climate change scenarios. Potential impacts include:
    a. Water quality and quantity
    b. Salinity management
    c. Biodiversity
    d. Riparian management
    e. All potential impacts resulting from land use change.

5. Provide advice on how carbon plantings can maximise environmental benefits, including identifying suitable areas for afforestation, and forest management options; and

6. Develop options for incorporating afforestation for carbon sequestration benefits into water access entitlement frameworks by 2011.

The method adopted to achieve these objectives was based on interviews with specialists from a range of disciplines relevant to carbon sequestration and forest hydrology covering research organisations, environmental management agencies, catchment management groups, and the forestry industry. Information obtained from interviews was used to undertake a high level review of relevant literature. High rainfall areas were defined as regions with mean annual rainfall greater than 600 mm y^{-1}.

Climate change scenarios considered included:

1. A 'most favourable 2030 scenario' based on a continuation of the long-term (1895 to 2006) averages for rainfall and runoff across the MDB;

2. A 'median 2030 scenario' based upon the median global warming scenario and associated rainfall and runoff; and

3. A 'least favourable 2030 scenario' based upon the actual climate of the MDB in the period 1997-2006.

A fourth scenario based on the dry extreme 2030 model was used in some analyses as a replacement for the least favourable 2030 scenario.

The method adopted to achieve these objectives was based on interviews with specialists from a range of disciplines relevant to traditional plantations, carbon sequestration plantations, and forest hydrology covering research organisations, environmental management agencies, catchment management groups, and the forestry industry. Information obtained from interviews was used to undertake a high level review of relevant literature. High rainfall areas were defined as regions with mean annual rainfall greater than 600 mm y^{-1}.

Principal findings

Part A - Effects of traditional forest plantations

Plantation water use

Effects of plantation water use on catchment water yields are difficult to measure where plantations cover less than 15-20% of catchment area. Consequently, at the basin scale and catchment scale where plantation cover ranges from 0.4% to 4%, effects of plantation water use on catchment water yields are small and may be below practical detection limits. In sub-catchments less than 100 km^2, where plantation cover is greater than 20%, effects on local stream flow may be significant, leading to reduced stream flow and drying of small streams during low flow periods. Tributary inflows progressively reduce the downstream impacts of plantations.

Changes in plantation area

Projections for expansion in plantation area in the Murray-Darling Basin have declined in the last decade. Initial estimates in 2002 of an increase of 141,400 ha were revised in 2008 to a more modest target of 52,000 ha by 2030. The forestry industry believes that even this target is ambitious, with maintenance of existing plantation area, perhaps with a small increase of around 5%, considered more likely under current conditions. The recent failure of managed investment schemes for forestry, and the collapse of several major forestry companies make it difficult to raise revenue required to establish new plantations. However, recent studies suggest that a carbon trading scheme with a high price on carbon may provide economic incentives to drive expansion of plantations.

In view of the uncertain economic outlook, a significant increase in the area of traditional forest plantations is unlikely in the foreseeable future, and consequently, the risk to water yields in the Basin is low.

Effects of climate change

A drier climate under the median 2030 scenario, with 9.7% less inflows to the MDB may see a contraction of traditional plantations to rainfall zones that receive greater than 800 mm y-1 mean annual rainfall. Projected end-of-system flow under median 2030 climate change models suggest a reduction in water yields of 25% across the Basin, with a possible decrease of 69% in dry extremes. Against this range of changes, the estimated reduction in end-of-system flow of 0.8% attributable to a 52,000 ha increase in plantations is small, and actual change is expected to be even smaller if industry projections are correct.

Recent analyses suggest that the adaptive capacity of forests to climate change, through changes in vegetation seasonality, root depth, depth of rain penetration in soil, and CO_2 effects, may partially offset the effects of forests on stream flow. The net effect of forest adaptation is that impacts on water availability under drier 2030 climate scenarios may be less than current predictions.

Risks to water yields

Under the median 2030 climate change scenario, a 0.8% reduction in stream flow following a 52,000 ha increase in traditional plantation area is likely to be masked by other sources of variation, such as climate variability. The same increase in plantation area under the least favourable dry extreme 2030 climate scenario will reduce end-of-system flow by 1.6% compared to the 69% reduction caused by climate change. Similar outcomes were estimated for the Murray, Murrumbidgee and Eastern Mount Lofty Ranges catchments where plantation expansion is most likely, although the relative impacts are greater in the smaller Eastern Mount Lofty Ranges catchment.

The risk to water yields will be much smaller than these estimates if industry projections of less than 5% expansion in plantation area are achieved. Conversely, if an expansion of 141,400 ha is realised, effects on water yields may be roughly estimated as a 2.4% reduction in end-of-system flows, and a 0.36% reduction in total water resource availability. These changes are still small compared to the expected effects of climate change and the estimated 4.9% reduction in stream flow by new farm dams.

Sources of uncertainty and knowledge gaps

The greatest sources of uncertainty are the potential increase in plantation area, and the most likely climate trajectory.

Other sources of uncertainty include:

- Difficulties in extrapolating effects of plantation increase at large catchment scales;
- Methods for dealing with variability in hydrological models;
- Different processes represented in models used to estimate plantation water use;
- The contribution of plantations to water use compared to other land uses;
- The role of forests and plantations in atmospheric coupling between evapotranspiration and precipitation;
- Approaches to monitoring plantation water use and impacts on water yields;
- The significance of plantation water use at different spatial scales;
- Net benefits of plantations in relation to water use;
- Impacts of climate change on plantation water use; and
- Uncertainty in the global economic outlook.

Part B - Effects of carbon sequestration plantations

Effects of afforestation for carbon sequestration

Effects of water use by carbon plantations on catchment water yields differ from effects of traditional forest plantations in several key ways. Firstly, carbon plantations are most likely to be established in regions with lower rainfall, since areas with greater than 600 mm y^{-1} rainfall are in demand for more valuable forms of production, such as agriculture or plantation forestry for wood production. Secondly, land suitable for carbon plantations tends to lie in low gradient parts of the Basin that are characterised by low runoff and high evapotranspiration rates. Consequently, effects of carbon plantations on water availability are likely to be less than effects of plantations in higher rainfall regions. Thirdly, the lower water availability to plantations in low rainfall areas means that different tree species, with different water requirements, are favoured in plantations intended to provide carbon sequestration benefits.

The rate of carbon sequestration is closely related to water availability, since trees store carbon by growing tissue, and growth rates are strongly determined by water availability. The greatest sequestration rates therefore occur in high rainfall zones, but economic drivers force most carbon plantations toward low rainfall zones.

Environmental plantations are often established primarily for other benefits such as salinity management, or habitat restoration, with carbon sequestration as a secondary benefit. Many species, such as oil mallees, can be grown in areas with very low reliable rainfall, but carbon sequestration is probably not viable in areas with less than 300 mm y^{-1}. Whilst plantations may reduce salinity impacts by lowering water tables or by intercepting saline groundwater before it enters rivers, trees may also intercept freshwater that dilutes saline discharge, resulting in increased salinity in some situations. Landscapes are typically heterogeneous, so targeted carbon plantings that contain a number of species will make greater contributions to biodiversity goals than monocultures.

Trees have traditionally been viewed as only having negative effects on water availability. However, afforestation may form an important part of strategies to reduce local scale warming and increased evaporation in heavily cleared landscapes.

Much of the current knowledge of environmental plantings has been derived from studies of traditional forestry plantations, or is based on modelling studies. The amount of information available directly from empirical studies of plantations established for carbon sequestration and other environmental benefits is comparatively small. This discrepancy leads to uncertainty in assessing the impacts and benefits of carbon plantations at a general scale.

Optimising the benefits and impacts of carbon sequestration plantations requires multiple trade-offs between a number of competing objectives, ranging from paddock to catchment scales.

Legislation and policies on afforestation for carbon sequestration

Statutory tools relevant to afforestation for carbon sequestration cover issues of forestry, water, climate change, land use and planning, environment, and vegetation management. Carbon sequestration plantations are encouraged by a raft of legislation and policies at State and Commonwealth levels. South Australia explicitly recognises the potential effects of plantations on water supply and stream flow under existing legislation. Legislation in the Australian Capital Territory, Victoria, and the Commonwealth includes provisions that capture aspects of plantation water use, subject to interpretation. Much of the relevant legislation has been enacted only recently, and responsibility for implementation is often diffused among different levels of government and multiple agencies, potentially leading to inconsistent application.

Rates of change in afforestation

Environmental plantings account for approximately 14,000 ha (5%) of the total 284,000 ha of plantations in the Basin. Interest in environmental plantings for carbon sequestration varies markedly among catchment management groups. Significant private investment in environmental plantings has not yet occurred in the MDB, with private plantations limited to 100 ha or less. Lack of investment is considered to be the major obstacle to environmental plantation establishment in suitable regions. Despite strong interest in establishing carbon plantations in some regions, the area of existing plantations is small and is unlikely to grow significantly in the short to medium term. Possible expansion in carbon plantings to 2030, based on current rates, is estimated at 100,000 ha.

Economic modelling based on a carbon price of \$28 $tonne^{-1}$ indicated a hypothetical increase in plantations of over 10 million ha by 2050, which was re-scaled to approximately 5 million ha by 2030 for comparative purposes.

Assessment of potential effects of afforestation for carbon sequestration

A vulnerability assessment framework was adapted assess potential effects of afforestation for carbon sequestration in combination with climate change scenarios on water quality and quantity, salinity, biodiversity, riparian management, and related effects of land use change. The vulnerability assessment framework combines exposure to plantations and sensitivity to impacts of plantations to derive an assessment of likely impacts. Any potential adaptive capacity that may reduce impacts of plantations and climate change is also considered, to derive an overall assessment of vulnerability.

Twelve scenarios were considered in the vulnerability assessments undertaken, including combinations of three climate scenarios, two carbon plantation scenarios (maximum and minimum), high and low impact on stream flow, and high and low impact on environmental management programs. Separate analyses using all 12 scenarios were done for stream flow, salinity, biodiversity, and riparian management, as well as a combined assessment. Assessments drew upon projected plantation areas in each sustainable yields region to provide a spatial comparison and ranking of vulnerable regions within the Basin.

Estimated changes in end-of-system flows as a result of maximum afforestation under the median 2030 climate scenario varied from 0% in the Paroo and Ovens catchments, to a reduction of 14% in the Border Rivers catchment.

Vulnerability of catchment water yields by 2030 is low at the catchment scale if plantations increase at the current rate. In contrast, vulnerability increases significantly under any scenario where the price of carbon is high enough to provide incentives for landholders to convert marginal agricultural land to carbon plantations. Vulnerability of water yields, and benefits to other environmental purposes are assessed as being greatest in the Eastern Mount Lofty Ranges, Moonie, Gwydir and Macquarie-Castlereagh catchments.

Maximising benefits of carbon sequestration plantations

Optimising the environmental benefits of plantations across objectives for carbon sequestration, salinity management, water quality, biodiversity, riparian zone management, and increasing rural land values, whilst minimising effects on catchment water balances and the reduced availability of valuable agricultural land, requires complex balancing of trade-offs. The outcome of any optimisation approach is that the amount of carbon sequestered will be less than the maximum that could potentially be achieved, which may reduce the income stream generated by carbon plantations, and also limit the area of agricultural land that is converted to plantations. Adoption of formal optimisation techniques is recommended to design plantations that deliver maximum net benefits within the constraints of local conditions.

Options to include carbon sequestration in water access entitlement frameworks

Five options are presented to allow water use by carbon sequestration plantations to be included in water access entitlement frameworks, based on access entitlements for regulated surface water, unregulated surface water, and groundwater systems:

Option 1: Purchase of environmental allocation from the Commonwealth Environmental Water Holder.

Option 2: Water licence tender.

Option 3: Afforestation of land with existing bundled water rights.

Option 4: Payments for environmental services (or contracts for afforestation services).

Option 5: A new afforestation entitlement across the Murray-Darling Basin.

Sources of uncertainty and knowledge gaps

Estimates of the future area occupied by carbon sequestration plantations involve a high degree of uncertainty, based around the possible price on carbon and the cost of water access by plantations.

Potential for climate adaptation at the plantation scale to reduce effects of stream flow requires further investigation to refine projections of future water yields and stream flow.

Options to manage plantation water use through tradable water access entitlements require more detailed assessment of the combined effects of water prices and carbon prices on carbon sequestration plantations.

Conclusions

The likelihood of expansion of traditional forestry plantations in the high rainfall zone of the Murray-Darling Basin, at a scale that will affect catchment water yields is low. The maximum impact on end-of-system flows under the least favourable 2030 climate scenario is estimated to be a 1.6% reduction in flow. The greatest risks exist in small sub-catchments less than 100 km^2 where plantations may occupy close to 100% of catchment area, and where seasonal reductions in stream flow by plantations may be hydrologically and ecologically significant.

Reduced rainfall under future climate scenarios may encourage traditional plantation area to remain static or contract to higher elevations within the existing 800 mm y^{-1} rainfall zone. The current trend toward smaller plantations distributed more widely may reduce effects on individual streams. The adaptive capacity of plantations under a drier climate may partially offset increased water use by new plantations established for wood production or carbon sequestration. .

Estimates of increases in plantation area for environmental purposes across the Basin range widely from a minimum of 100,000 ha to over 10 million ha driven largely by the existence of a price on carbon emissions. A carbon price of $28 $tonne^{-1}$ results in a 13% reduction in catchment water yields, and an 8% reduction in end-of-system flow across the Basin by 2050, in addition to effects under the median 2030 climate change scenario.

Catchments with large areas of low land values in the low rainfall zone are vulnerable to reduced water yields and stream flows as a result of converting agricultural land to carbon sequestration plantations. Additional benefits are likely to be achieved by optimising objectives for water quality, salinity management, biodiversity and riparian management.

A future price on carbon and charging for water used by plantations may provide additional drivers for new traditional plantations beyond the levels considered to be realistic in this assessment. The uncertainty regarding the future price of carbon means that estimates of expansion for all plantation types, and environmental impacts, based on hypothetical carbon prices, may be unrealistic. However, the possibility of a high carbon price points to a need for a mechanism to manage plantation water use.

The uncertainty surrounding the influence of economic and other drivers on the potential increase in carbon sequestration plantations creates a wide range of possible impacts on water availability within the Basin. Under current rates of afforestation, the risk to catchment water yields and stream flow is very low. However, the potential for reduced water availability resulting from large-scale plantation establishment exceeds the projected reduction under the median 2030 climate change scenario in some regions, and presents a significant risk to water resources and ecosystems.

It would be prudent to reassess the conclusions from this study when there is greater certainty regarding the price of carbon.

ABBREVIATIONS

BRS – Bureau of Resource Sciences

CEWH – Commonwealth Environmental Water Holder

CMA – Catchment Management Authorities

CPRS – Carbon Pollution Reduction Scheme

EMI – Environmental Management Incentives

ETS – Emissions Trading Scheme

GGAS – Greenhouse Gas Abatement Scheme

HRZ – High Rainfall Zone

LRZ – Low Rainfall Zone

MAUT – Mutli-Attribute Utility Theory

MCA – Multi-Criteria Analysis

MDB – Murray-Darling Basin

MDBA – Murray-Darling Basin Authority

MNES – Matters of National Environmental Significance

NRM – Natural Resource Management

NWC – National Water Commission

NWI – National Water Initiative

MIS – Forestry Managed Investment Schemes

SDL – Sustainable Diversion Limit's

SEQ CCMP – South East Queensland Climate Change Management Plan

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1 INTRODUCTION

1.1 Background

Afforestation provides potential environmental benefits, including sequestration of atmospheric CO_2 to mitigate greenhouse gas emissions, habitat improvements for biodiversity conservation, soil improvement, and improvements in water quality. Traditional forest plantations also provide economic benefits (Zhang et al 2003; Polglase and Benyon 2009) from timber production and pulp and paper manufacturing. In 1997, the Australian Government released *Plantations for Australia: the 2020 Vision,* produced through a strategic partnership between the Commonwealth, State and Territory Governments and the plantation timber growing and processing industry. Whilst there are sound environmental, social and economic arguments in support of plantation development in selected regions, increased water use through afforestation has raised concerns over the potential for reduced stream flows in parts of the Murray-Darling Basin (CSIRO 2008; Zhang et al 2003; Zhang et al 2007; Hafi et al 2010; Polglase and Benyon 2009).

Increase in water interception by forest plantations can be expected to decrease the volume of water available for downstream use (Hafi et al 2010; Zhang et al 2003). Plantations reduce water availability by intercepting rainfall, which in turn decreases runoff, groundwater flow and soil water storage (Zhang et al 2003; CSIRO 2008). This reduction is likely to significantly affect agricultural activities, town water supply and environmental assets. In some northern catchments, the effects of afforestation on end of system flows are more than three times the reduction in stream flow from climate change alone (Hafi et al 2010).

Converting grassland to forest can have a proportionally greater impact on dry season flows than on mean annual flows, creating adverse effects on ecosystems and users that depend on dry season flows (Polglase and Benyon 2009; Hafi et al 2010). Hypothetically, 10 million hectares of cleared land in the MDB could be converted to forests (Hafi et al 2010), representing a 45% increase in forested area within the Basin. A change of this magnitude may decrease water yield by 13% in addition to effects of climate change by 2050, with end-of-system flow decreasing by 8% as a result of afforestation (Hafi et al 2010). Afforestation may therefore present an additional challenge to government initiatives to increase the availability of water for environmental purposes whilst maintaining economic productivity and social and cultural values. For example, a potential loss of 360 Gl y^{-1} at the Murray River mouth as a result of afforestation, will require a total of 860 Gl y^{-1} to achieve objectives of recovering 500 Gl y^{-1} for the environment (Hafi et al 2010).

For the purposes of this study, traditional forest plantations refer to plantations established for the purpose of commercial harvest for wood products. This practice is distinct from plantations that are established primarily for the purpose of carbon sequestration, and which may or may not be operated on a commercial basis.

This project aims to synthesise the existing knowledge and to identify knowledge gaps and options for future planning and program development in relation to traditional plantation establishment in high rainfall areas, and carbon sequestration afforestation, and their associated potential impacts and benefits within the MDB.

The effects of afforestation on catchment water yields are driven by hydrological processes at multiple scales. The Risk Assessment program conducted by the MDBA has initiated a number of inter-related projects to address these different scales. This project, CP1 addresses the issues arising from changes in area of plantation forestry, drawing on existing information on forest water use, anticipated changes in plantation area, economic drivers, and effects of climate change scenarios adopted by the MDBA. The effects of plantation management on water use by forests and resulting impacts on catchment water yields are addressed in project CP2. Physiological water use by trees at scales ranging from individual plants to forest ecosystems, and the influence of environmental factors on forest water use are the focus of project CP3.

The project has been divided into two parts on the basis of the drivers for traditional afforestation activities in the higher rainfall areas of the Basin, and investigating plantings specifically for carbon sequestration throughout the Basin as a whole. High rainfall areas are considered for the purpose of this project to represent regions which receive at least 600 mm y^{-1} average rainfall (Figure 1). These requirements are addressed in separate sections if this report.

1.2 Objectives

1.2.1 Part A

The objective of this part is to present a review and synthesis of the current understanding of water yield impacts of traditional plantations in the high rainfall catchments of the Basin. This objective is addressed through two principal components relating to water balances and climate change implications, identified as:

1. Collate and synthesise current scientific knowledge on the impact traditional plantations have on catchment water balances, including surface and groundwater, with a focus on high rainfall areas; and

2. Analyse the information in terms of the significance of the water yield impacts to MDB catchments and stream flow, using three climate change scenarios (see below) and taking into account growth projections for the increased establishment of plantations in high rainfall areas.

1.2.2 Part B

The objective of this part of the project is to review and synthesise available knowledge on multipurpose forest, commercial and non-commercial afforestation, in all rainfall areas in the Murray-Darling Basin. The review covers both current and proposed plantations planted specifically to provide carbon sequestration benefits.

Specific objectives are to:

(ii) Achieve a clear understanding of the current scientific knowledge and gaps on the impacts of afforestation for carbon sequestration benefits and the impacts on catchment water balances;

(iii) Identify current legislation and policies in each jurisdiction relating to afforestation for carbon sequestration, with a focus on the water use impacts of these policies;

(iv) Identify current and proposed rates of increase or decline in afforestation types across the MDB, areas which may be most impacted and associated land use changes;

(v) Design a framework and undertake an assessment of the potential impacts, both positive and negative, that afforestation for carbon sequestration is having or will have on a catchment and basin wide scale, under three climate change scenarios. Potential impacts include:

a. Water quality and quantity

b. Salinity management

c. Biodiversity

d. Riparian management

e. All potential impacts resulting from land use change

(vi) Provide advice on how carbon plantings can maximise environmental benefits, including identifying suitable areas for afforestation, and forest management options; and

(vii) Develop options for incorporating afforestation for carbon sequestration benefits into water access entitlement frameworks by 2011.

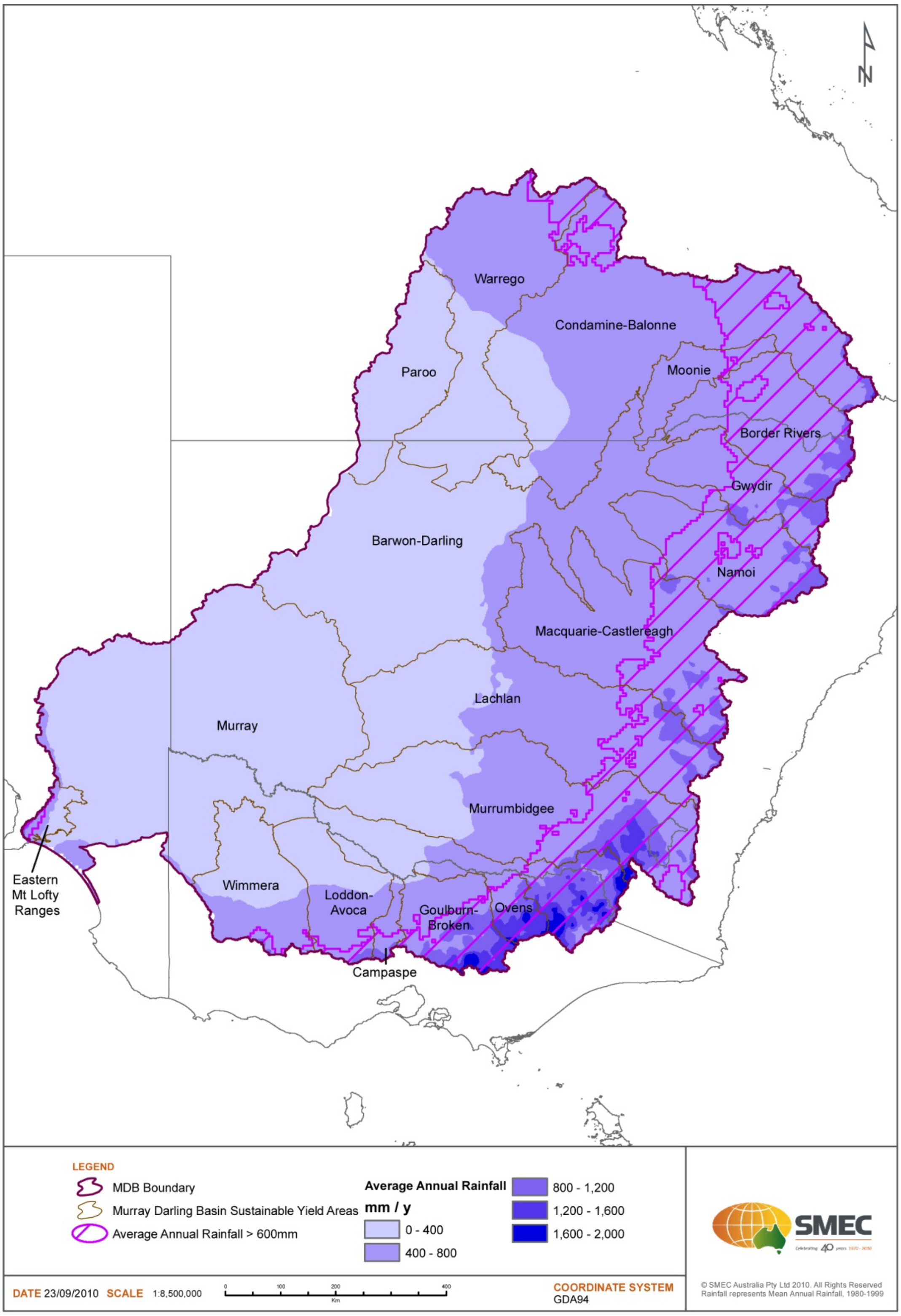

Figure 1 : Distribution of mean annual rainfall in the Murray-Darling Basin.
The hatched region shows the areas receiving over 600 mm y^{-1}, which are defined as the High Rainfall Zone for this project.

2 PROJECT APPROACH

The scientific literature on catchment hydrology, water balance, climate change, and the effects of different vegetation types on stream flow and groundwater is extensive, and has been the subject of several recent comprehensive reviews (eg Vertessy et al 2001; Brown et al 2005; Farley et al 2005; Jackson et al 2005; Benyon et al 2007; Brown et al 2007; van Dijk and Keenan 2007; Zhang et al 2007; Vanclay 2009; McVicar et al 2010). Rather than repeating earlier literature reviews, the approach adopted for this project in consultation with the MDBA involved targeted interviews of leading specialists in relevant technical fields to allow rapid identification of the most pertinent information and informed opinions on the risks posed by expansion of traditional forestry plantations. Recent literature identified through interviews was then summarised to provide documented support for the opinions expressed. This approach also provided for a better understanding of the contemporary issues facing land managers and scientists given the prevailing regulatory environment which inexorably influences decisions in natural resources management.

In consideration of the objectives of Parts A and B (see Section 1.1) and the inter-related nature of elements of both reviews, the interviews sought to address the requirements of both parts where the technical expertise of the interviewee permitted. To this effect, the approach described in the following sections was employed.

2.1 Part A

2.1.1 Task identification

Two primary elements of the interview process were designed to ensure that project outcomes aligned with the objectives set in the brief.

Task A.1: Collate and synthesise impacts on catchment water balances

1. Interview selected leaders from the forestry industry, leading catchment hydrology scientists, and independent thinkers on catchment management and climate change to distil existing information. Emphasis was placed on respondents with current information and detailed knowledge of previous projects, and industry trends, including individuals and organisations identified in consultation with MDBA.

2. Develop standardised questions to ensure consistency, rigour and repeatability, supplemented by additional questioning on responses.

3. Interviews to be conducted by one team of two people.

4. Provide follow-up with respondents via email and telephone to clarify issues and obtain further information as required.

5. Interviews to identify key technical reports supporting views expressed by each respondent.

6. Maintain records of sources of information, geographical areas and different types of forests to assist in identifying knowledge gaps.

Task A.2: Analyse the significance of water yield impacts to MDB catchments and stream flow under various climate scenarios

1. Include climate change scenarios in questions for Task A1.
2. Include questions on changes in forest area and afforestation types in questions to support Part B.
3. Provide report on water yield impacts of traditional plantations in high rainfall catchments in MDB.

2.1.2 Methods

A standardised interview questionnaire (Appendix A) was designed to ensure consistency in questions asked and to guide the discussions constantly in the direction of the project objectives. The questionnaire was created to cover the requirements of both Parts A and B of the project, to minimise the logistical input in follow-up meetings, and to more readily identify common elements and themes between each part. Interviews were conducted by two SMEC personnel during June 2010 and included face-to-face meetings, telephone interviews and emailed responses to the questionnaire.

To accompany the survey questionnaire, two map sheets were prepared to provide a spatial reference for features within the area of interest and to also allow the interviewers to capture the geographical context of specific responses. The land use map was produced using Australian Land Use and Management Classification data published by the Bureau of Rural Sciences[1], and forest plantation data from BRS supplied by the Murray-darling Basin Authority. The rainfall map was produced from mean annual rainfall data published by the Bureau of Rural Sciences (BRS) for the period 1980-1999. The national-coverage rainfall grid data was also transformed into 100mm isohyets and displayed within the context of the Basin.

During interview coordination and liaison with the identified interviewees, a copy of the interview questionnaire and maps was also circulated. This ensured that the intent of the interviewers was apparent and allowed time for the interviewee to gather any relevant sources in advance of the meeting.

Interviews were conducted by two people from different technical backgrounds. Dr Elvira Lanham is a terrestrial ecologist with experience in vegetation management and fauna habitats. David Bannigan is a catchment hydrologist with experience in surface water and groundwater hydrological methods and modelling. Where possible, interviews were conducted by both interviewers.

Hand-written notes taken by the interviewers were later transcribed into a secure online information management tool.

Interview respondents

The respondents in Table 1 were interviewed to contribute to the body of knowledge presented in this report, based on their recognition as leaders in the fields of catchment hydrology, forestry practices and climate change as it relates to afforestation and catchment management.

[1] http://adl.brs.gov.au/mapserv/landuse/

Table 1 : Interview respondents and areas of expertise.

Name	Organisation	Area of Expertise
Prof Damian Barrett	University of Queensland	Landscape hydrology and carbon and nutrient cycling; climate change and greenhouse gas mitigation; and valuing ecosystem services to develop sustainable management practices.
Assoc Prof Leon Bren	University of Melbourne	Forest hydrology and groundwater movement in riparian forests, geometry of stream buffering systems, and impacts of riparian plantings on stream flow.
Kevin Burns	ABARE	Forestry economics and effects of carbon pricing.
David Bush	CSIRO Plant Industry	Forest species selection, domestication of species suited to traditional forestry and environmental purposes including carbon sequestration.
Mark Cotter	Goulburn Broken Catchment Management Authority	Catchment hydrology and impacts of land use on water balances.
Prof David Ellsworth	University of Western Sydney	Ecology and environmental science focusing on the response of forests to climate change.
Ahmed Hafi	ABARE	Agricultural resources and water economics.
Kenton Lawson	ABARE	Forestry economics and effects of carbon pricing.
Greg Lundstrom	SA Murray-Darling Basin Natural Resources Management Board	Project Officer
Gavin Matthew	Australian Plantation Products and Paper Industry Council (A3P) –	Forest management, timber processing industries and forest consultancy. Softwood marketing and merchandising.
Geoff Minchin	Lachlan CMA	Catchment Officer, Partnerships Training & Advisory Services
Dr Nick O'Brien	New Forests	Forestry economics, forestry carbon accounting, investment opportunities in forest management and carbon investment products.
Dr Phil Polglase	CSIRO Sustainable Ecosystems	Forest ecosystem ecology, management of forested catchments; and impacts of climate change on forest functioning including water quality, biodiversity and carbon storage.
Warwick Ragg	Australian Forest Growers Association – represents smaller farm forestry growers	Plantation management, water use by trees, forestry science.
Rhonda Toms-Morgan	Queensland Murray-Darling Committee	Regional Climate Change Officer
Dr Narendra Tuteja	Bureau of Meteorology	Catchment hydrology, forestry effects on hydrology at paddock, hill slope and catchment scales, and effects of climate on catchment water balance, vegetation growth, and recharge-discharge dynamics.
Dr Albert van Dijk	CSIRO Land and Water	Catchment hydrology, interactions between climate and vegetation, and its role in coupling the water and carbon balances.

Climate change scenarios

This assessment considered effects of climate change on catchment water yields for surface water and groundwater, under three standardised climate scenarios adopted for other projects by the MDBA. These scenarios are:

1. A 'most favourable 2030 scenario' that is based on a continuation of the long-term (1895 to 2006) averages for rainfall and runoff across the MDB;

2. A 'medium 2030 scenario' that is based upon the medium global warming scenario and associated rainfall and runoff described in the CSIRO report "Water Availability in the Murray–Darling Basin" of October 2008; and

3. A 'least favourable 2030 scenario' that is based upon the actual climate of the MDB in the period 1997-2006 (this includes 15% less rainfall and 50% less runoff in the southern MDB when compared with the long-term average).

Synthesis of results

Responses to interviews were combined with key references to develop a synthesis of all available information, drawing together disparate views expressed by different sectors to present a cohesive analysis of pertinent published information and expert opinion.

2.2 Part B

2.2.1 Review current scientific knowledge and gaps on the impacts of afforestation for carbon sequestration

Selected leaders from the forestry industry, leading catchment hydrology scientists, and independent thinkers on catchment management and climate change were interviewed to distil existing information. Standardised interview questions were developed to ensure consistency, rigour and repeatability, supplemented by additional questioning on responses. Interviews were conducted by one team of two people. Respondents were followed up via email and telephone to clarify issues and obtain further information as required. Interviews also identified key technical reports that supported views expressed by each respondent.

2.2.2 Review of legislation and policies in each jurisdiction relating to afforestation for carbon sequestration

A comprehensive search of legislation and policy in each State, Territory, and Commonwealth jurisdiction was undertaken to identify guidelines with explicit, or implicit, implications for afforestation for carbon sequestration, and potential effects on water use and availability.

2.2.3 Assessing rates of change in afforestation by region in the MDB

Following on from the legislation and policy review, each Catchment Management Authority or Natural Resource Management group in the MDB was contacted to obtain information on regional plantation activities and trends, including:

- Area currently under plantation forestry in their catchment (if known);
- Area of plantation that is primarily intended for carbon sequestration;
- Commitment to, or interest in future carbon sequestration plantings; and
- Availability of funding for carbon plantings.

This information was supplemented by responses from interviews where interviewees were aware of specific initiatives.

2.2.4 Potential effects of afforestation for carbon sequestration at catchment and Basin-wide scales, under three climate change scenarios

A vulnerability assessment framework was developed and applied to consider the exposure of each sustainable yields region to afforestation for carbon sequestration, sensitivity of each region to impacts of plantations, impacts expected, adaptive capacity, and resulting vulnerability. Vulnerability was determined for water quantity, water quality, salinity, biodiversity, and riparian management, as well as for the combined assessment of positive and negative effects. Assessments were completed for a total of 12 scenarios, covering three climate change scenarios, high and low afforestation scenarios, and high and low scenarios for stream flow and other factors to develop relative scores that allowed regions to be ranked qualitatively according to the magnitude and likelihood of potential benefits and impacts.

2.2.5 Maximising environmental benefits of carbon plantings

Results of previous sections were integrated to consider ways to maximise the environmental benefits of carbon plantings, and to identify potential decision support tools to assist in designing carbon plantations across a range of spatial and temporal scales.

2.2.6 Options for including afforestation for carbon sequestration benefits into water access entitlement frameworks

Existing water entitlement frameworks were reviewed briefly in view of the identified potential impacts of plantations, area planted to deliver carbon sequestration benefits, and existing legislation and licensing arrangements in the Murray-Darling Basin jurisdictions. Several options were developed, based on existing and novel approaches, to include water use by carbon sequestration plantations in water access entitlements in the Murray-Darling Basin.

PART A

EFFECTS OF TRADITIONAL FOREST PLANTATIONS ESTABLISHED FOR WOOD PRODUCTS

3 CATCHMENT WATER BALANCES

3.1 Water use by traditional forest plantations

Traditional forest plantations have been identified as having the potential to intercept increased quantities of water compared to pasture or grasslands. This has caused concerns that expansion of forestry activity may reduce water availability in the Murray Darling Basin.

There is strong evidence that trees use more water than grasslands or crops, resulting in lower stream flows. Higher water use by trees is attributable to a number of factors including:

- Deep root systems which are able to draw moisture from deeper in the soil profile;
- Longer growing cycles;
- Higher absorption of radiation, given sufficient canopy area; and
- Higher interception of rainfall.

Evapotranspiration is the dominant process of the water cycle in vegetated catchments. Water that is not lost to evapotranspiration is available for stream flow and groundwater recharge. Zhang et al (1999) used the results of worldwide water balance studies in more than 250 catchments to develop generalised curves showing the comparative relationship between rainfall and evapotranspiration for forests and grassland (Figure 2).

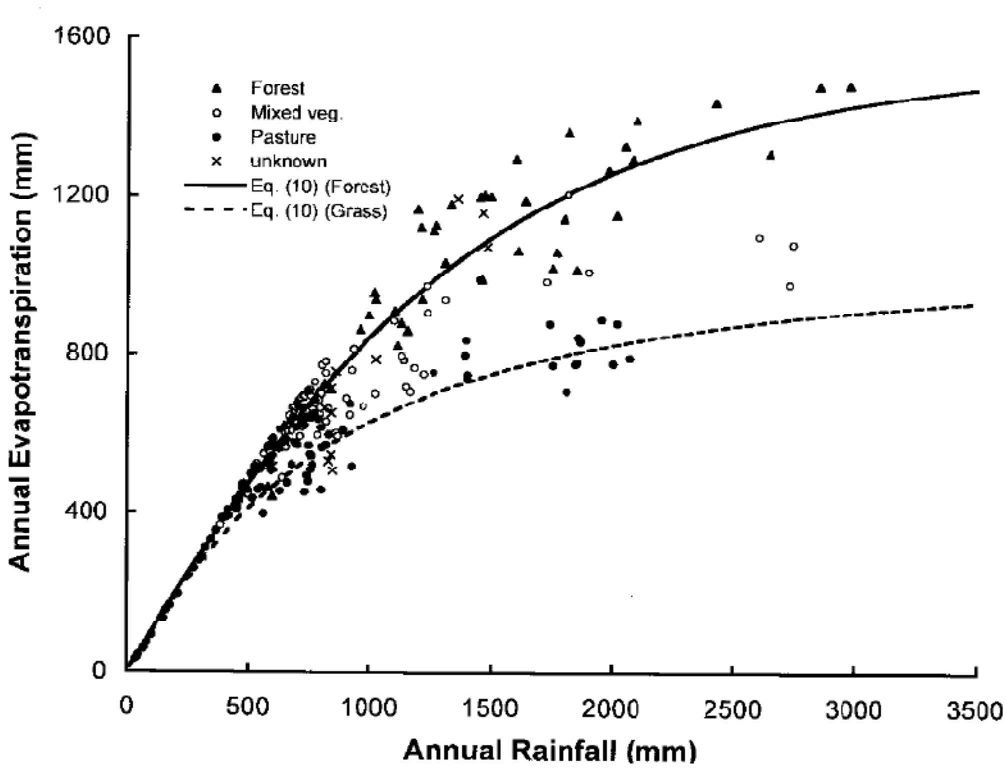

Figure 2 : Relationship between annual rainfall and evapotranspiration or catchment water yield for forest and grass vegetation cover.
Actual conditions for individual catchments vary depending on density of grasses and trees, and the mix of vegetation types (Zhang et al 1999).

These relationships have been extensively applied to water balance investigations to predict the potential effect on water availability of conversion from pasture to plantation forestry. In cleared sub-catchments with annual rainfall of 1000 mm converted to 100% plantation cover, Zhang curves predict a 213 mm reduction in water yield from runoff and groundwater. However, the variability reflected by the scatter of data points about these curves highlights site specific factors that can alter the relative differences between grass and forest. In some instances grass may have higher evapotranspiration than forest for a given rainfall depth. Actual differences in water use between plantation forests and grassland are influenced by many factors, including land management practices (Benyon et al 2007).

Access to groundwater can increase evapotranspiration significantly. Field studies in Victoria have shown that where trees have access to groundwater, mean evapotranspiration was 1093 mm y^{-1} compared to 585 mm y^{-1} predicted by the Zhang curves (Figure 3) (Benyon and Doody 2004).

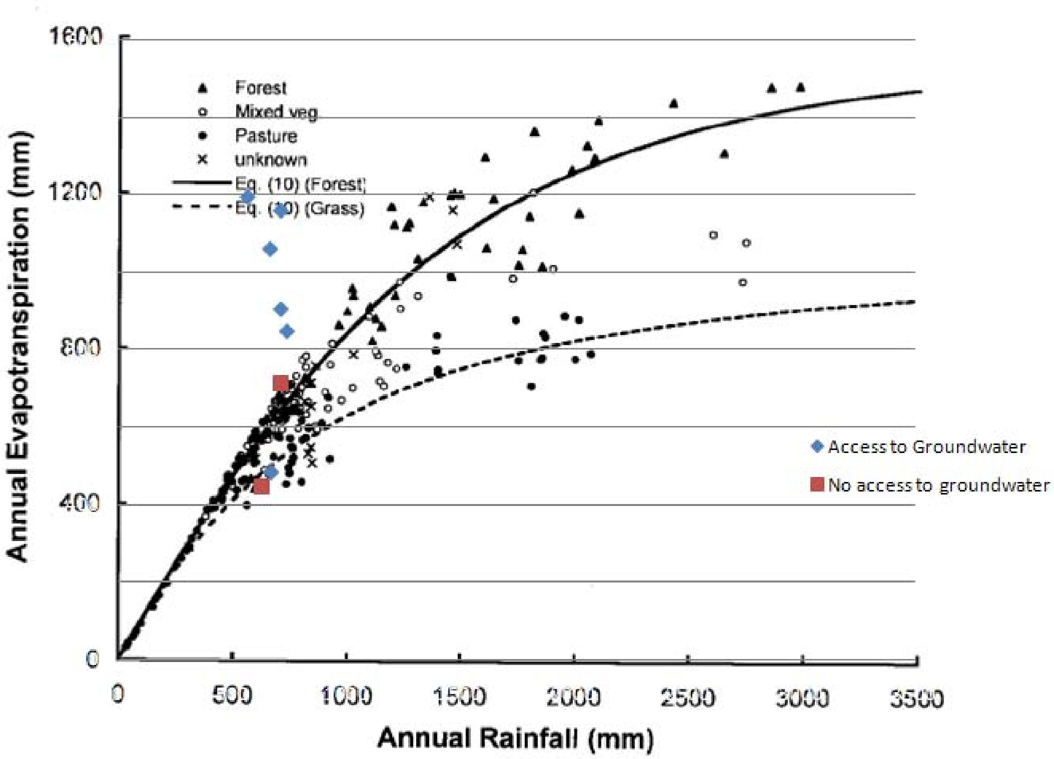

Figure 3 : Effect of groundwater access on evapotranspiration.
Blue symbols show evapotranspiration of plantations with access to groundwater superimposed on Zhang curves, compared to red symbols reflecting plantations without access to groundwater (Zhang et al 1999; Benyon and Doody 2004).

Benyon et al (2007) found that the Zhang curves are reasonably accurate as point estimates when averaged over a number of sites under conditions where there are deep soils, gentle slopes and where rainfall is the only source of water. The curves have been derived mainly from mature forests with canopy cover greater than 70%. In plantation scenarios, the average water use would be expected to be lower than predicted by the Zhang curves as water use is lower than average in the early years of the growth cycle (Benyon et al 2007).

Parsons et al (2007) point out that it is difficult to reliably detect the effect on runoff of conversion to plantations if the reforested area is less than 15 to 20% of the catchment area in smaller catchments. In larger catchments the threshold may be lower but is dependent on variations in rainfall and runoff and other land use factors in the catchment. Tuteja (2006) predicted changes at the 10% level, based upon stream flow measurements in catchments containing large-scale pine plantations in the Snowy Monaro region in south eastern New South Wales.

While most research on water use by plantations has focussed on small scale paired catchment studies, Tuteja et al (2006) examined the effect of large-scale pine plantations within large subcatchments in the Snowy Monaro region. The study area covered rainfall zones ranging from less than 600 mm to in excess of 900 mm annual rainfall. Study sub-catchment areas ranged from 187 km^2 to 7135 km^2 with levels of plantation development varying over time. The plantations were located with areas that previously included both pasture and native woody vegetation. This study found strong evidence of a reduction in flows in the Snowy River resulting from plantation expansion over the period 1960 to 2000 (Table 2). Changes in runoff, standardised to 10% of the catchment converted to plantation (Annual Yield Impact - AYI/10%) ranged from 14.3 to 19.2 mm y^{-1}, with total reductions in the range of 22 to 52 mm y^{-1} (Tuteja et al 2007).

Table 2 : Summary of plantation water balance impacts in Snowy Monaro region. (Tuteja et al 2006).

Catchment Area	Catchment Area (km^2)	Annual Rainfall (mm)	Observed Runoff	Area Under Pines (km^2)	AYI/10% (mm y^{-1})
Delegate	1136	859	134	159	15.7
Little Plains	614	859	146	127	14.3
Bombala	563	783	199	151	19.2

Polglase and Benyon (2009) noted that the effect of plantations on available water at a whole of basin scale is negligible because plantations typically occupy only a very small percentage of the total basin. However at local scales, down to less that 100 km^2 plantations may occupy the majority of the catchment and their impacts on available water locally are more noticeable. This effect is shown clearly in a review by Andreassian (2004), who showed an increasing reduction in annual runoff as the afforested area of catchments increased from 0% to 100% (Figure 4). It is worth noting the large variation about this trend, with some catchments with 100% afforestation showing no reduction in runoff. Catchments that are 100% afforested tend to be small in area, compared to entire catchments in the Murray-Darling Basin where the area of plantations ranges between 1.5% and 4.0% of catchment area (BRS 2009).

There is extensive literature demonstrating that deforestation leads to increased catchment water yields, and that afforestation decreases water yield. However, Eamus (2009) provides three critical caveats. Firstly, variability in responses to afforestation is huge, and reliance on mean responses can be grossly inaccurate. The corollary to this caveat is that models that represent mean conditions without accounting for stochastic variability may be misleading. Secondly, the effects of changes in forested area vary according to the rainfall received each year, and in dry years the effect of increasing forested area can be close to zero. Finally, the effects of changes in forested area on water yield change substantially over time according to the age of the plantation and changes in species composition.

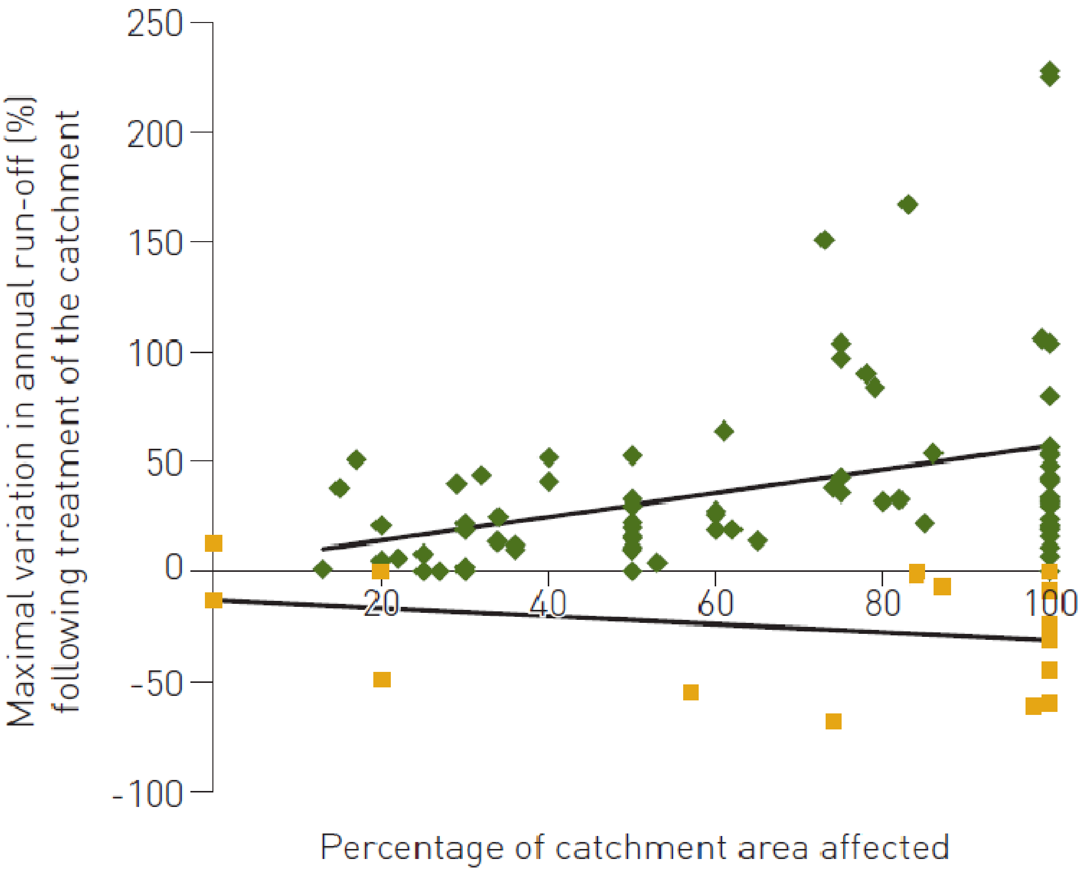

Figure 4 : Changes in runoff following afforestation and deforestation in relation to area of catchment. (from Eamus 2009, after Andreassian 2004).

3.2 Summary of expert opinions on water balances

Current scientific knowledge on the effects of traditional forestry plantations on catchment water balances including surface water and groundwater, in the Murray-Darling Basin is summarised from interview responses in Table 3. Opinions presented are derived from the interview questionnaire included in Appendix A.

3.3 Impacts of plantation forestry on catchment water balances

Water use by forest plantations has been reviewed in detail over the last decade (eg Vertessy et al 2001; Zhang et al 2003; Brown et al 2005; Farley et al 2005; Jackson et al 2005; Marcar et al 2006; Benyon et al 2007; van Dijk and Keenan 2007; Zhang et al 2007; Polgalse and Benyon 2009). Empirical and modelling evidence that use of water by trees can affect catchment water yields and stream flows is compelling. However, interpretations of available data, assumptions involved, and the reliability of scaling empirical and modelling results to different catchment units have triggered differing opinions about the significance of impacts of plantations. Projections of future expansion in plantation area, from large-scale expansion to minimal changes from current conditions, therefore have potential to generate substantial debate regarding the magnitude of future impacts, and the risks posed by traditional forestry plantations to catchment water supplies.

Existing plantations account for only a small proportion of total land use (Table 4), with a maximum value of 4% in the Murrumbidgee catchment. In contrast, native forest cover ranges between 21.7% in the Lachlan, Macquarie-Bogan catchments combined and

Table 3 : Summary of opinions on effects of plantations of catchment water balances.

Issue	Synopsis of opinion
Understanding of current scientific knowledge of the effects of traditional forestry plantations on catchment water balances, with regard to both surface water and groundwater	▪ Plantations represent a small proportion of land use in the MDB, covering only 0.4% of the entire Basin. Mean plantation cover in forested catchments is 2.6%. ▪ Effects of plantation forestry on stream flow in high rainfall zones within MDB are highly localised. ▪ Magnitude of effects diminishes with increasing distance downstream as the percentage of catchment covered by plantations decreases. ▪ In high rainfall zones, most forestry is located on hill slopes away from groundwater aquifers and effects on groundwater are less than effects on surface water. ▪ Plantations may have positive effects on quality of surface water and groundwater. ▪ Forest water use is well understood at the plantation scale, but variability in observed responses, and changes in response over time, create a high level of uncertainty when translating results to the catchment scale. ▪ Current approaches to forest water use do not account for atmospheric coupling between evapotranspiration and precipitation, and the effects of afforestation and deforestation on the distribution of rainfall.
Water balance distinctions between softwood and hardwood plantations	▪ Plantation management has a larger influence on water use than tree type. Hardwoods have short rotation times (10-12 y versus up to 30 y in softwoods) and a greater proportion of rotation is in high water use phase, so that hardwood plantations tend to have a greater effect on catchment water yields over multiple rotations. ▪ Differences in water use between softwood and hardwood plantations are relatively small compared to difference between grassland and forests. ▪ Softwoods tend to use slightly more water in early stages of growth, and have higher interception rates.
Water balance effects of plantations in cleared land as opposed to plantations among native forest	▪ National policies largely prohibit clearing native forest for plantations. ▪ Conversion of cleared land to plantation forestry typically results in reduced catchment water yield. ▪ New plantations have high water consumption in early stages, reaching a maximum at 10-20 years and diminishing as trees mature. Pasture water use is more uniform over time. ▪ While transpiration is higher for forestry, evaporation from the soil may be reduced by forest shading and wind reduction.
Principal factors that determine plantation effects on water yields	Plantation effects on water yield are influenced by: ▪ The baseline condition land use – (native forest or cleared land) ▪ Plantation growth rate and plantation age ▪ Management practices eg rotation times, plantation design, thinning, use of fertiliser ▪ Topography and soil types ▪ Rainfall depth and seasonal distribution ▪ Presence of groundwater aquifers ▪ Location and size of plantation ▪ Climate variability
Projected change in forestry plantation area in high rainfall zones in the Murray-Darling Basin	▪ Expansion of plantations by 5-15% by 2020 is considered as aspirational. Maintenance of existing area is more realistic. ▪ Earlier expansion targets of 52,000 ha (18%) by 2030 are now considered to be unrealistic. ▪ The 2020 vision to treble the area of plantation forestry is considered to be

Issue	Synopsis of opinion
	unrealistic. ▪ The long-term financial outlook, costs of acquiring land, and potential incentives (eg a carbon price) exert a strong influence on the potential for expansion.
Which areas in the Murray-Darling Basin are likely to support large-scale expansion in forestry plantations	▪ Large-scale expansion is unlikely. ▪ Earlier projections of possible increases by 2030 of 33,000 ha in the Upper Murray, 17,000 ha in the Murrumbidgee and 2,000 ha in the Eastern Mt Lofty Ranges regions are ambitious under foreseeable economic conditions.
Effect of economic issues such as land values and profitability of alternative land uses such as cropping and grazing, on potential growth of forestry plantations	▪ Removal of incentive schemes for forestry has resulted in a rationalisation of the industry and collapse of major companies. ▪ Future introduction of a carbon trading scheme may increase the viability of traditional plantations. ▪ Population growth and climate change may increase global demand for food production, resulting in higher agricultural land values and reduced opportunities for forestry expansion. ▪ Integration of plantations with other land uses may yield better outcomes in future for smaller landholders.

68.1% in the Upper Murray catchment. Agricultural land use ranges from 27.1% in the Upper Murray to 73.9% in the combined Lachlan and Macquarie-Bogan catchments.

Based on proportional catchment area, native forest and agriculture exert a much greater effect on runoff and stream flows than plantation forests, and even an estimated 18% expansion in plantation area (CSIRO 2008) will have a minimal effect on the proportion of catchment area covered by forests. At the Basin scale, plantations account for 0.4% of the total area. When water use by plantation forests is considered at this scale, changes in catchment water yield as a result of increases in plantation area are likely to be small.

Traditional forestry plantations are mostly located in regions with over 800 mm annual rainfall, with only 5% of the current 284,000 ha of plantations receiving less than this amount (Figure 5) (Zhang et al 2007).

3.3.1 Understanding of current scientific knowledge

Impacts of forestry plantations on catchment water balances depend on a number of factors operating at different scales, ranging from tree physiology at the scale of individual plants through to forest ecosystems; plantation management practices; and catchment-scale hydrological processes that integrate the above processes with climatic and atmospheric processes.

While the Zhang curves show the general effects of conversion from pasture to forest, many site-specific factors influence the degree of impact on the water balance (Table 5). Of all factors listed, access to groundwater by plantations located at the bottom of hill slopes has the greatest influence on total plantation water use (Polglase and Benyon 2009).

Table 4 : Land use in catchment areas with above 600 mm y^{-1} mean annual rainfall. (Based on plantation areas as at 2005, BRS 2009).

Catchment	Land use proportion of catchment %			
	Plantations	Agriculture	Native forest	Other uses
Lachlan, Macquarie–Bogan	1.5	73.9	21.7	3.0
Murrumbidgee	4.0	53.8	40.0	2.2
Upper Murray	2.5	27.1	68.1	2.5
Goulburn, Broken, Ovens, Kiewa	2.2	43.1	52.9	1.8

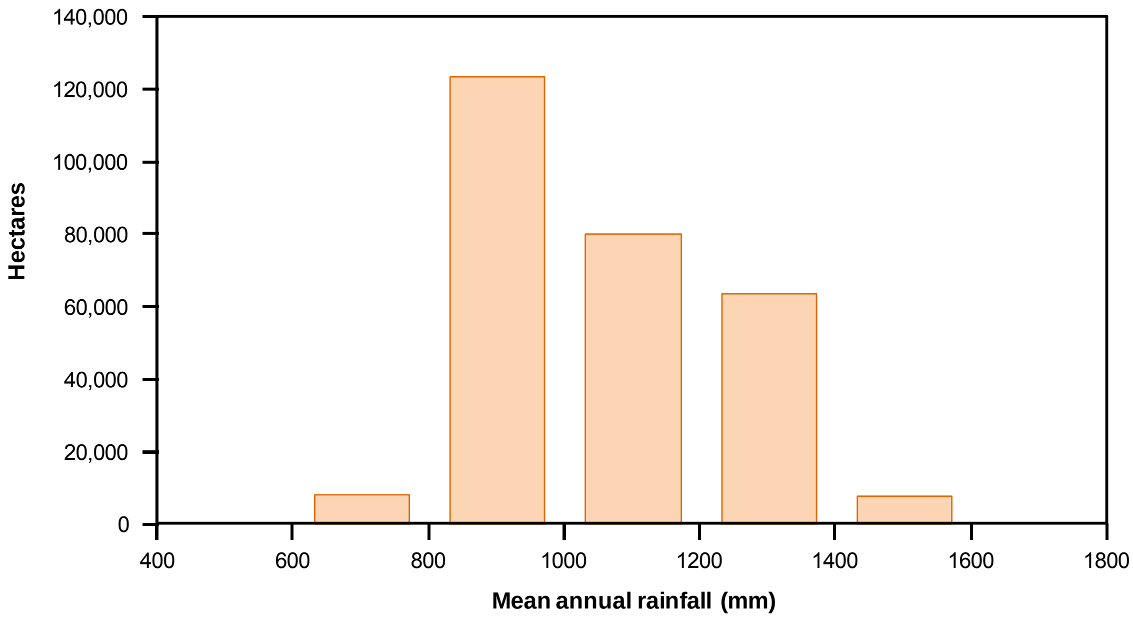

Figure 5 : Distribution of commercial forestry plantations in the Murray-Darling Basin in relation to mean annual rainfall.
(after Zhang et al 2007).

Table 5 : Factors affecting water use by Eucalyptus globulus plantations.
Assuming rainfall of 700 mm y^{-1}, baseline plantation water use of 610 mm y^{-1}, and grassland water use of 520 mm y^{-1} (Benyon et al 2007). Estimates are indicative and should be used with caution.

Component or management practice	Water use or change in water use (mm)	Estimated contribution to plantation water use
Mean Annual Rainfall Plantation water use (evapotranspiration) Grassland water use (evapotranspiration) Average difference in water use (plantation – grassland)	700 610 520 90	100%
Plant-available water ▪ Deep soil ▪ Shallow soil	+50 -60	8% -10%
Rainfall season ▪ Summer ▪ Winter	+50 -20	8% -3%
Aspect with greater slope (assuming same soil) ▪ Northerly ▪ Southerly	+50 0	8% 0%
Soil nutrient status ▪ High ▪ Low	+40 -40?	7% -7%
Rotation length ▪ Longer ▪ Shorter	+30 -30	5% -5%
Spacing ▪ Close ▪ Wide	+? -?	? ?
Thinning ▪ Unthinned ▪ Thinned	0 -40?	0% -7%
Forest health ▪ Good ▪ Poor	0 -40	0% -7%
Landscape position (assuming same soil) ▪ Bottom of slope (groundwater access) ▪ Top of hill (no groundwater access)	+450 0	74% 0%

Water use over time varies depending on the forest age. Mountain ash *Eucalyptus regnans* forests in Victoria demonstrate the decline in catchment water yields as forests regrow up to approximately 40 years of age, followed by a progressive increase in water yield in old growth forests (Kuczera 1985). The variability about this relationship is, however, extremely large (Figure 6) (Zhang et al 2007). More recently, Wood et al (2008) demonstrated that water use by mountain ash is much more constant that this figure suggests, and that the decline and increase in runoff reflects the establishment and decline of the forest understorey species as mountain ash forest regenerates.

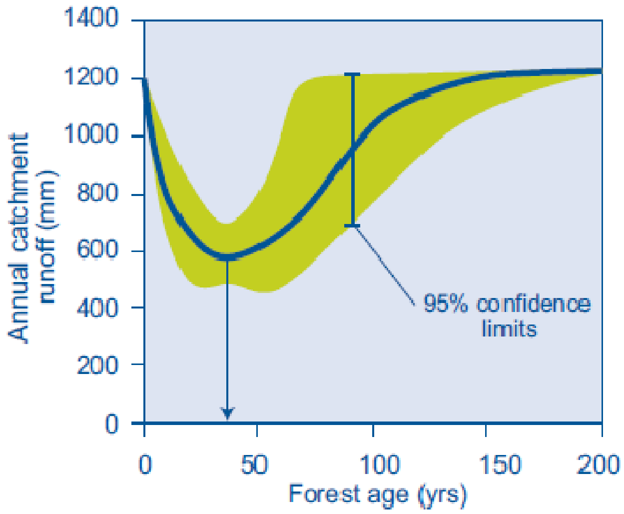

*Figure 6 : Changes in catchment runoff over time in a pure stand of mountain ash forest.
In old growth forests runoff is similar to that during early regrowth. (From Zhang et al 2007, after Kuczera 1985).*

Forrester et al (2010) studied transpiration in blue gum *Eucalyptus globulus* plantations in south-eastern Australia and found a linear relationship between leaf area index and transpiration. Transpiration increased from 0.4 mm d^{-1} at 2 years of age to 1.6 to 1.9 mm d^{-1} at 7 years. There was a decline in transpiration rates after 7 years to 1.1 mm d^{-1}.

Vanclay (2009) also suggests that some of the observed time dependent changes may be attributable to land management practices rather than specific effects of plantation establishment. For example, plantation management modifies the soil to minimise runoff compared to other land uses that may reduce infiltration by compacting soils (Trimble and Mendel 1995; Hamza and Anderson 2005).

Predictive land use models have been developed and successfully validated against field measurements in case studies to model changes in yield associated with plantation forestry. For example, studies in the Goulburn-Broken (Zhang et al 2003), Murrumbidgee (Brown et al 2007) and Macquarie (Herron et al 2002) catchments have estimated large scale changes in downstream water availability following increased plantation areas upstream. However, application of models to predict the likely effects of forests is not always reliable. In particular, models developed from small scale paired catchment studies may significantly overestimate yield reductions when applied to larger scale catchments (Vanclay 2009; A van Dijk pers comm). Furthermore, models that do not consider atmospheric coupling between evapotranspiration and precipitation may provide unreliable results at large spatial scales (Makarieva et al 2006; Gordon et al 2008; Vanclay 2009).

The effect of traditional plantation forestry on stream flow in the high rainfall zones is localised, and the basin wide impacts of plantation forestry appear to have been overstated, given the small areas occupied by plantations at the basin scale (Polglase and Benyon 2009). The magnitude of plantation effects on the catchment water balance diminish as the percentage of catchment area covered by plantations decreases (Andreassian 2004). In catchments where plantations provide 100% land cover, reductions in runoff range from 0% to over 50%, whereas in catchments with close to zero afforested areas, changes in runoff may range from approximately +10% to -10%. In practice, these results may be confounded with catchment size, as 100% afforestation with plantations is only feasible in relatively small catchments. Using the Murrumbidgee catchment as an example, Polgalse and Benyon (2009) report 2% of the catchment area as occupied by plantations. At finer catchment scales less than 1000 km^2, plantations may occasionally cover 20% of the catchment, whereas in small sub-catchments less than 100 km^2, plantations may cover 80-90%, and at this scale impacts on water yield can be significant. Estimated maximum reductions in mean annual stream flow as a result of increased plantations in tributary catchments of the Murrumbidgee River ranged from 1.4 % to 23.3%, with most reductions less than 8% (Brown et al 2007).

Approximately 40% of stream flow in the Murray-Darling Basin is generated from the upland high rainfall catchments in northeast Victoria (Benyon et al 2007) that occupy only 2% of the basin. Hence land use changes in this 2% would potentially have a greater effect on end-of-system flow than changes of an equivalent scale in other regions.

Plantation forests will extract groundwater locally where available. In the high rainfall zones, most forestry is located on hill slopes away from groundwater aquifers and groundwater impacts are therefore less significant than surface water impacts (Polglase and Benyon 2009). For example in similar rainfall zones in South Australia, blue gum plantations where the water table depth exceeded 6 m used 612 mm y^{-1}, whilst plantations above water tables less than 6 m deep used 1059 mm y^{-1} (Polglase and Benyon 2009). Equivalent water use for radiata pine *Pinus radiata* plantations was 661 mm y^{-1} where the water table depth exceeded 6 m, and 985 mm y^{-1} for plantations above water tables less than 6 m deep.

Groundwater use by plantations has potential to intercept base flow in small tributaries, leading to drying of the stream during periods of low rainfall (Figure 7). The resulting changes from perennial to ephemeral stream flow may have significant implications for the stream habitat templates that determine the species composition of ecological communities that inhabit small streams in forested catchments. However in larger catchments, the effects of plantations on dry season low flows are typically smaller because of the more stable base flow from multiple tributaries without plantations.

In Goulburn-Broken catchment, planning focuses on wide water quality issues, and plantations are planned where they are likely to have the largest positive influence on water quality and smallest reduction in stream flow (M Cotter pers comm). Planting is avoided in areas that are likely to have a higher impact on surface water flow, such as toward the bottom of slopes and along stream lines. High impact areas identified from current land use, topography, position of plantations within the catchment and height of the water table as modelled in Zhang et al (2003) and discussed in Parsons et al (2007) are avoided in plantation planning to minimise effects on stream flow. However, tradeoffs are commonly required to maintain riparian buffer zones to protect stream habitats and to maintain water quality, against the requirement to minimise effects on stream flow.

The Zhang curves indicate that for practical purposes, water use by forests is similar to that of cleared land in low runoff regions where annual rainfall is less that 600 mm. However, comparison of modelling results with stream flow data indicates that the similarity in runoff from agricultural land and forested land may actually extend to areas with precipitation rates of 600–1000 mm y^{-1} (van Dijk et al 2007), suggesting that reforestation in these regions would have a limited effect on stream flow. This somewhat unexpected result was attributed to agricultural land generating less runoff than expected. As a result of this analysis, the estimated reduction in total surface water availability in the Murray-Darling Basin due to plantation expansion was estimated at <0.3% by 2020 (van Dijk et al 2007), and plantation expansion was only predicted to alter flow regime in catchments smaller than 2000 km^2.

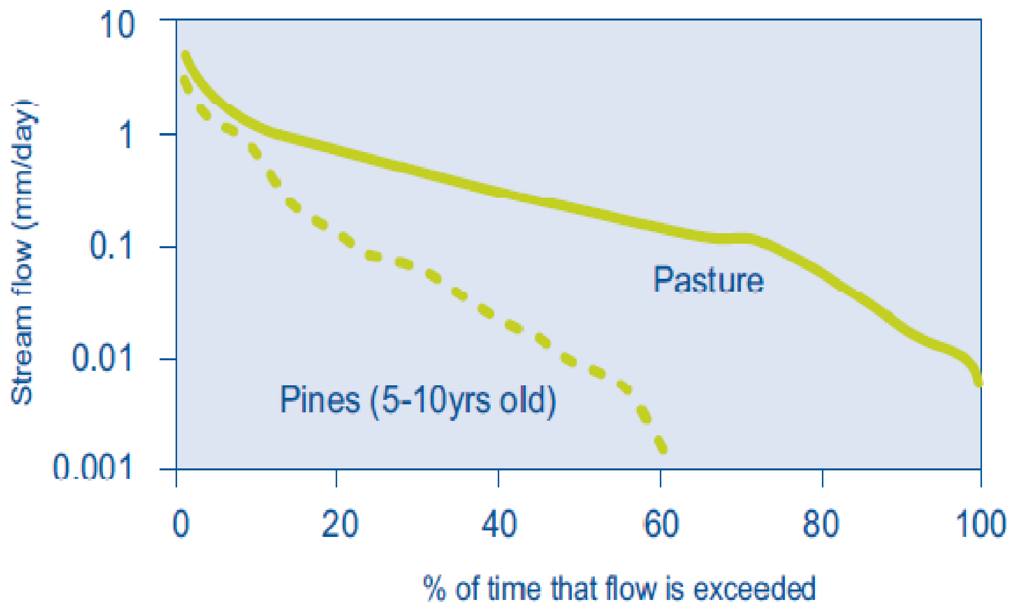

Figure 7 : Flow duration curves for two similar streams near Tumut in New South Wales.
The stream with a catchment dominated by pine plantations only flows for 60% of the time, whereas the nearby catchment with pasture vegetation flows year-round. The two streams have similar flow during high flow events (Zhang et al 2007).

3.3.2 Softwood and hardwood plantations

Intrinsic differences between hardwood and softwood trees are less important than the impacts of forestry practices used for each type of wood. In Australia most hardwoods are used for pulp and have a rotation time of 8-12 years, while softwood rotations are usually 20-30 years (BRS 2009). Differences in water use between the two types of wood are related to differences in rotation times and forest maturity between softwood and hardwoods rather than the water use characteristics of specific tree types (D Bush pers comm).

Rainfall interception is generally higher in softwoods compared to hardwoods. Crockford and Richardson (2000) found differences in interception between softwoods and hardwoods of up to 3 mm per rainfall event. It is difficult to draw definitive conclusions about interception rates of particular forest types because interception is strongly influenced by nature of rainfall and other meteorological conditions at the time of measurements (Crockford and Richardson 2000).

3.3.3 Plantations in cleared land and among native forest

Plantations grown in previously cleared land generally reduce surface water runoff as described by the Zhang curves, and use more groundwater by accessing soil moisture with their deeper root systems. However, the differences in water use between plantations and grasslands are relatively small in areas with rainfall below 600 mm y^{-1} (Parsons et al 2007). Both positive and negative effects on water balance were identified. Intercepting activities such as forestry generally result in reduced availability of surface water or groundwater (Polglase and Benyon 2009), however water quality can be improved (eg deep rooted vegetation can reduce salinity of groundwater) (van Dijk et al 2007).

Effects of plantations on salinity in streams do not necessarily conform to popular expectations of reduced salinity. Changes in salinity depend on surface flow and groundwater flow rates. If plantations intercept fresh surface water in locations where groundwater is saline, then a reduction in freshwater flushing will result in an increase in riverine salinity. Conversely, where salinity in-stream is derived from saline surface water or shallow aquifers, plantation water use may provide effective interception to prevent salt entering the stream. Extensive guidelines have been developed to assist landholders and forestry managers to determine plantation strategies to achieve the best outcomes for salinity (Stirzaker et al 2002; Robins 2004). Other water quality studies in south-east Queensland have found median suspended sediment concentrations in forested catchments were 30% lower than in grazed catchments, while phosphorus concentration was 57% lower, and nitrogen concentration 29% lower in streams with forested catchments (Chiew et al 2002).

Comparing modelled projections with stream flow observations in the Murray-Darling Basin indicated that actual reductions in stream flow were smaller than predicted from paired catchment tests (van Dijk et al 2007). Furthermore, in areas with 600 to 1000 mm y^{-1} rainfall, runoff from agricultural land was very similar to runoff from forested land, indicating that afforestation in these regions would have limited effects on stream flow. These authors estimated the reduction in surface water resources across the basin resulting from future plantation expansion as <0.3% by 2020. The reasons for this smaller than expected impact on stream flow is unclear but it may be that afforestation at a larger scale has some compensatory effects. For example deeper roots may extract more groundwater but shading by the forest canopy and wind reduction at ground level may reduce evaporation from the soil (Vanclay 2009). However, it may just be that if forestry takes up less than 20% of the catchment, the impact on stream base flow is difficult to detect at that scale (Benyon et al 2007).

Where plantations are located among existing native forests within catchments, the greater similarity in water use between plantations and native forest, compared to cleared agricultural land, is likely to result in little difference in catchment water yields for most practical purposes.

3.3.4 Plantation effects on water yields

Principle factors that determine water use by plantations have been presented in Table 5, with the location of plantations on hill slopes and consequent access to groundwater accounting for up to approximately 74% of water use in blue gum plantations (Polglase and Benyon 2009).

Other contributing factors include the baseline land use condition and whether the plantation is replacing deep-rooted vegetation such as native forest or cleared land planted with crops or pasture grasses that have shallower roots and shorter growing seasons (Parsons et al 2007).

Plantation growth rate and plantation age also affect water yields as described by Kuczera (1985), with plantations up to 5 years old, and old growth forests resulting in twice the stream flow compared to forests that are 20-50 years old (Benyon et al 2007). In addition, only a proportion of plantings are drawing their peak water requirements at any one time because of differences in tree age during the production cycle. Staged plantings therefore result in impacts on water yields by plantations being less than projections based on Zhang curves. Average water use by pine plantations over the full production cycle is closer to 70% of peak water use (Pratt Water 2004).

Changing plantation practices will also significantly reduce effects on water yields. Most existing pine plantations in Australia were established on large areas of public land, which concentrate plantation water use within catchments and tend to maximise effects on water yields. More recently, however, new plantations in the last 10 years tend to be spread in blocks that cover smaller proportions of subcatchments (Parsons et al 2007). This practice is likely to have the effect of dispersing the effects on water yields over a larger area of the catchment for a given level of plantation water use, resulting in reduced impacts on individual subcatchments.

Different tree species vary greatly in their water use, and in their susceptibility to factors that influence water use. For example, a dry sclerophyll eucalypt forest intercepted between 5% and 9% less water than an adjacent pine plantation, and interception by the eucalypts was much more variable among rainfall events than in pine plantations (Crockford and Richardson 1990). Similar differences have been reported between blue gum and radiata pine plantations (Benyon and Doody 2004). Water use by a wide range of *Eucalyptus* species tends to be constant per unit leaf area depending on water availability (Hatton et al 1998), so that observed differences between species reflect a combination of conditions that determine leaf area index, and preferred growing conditions. Leaf area index itself is closely related to long-term water availability.

Estimates of plantation effects on water yields vary widely, with many studies adopting modelling approaches to estimate reductions in water yield under hypothetical plantation scenarios. For example, Zhang et al (2003) estimated water yield reductions in the Goulburn-Broken catchment based on three scenarios involving blue gum plantations: (i) 100% plantation cover in suitable areas for forestry; (ii) 50% plantation cover in high suitability areas and 25% cover in moderately suitable areas; and (iii) 10% plantation cover in suitable areas. The maximum plantation area in scenario (i) resulted in a projected 21% catchment forest cover upstream of Goulburn Weir, and a predicted 14% reduction in mean annual flow. Scenario (ii) provided 5.8% catchment forest cover above Goulburn Weir and a projected 4% reduction in stream flow. Scenario (iii) resulted in a 2.1% forest cover above Goulburn Weir, with a 2% reduction in water yield. The two higher plantation scenarios were considered to be unrealistic for plantation growth, with the lower conversion scenario representing a more likely future condition.

As described previously, actual reductions in stream flow and water yield tend to be less than predicted results from catchment modelling (van Dijk et al 2007; Polglase and Benyon 2009; Parsons et al 2007), partly because of the unreliability of scaling results up to larger catchment scales, and propagation of errors in models. Another consideration is that adoption of scenarios that overestimate plantation expansion provide maximum impact projections that, in turn, greatly overstate potential risks to water yields.

Based on projections for plantation area by BRS, CSIRO (2008) estimated that water use by plantations across the whole Murray-Darling Basin accounted for approximately 0.1% of inflows, and 0.6% of end-of-system flows under historical climatic conditions. When translated to individual catchments, plantation effects on end-of-system flows were 0.4% in the Murray and Murrumbidgee catchments, and 2.5% in the Eastern Mount Lofty Ranges catchment.

Despite the large uncertainties involved in modelling plantation impacts on water yields, the discrepancies between empirical and modelled reductions in flow, and large spatial and temporal variability in plantation water use, the inescapable conclusion is that the effect of traditional forest plantations on water yields at the catchment scale is small.

3.3.5 Projected change in forestry plantation area

Estimates of future changes in forestry plantation area vary. The 2020 Vision advocated a trebling of national plantation area by 2020, which has been misinterpreted to imply that all plantation areas across the country will exhibit uniform expansion (Polglase and Benyon 2009). Actual growth in plantation area at a national level to 2009 is presented in Figure 8. This is equivalent to a target of approximately 900,000 ha of plantations in the

Murray-Darling Basin compared to the 2005 estimate of 284,000 ha. Adopting this target as the basis for modelling projected impacts on catchment water yields led to significant overstating of risks to water yields. More realistic projections for the Murray-Darling Basin were typically much lower. Ferguson et al (2002) estimated potential for a 141,400 ha increase in plantations in the Basin (Table 6). More recent estimates include 52,000 ha (BRS, as reported by CSIRO 2008), less than 50,000 (Parsons et al 2007), and industry estimates obtained through interviews that suggest maintaining current plantation areas or a modest increase of 5% are most realistic in the current economic and investment climate.

A hypothetical model by Australian Bureau of Agricultural and Resource Economics (ABARE) suggests that there is economic potential for afforestation in the MDB of more than 10 million hectares by 2050, subject to the introduction of a carbon price of $28 tonne^{-1}. However, much of this area consists of environmental plantings in lower rainfall areas rather than traditional forestry plantations. This estimate represents a total increase in forested land area of 45% across the entire MDB, ranging from no change in the Lower Murray and Ovens catchments, to a maximum increase of 161% in the Gwydir catchment (Hafi et al 2010). This scenario is based on simplified economic modelling, largely based on forest productivity estimates for land use, without considering other social or environmental limits to forestry expansion. This scenario should be considered as an upper limit for afforestation, used to emphasise potential impacts of afforestation under the influence of economic drivers such as a price on carbon emissions (Hafi et al 2010). Polglase and Benyon (2009) caution against literal interpretation of modelling studies that use unrealistic plantation development scenarios and which therefore generate worst case impact assessments that overstate the true risks of impact.

In contrast, the Australian Forest Growers Association suggests that such a large plantation expansion is unlikely at a carbon price of $28 tonne^{-1}, and that a price of $100 tonne^{-1} would be required to make large scale conversion from alternative land uses to carbon sequestration plantings viable (W Ragg pers comm). This suggestion is supported by Schrobback et al (2009) who suggest that $50 tonne^{-1} is a minimum carbon price to motivate landholders to change land use to carbon sequestration plantings.

Forestry expansion at a lower carbon price may be more feasible in lower rainfall zones (400-600 mm) where there are potentially carbon sequestration, salinity and biodiversity benefits that might offset water use and where the economic value of alternative land uses is often marginal. These areas are not likely to support highly productive traditional forestry plantations and commercial tree species, so species selection and incentives, as well as useful forest products other than timber, are likely to be important drivers of expansion in plantation area.

Areas with rainfall greater than 600 mm y^{-1}, south-easterly aspect, soils greater than 1 m depth and slopes less than 10% are have been identified as suitable for forestry. Datasets generated by the Centre for Land Protection Research (2000) were used by Zhang et al (2003) to determine areas of suitability for forestry, particularly for blue gum, in the Goulburn-Broken Catchment. Biophysical criteria and the most limiting factor method were used to determine the maximum area in the catchment that could be afforested, excluding social and economic factors. Areas of suitability for a maximum conversion of land to forestry are confined to the southern part of the catchment upstream of Goulburn Weir (Zhang et al 2003) and represent an increase in forest cover of 224,600 ha, compared to recent maximum estimates of <50,000 ha for the entire Murray-Darling Basin.

It is evident that several earlier estimates of potential conversion of land to traditional forestry plantations have only taken into account land suitability for forestry, and have not considered social or economic factors in estimating the likelihood of changes in land use.

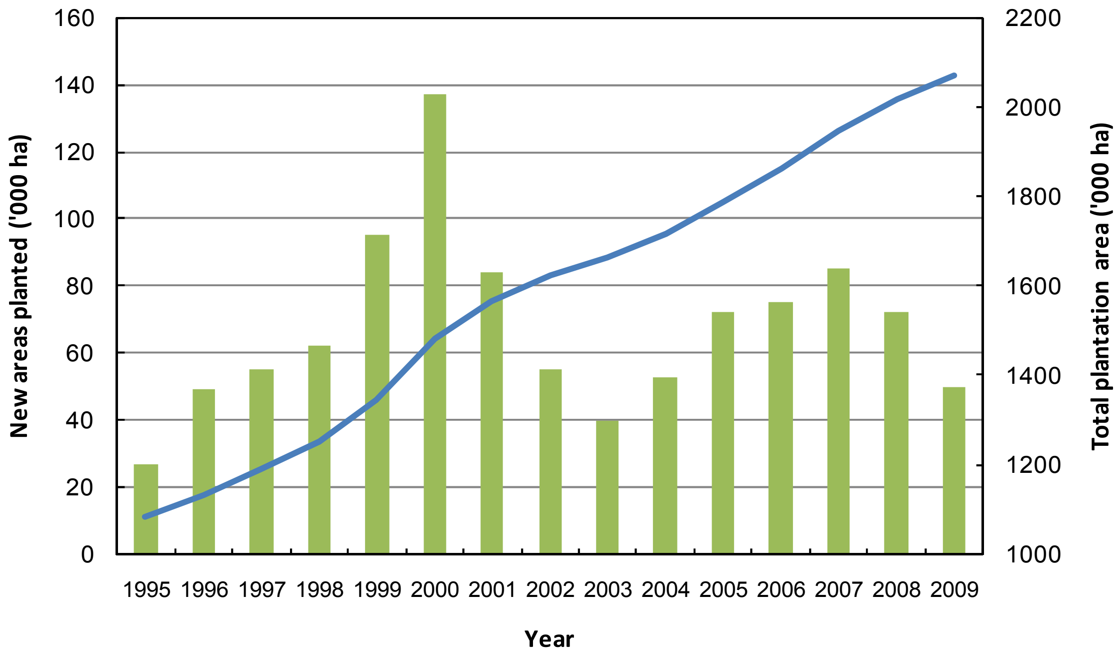

Figure 8 : Expansion of total plantation area in Australia to 2009. (Gavran and Parsons 2010).

Table 6 : Estimated expansion of traditional plantation areas in the Murray-Darling Basin by 2020. (Ferguson et al 2002).

NPI Region	Short Rotation Hardwood (ha)	Long Rotation Hardwood (ha)	Total Hardwood (ha)	Total Softwood (ha)	Total New Plantation (ha)
Murray Valley	15,400	15,300	30,700	15,300	46,000
Southern Tablelands	-	1,900	1,900	21,500	23,400
Central Tablelands	-	5,400	5,400	59,500	64,900
Northern Tablelands		5,100	6,500	600	7,100
Total	16,800	27,700	44,500	96,900	141,400

Areas suitable for expansion of traditional plantation forestry are limited in the Murray-Darling Basin. The forestry industry has identified proximity to market as the most important factor in determining if and where expansion was likely to occur. Areas around existing plantations and milling facilities are considered the most likely areas for expansion (eg Tumut and Bathurst). Other areas identified as feasible for forestry expansion include the upper reaches of the Ovens catchment, the Upper Murray catchment, and to a more limited degree, the Eastern Mount Lofty Ranges (CSIRO 2008). Areas between Tumut and Albury, close to existing facilities and markets are seen as most feasible. Introduction of an emissions trading scheme is acknowledged by the forestry industry and scientific community as potentially leading to forestry operations in areas that are currently not profitable, however the effect of a carbon price is expected to be insufficient to justify construction of new mills to support expanded traditional forestry plantations.

Catchments potentially affected by changes in plantation area are shown in Figure 9. These areas include the upper reaches of the Macquarie, Lachlan, Murrumbidgee, Murray and Goulburn-Broken catchments, with smaller plantations in the upper Avoca and Eastern Mount Lofty Ranges catchments. There are no traditional forestry plantations of significance in more northerly catchments, and no plans for expansion into these catchments. Projections for future impacts of forestry plantations on catchment water yields are therefore largely confined to the upper reaches of the southern regions of the Murray-Darling Basin.

Projections of an increase in plantation forests of 52,000 ha were used for modelling by CSIRO (2008) to investigate impacts of plantations on water availability in the MDB. Such an increase would reduce surface water availability by 28 Gl y^{-1}, compared to current estimates of total surface water availability of 23,417 Gl y^{-1} (CSIRO 2008). This projected expansion represents an increase of 18% of total forestry plantations, and is based on possible expansion of 33,000 ha in the Upper Murray, 17,000 ha in the Murrumbidgee, and 2,000 ha in the Eastern Mount Lofty Ranges catchments.

3.3.6 Economic issues

Expansion of forestry plantations in high rainfall zones, will be largely driven by economic considerations and opportunity cost of competing land uses. Aspirational targets within the forestry industry for expansion of plantations are 5-15% by 2020, but the maintenance of existing plantation areas is considered a more realistic target, since significant investment is required to replant harvested plantations and to maintain existing areas, with further complex investment systems required to expand plantation forestry (G Matthew pers comm; W Ragg pers comm).

The main obstacles to plantation expansion are the availability of significant long-term investment (W Ragg pers comm) and community opposition, based primarily around environmental concerns. However, current projections suggest an increased need for forestry products as Australia’s economy recovers from the global economic crisis (Low and Mahendrarajah (2010).

In terms of timber production and economics of forestry operations, the effects of increased CO_2 on plant growth efficiency under all climate scenarios may partially offset impacts of reduced water availability on tree growth. Experimental results for woody plant growth under enriched CO_2 conditions suggest enhanced growth by 20% to over 30% (Curtis and Wang 1998, de Graf et al 2006), although these increases were typically halved under conditions of nitrogen limitation, and further enhanced by water limitation (McMurtrie et al (2008). Forest profitability may benefit from enhanced tree growth under elevated CO_2 conditions, potentially leading to reduced rotation times. The forestry industry also recognises that increased fire risk under a warmer, drier climate may see greater community resistance to forestry, increased investment risk and higher fire insurance costs, which may contribute to further contraction of plantation areas.

Potential for expansion in traditional forestry plantations is most strongly driven by economic factors external to the forestry industry itself, rather than internal drivers. Tax incentives have historically encouraged investment in forestry. Following removal of tax incentive schemes the forestry industry is going through a period rationalisation and adjustment that emphasises maintaining existing plantations rather than aspirational expansion.

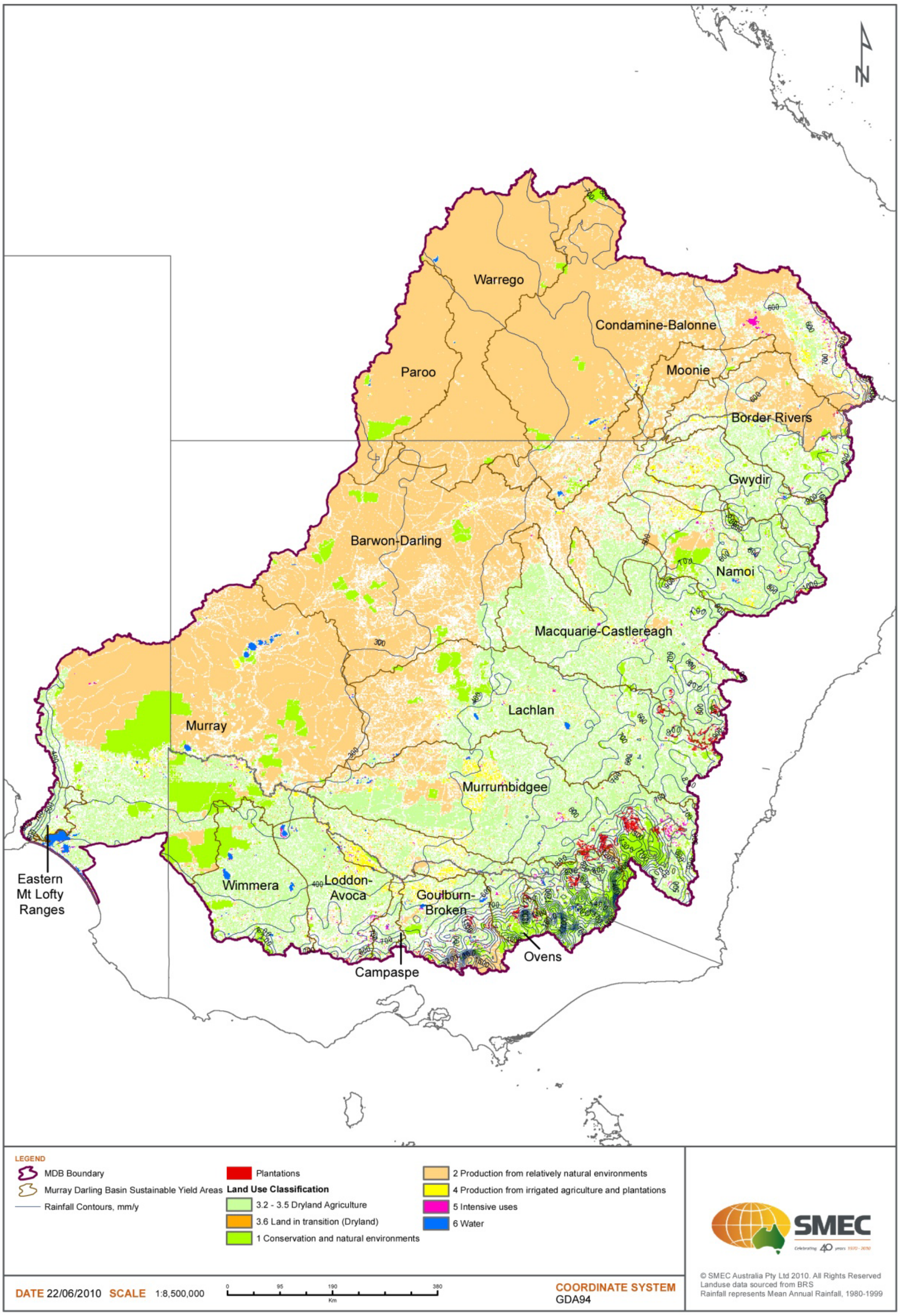

Figure 9 : Distribution of plantations in the Murray-Darling Basin in relation to other land uses.

The recent collapse of several major forestry companies which managed a combined total of 463,000 ha of plantations around Australia, illustrates the uncertain future for potential investors in plantation forests. A report in The Weekend Australian (18 September 2010) claims that the closure of these companies represented a combined loss of $4.2 billion in invested funds. Furthermore, the article indicated that the managed investment schemes that supported the industry encouraged planting of more than 30% of existing plantations in areas where tree growth rates were not economically viable (Figure 10).

The introduction of an emissions trading scheme in future may alter the economics of forestry depending on the price of carbon. Recent scenarios for plantation expansion have used prices for carbon ranging between $20 tonne^{-1} and $45 tonne^{-1} (Lawson et al 2008, Hafi et al 2010). Schrobback et al (2009) considered hypothetical carbon prices of $25 tonne^{-1}, $50 tonne^{-1} and $100 tonne^{-1} , and estimated the land areas converted to forestry as 0 ha, 20,000 ha and 1.15 million ha respectively in the south-eastern catchments of the Murray-Darling Basin. These increases were considered likely to represent plantations established for both carbon sequestration and timber production, and are supported by the Australian Forest Growers Association which believes that a carbon price near $100 tonne^{-1} is required to provide sufficient economic incentives to stimulate an increase in the area of plantation forests through conversion of existing agricultural land (W Ragg pers comm).

Hard choices for hardwood plantations mismanaged by investment schemes

Some have sold, but others languish

ANDREW MAIN
AGRIBUSINESS

PICTURE an Australian timber plantation 68km by 58km, and think of the amount of sweat and money that's gone into creating it over the past 20 years.

It's all for sale, or has been sold, by administrators and liquidators in the past year, even though it's never been burnt out or had significant numbers of trees die because of drought.

This is because the plantations were all in rural managed investment schemes (MIS), an investment model that has been comprehensively demolished by the fact that all the biggest players in the business have collapsed since April last year, taking about $4.2 billion of investors' monies with them.

The trees are all still there, mostly blue gums, accidentally doing their bit for carbon capture, but essentially put there to be harvested when mature, reduced to woodchips and shipped offshore for paper manufacture.

They went broke because they weren't actually self-sustaining. Once upfront fees of 10 per cent were paid to investment advisers, promoters overpaid for leases and the various other costs were taken out, even after the trees were harvested there was less money being earnt than spent.

The 68km by 68km area represents the 463000 hectares that were managed by the biggest four companies, now defunct, operating in the MIS space.

Timbercorp collapsed in April 2009 with 98,000ha under plantation, followed a month later by Perth-based Great Southern Plantations with a whopping 240,000ha. Forest Enterprises Australia of Tasmania added another 72,000ha in April this year and then on September 6, Willmott Forests, a Melbourne-based operator that had been going for 30 years, added another 53,000ha to the total. They've caused nightmares for about 75,000 grower investors, who put money into what were often called "June 30" schemes. They were allowed to claim immediate upfront deductibility in one year for money that would be spent in the following year.

What's remarkable about the schemes is how long they lasted. In 2007, the government had to stipulate that deductibility would only apply to schemes where 70 percent or more of the money was actually spent on forestry, suggesting that before then, the schemes would have been lucky to see much more than 50 per cent.

The key to the longevity is what the cynics have been calling the Ponzi scheme element. Until two years ago the inflow of funds every June gave a transfusion to the schemes, leaving new investors dreaming of the trees they were going to own and previous investors unwittingly collecting their smaller-than-expected exit payout from the new investors.

Although the tax deductibility still exists, the MIS schemes' inflows were hit in 2007 by a dispute with the tax office about deductibility of other schemes, such as grapes and almonds.

While some grower investors thought, incorrectly, that it would also apply to timber schemes, they were then hit by the global financial crisis in 2008, greatly reducing the amount of income seeking a tax break, and the flow of new "June 30" money dropped in many cases by more than 80 per cent.

That's when the collapses began and it then emerged that some plantations had been sown more because the money was coming than they could make good returns in future.

Management consultant Doug Parsonson said yesterday that "let's say more than 30 per cent of the areas planted today would not be replanted in future because the trees simply haven't grown enough".

He added that in other cases, such as the Tiwi Islands off Darwin, the trees had grown well, but the absence of a suitable port had added to transport costs.

More reassuring is the news that not only are a number of reputable timber groups, such as Gunns, picking up the management responsibility for schemes, thus giving investors the chance of some money when the trees are eventually harvested, but a number of institutional investors are looking closely at buying the land the trees are on, and in some cases the land plus the trees.

David Brand, managing director of the Sydney-based New Forests Group, made it clear there are buyers around for plantations in Australia that are "well positioned in coastal regions, with proximity to ports". He says they are looking to new markets such as China and India for both hardwoods and woodchips.

Figure 10: Excerpt from The Weekend Australian, 18 September 2010.

Potential forestry expansion based on the introduction of a carbon price ignores the opposing impacts of climate change, population growth, and a potential shrinking of the world's food growing areas, placing increased demand for agricultural production from land in the Murray-Darling Basin with sufficient rainfall to support non-irrigated cropping and grazing land uses into the future (D Bush pers comm). Increased demand for agricultural production could accentuate social and economic pressures against potential expansion of afforestation programs.

Demand for increased agricultural production could, however, make agroforestry, or integrated forestry more financially attractive. Integrated forestry allows smaller plantations to be established on areas within farms that are less suited to crops or grazing to diversify income streams for farmers, and to reduce financial risks. Integrated plantation agroforestry in high rainfall zones may encounter less community resistance, and could potentially provide environmental benefits as well as financial benefits to farmers. The introduction of a carbon price would make these types of plantations more attractive within the forestry industry.

Economic feasibility of expansion in plantation forestry may also be affected in the future if plantation owners are required to pay for water intercepted by plantations following the introduction of Sustainable Diversion Limits in the Murray-Darling Basin. Schrobback et al (2009) estimated break even prices for water used by plantations in the south-eastern

Murray-Darling Basin, ranging from \$43 - \$129 Ml^{-1} under a carbon price of \$25 $tonne^{-1}$, to \$173 - \$515 Ml^{-1} at a carbon price of \$100 $tonne^{-1}$.

Potential economic incentives for forest expansion therefore include introduction of a carbon emissions trading scheme, increased forest growth under climate change scenarios with elevated CO_2 and temperature effects and reduced fire insurance premiums through restructuring existing plantations into a larger number of smaller agroforestry plots.

Negative incentives to forest expansion include increased value of agricultural land in areas suitable for forest plantations, introduction of a price on water intercepted by forests, increased fire risk under future drier climate scenarios, and increased plantation management and transport costs of agroforestry systems located greater distances from processing facilities.

4 WATER YIELD IMPACTS UNDER CLIMATE CHANGE

4.1 Climate change effects on water yields

Three climate change scenarios, based on CSIRO (2008), were assessed to determine potential effects on plantation expansion, and resulting impacts on catchment water yields.

Scenario 1 - A 'most favourable 2030 scenario' based on a continuation of the long-term (1895 to 2006) averages for rainfall and runoff across the MDB, with current levels of water resource development.

Scenario 2 - A 'median 2030 scenario' based upon the median global warming scenario and associated rainfall and runoff across the MDB, with current levels of development.

Scenario 3 - A 'least favourable 2030 scenario' based upon the actual climate of the MDB in the period 1997-2006

As a median of multiple models, the median 2030 scenario allows a range of uncertainty to be expressed, based on outputs from the wet extreme 2030 model, and the dry extreme 2030 model. As some effects under Scenario 3 (least favourable 2030) are not described by available modelling, the dry extreme global warming scenario used by CSIRO (2008) is used in places to provide a more complete assessment.

Assuming a constant increase in plantation area of 52,000 ha under the different climate scenarios to 2030, allocated across the Murrumbidgee, Murray and Eastern Mount Lofty Ranges, effects of plantation increase on inflows, runoff and end-of-system flows as estimated by CSIRO (2008) are summarised in Table 7. These estimates should be considered as maximum values because the expected increase in plantation area is now considered to be closer to zero. In the much smaller Eastern Mount Lofty Ranges catchment, the effects of expanded plantations on water yields are much larger than in the Murrumbidgee or Murray catchments. Whilst the effects are small overall, impacts of plantations on end-of-system flows are greatest under the dry extreme scenario, and least under historical conditions.

Likely effects of climate scenarios on plantation area, and resulting impacts on water yields and stream flow were derived from interviews described in Section 3. Findings are summarised in Table 8.

4.2 Effects of plantation forestry on catchment water yields under climate change scenarios

Estimates of the relative impacts of climate change and expansion of plantation forestry on catchment water yields vary. At the basin scale for the whole MDB, CSIRO (2008) estimated expansion of traditional forest plantation area of 18% by 2030 would result in an increase in water use of 28 Gl y^{-1}, equivalent to a reduction in runoff of less than 1%. By including plantations for carbon sequestration and traditional plantations, Hafi et al (2010) estimated the potential additional impact of forest plantations on water yield to be a 13% reduction in total water yield averaged across the Basin.

Table 7 : Estimated effect of projected plantation expansion on inflows, runoff and end-of-system flows under selected climate scenarios.
Data from CSIRO (2008).

	MDB	Murrumbidgee	Murray	Eastern Mt Lofty Ranges
Total plantation area (ha)	290,000	118,400	169,500	2,100
Projected increase (ha)	52,000	17,000	33,000	2,000
% increase plantation area	18%	14%	19%	95%
Reduction in inflows as a result of increased plantation (%)				
Median 2030	0.1%	0.1%	0.2%	2.9%
Wet extreme 2030	0.1%	0.1%	0.2%	2.8%
Dry extreme 2030	0.1%	0.2%	0.2%	3.3%
Reduction in total runoff as a result of increased plantation (%)				
Median 2030		0.3%	0.3%	0.3%
Reduction in end-of-system flows as a result of increased plantation (%)				
Historical 2030	0.6%	0.4%	0.4%	2.5%
Median 2030	0.8%	0.5%	0.5%	3.3%
Dry extreme 2030	1.6%	1.0%	0.6%	3.8%

Effects of climate scenarios on plantations and catchment water yields have been summarised by Polglase and Benyon (2009). These authors used a climate timeframe of 2070, which involves larger changes that expectations for 2030 as used in the current assessment. Whilst the nature of changes in plantation water use is expected to be similar, the magnitude of responses by 2030 is likely to be less than effects projected for 2070. Expected outcomes for 2030 from Polglase and Benyon (2009) may be summarised as:

- Reduced rainfall will result in less water available for evapotranspiration;
- Increased drought frequency may result in increased tree death, incursion of pests and diseases, transient reduction in evapotranspiration, more frequent and more intense fires, and changes in forest type;
- Increased temperature is expected to increase tree growth and losses through evapotranspiration, potentially offset in winter by increased stream flow as a result of the increased proportion of precipitation as rainfall rather than snowfall;
- Increased solar radiation may result in increased tree growth and increased water losses from interception and evapotranspiration; and
- Increased atmospheric CO_2 concentration is expected to result in increased growth and water losses, which will be offset by reduced stomatal conductance leading to increased catchment water yields.

These results are largely supported by forest physiological models that project the cumulative effect of factors including precipitation, evapotranspiration, rain depth, and root depth (McVicar et al 2010). By combining effects of climate change, forest physiology and projected changes in forest area (Hafi et al 2010), reductions in runoff as a result of increased tree plantings under the median 2030 climate scenario range from 0% to 14% among catchments (Table 9), with an unweighted average reduction of 5% due to

Table 8 : Summary of interview responses on effects of climate change on plantation expansion.

Issue	Summary of responses
Impact of the three climate scenarios in relation to growth projections for plantations in high rainfall areas	
Scenario 1 - A 'most favourable 2030 scenario' based on a continuation of the long-term (1895 to 2006) averages for rainfall and runoff across the MDB.	▪ Plantation area in the high rainfall zone is expected to remain static or to increase by about 5%. Expansion of forestry plantations will be based largely on economic factors and competing land use. ▪ Interpolating this expansion from Table 7 provides an estimate of 0.03% reduction in inflows, and 0.2% reduction in end-of-system flows for the whole basin (estimated as one-third of the impacts of a 52,000 ha expansion).
Scenario 2 - A 'median 2030 scenario' based upon the median global warming scenario and associated rainfall and runoff described in the CSIRO report "Water Availability in the Murray–Darling Basin" of October 2008.	▪ Moderate reduction in rainfall may result in a contraction in forestry plantations within the existing 600 mm y-1 to 800 mm y^{-1} rainfall zone. ▪ Effects of increased CO_2 and temperature on plant growth efficiency may offset impacts of reduced water availability on tree growth. Outcomes for forest productivity are uncertain. ▪ Increased water scarcity may make other competing land uses more attractive. ▪ Relocation of plantations toward areas with greater than 800 mm y^{-1} rainfall under current conditions combined with the trend toward smaller plantation blocks may spread effects on stream flow over a larger area, with little overall effect on stream flow.
Scenario 3 - A 'least favourable 2030 scenario' based upon the actual climate of the MDB in the period 1997-2006 (this includes 15% less rainfall and 50% less runoff in the southern MDB compared with the long-term average).	▪ Plantations will be greatly reduced in areas that currently receive less than 800 mm y^{-1} rainfall. ▪ Plantation water use as a proportion of rainfall will increase. ▪ Increased rainfall intensity may result in increased runoff even though average rainfall will be less. ▪ Increased fire risk may see community resistance to forestry, increased investment risk and higher insurance costs. ▪ Reduced plantation area and reduced water availability is likely to reduce impacts of plantations of catchment yields compared to estimates in Table 7.
Main gaps in existing scientific knowledge on impacts of forest plantations and catchment water balances, and potential responses to climate change.	▪ Extrapolation of small scale studies of forest water use may overestimate catchment scale impacts on water yield and stream flow. Further research is required to increase the reliability of up-scaling from previous studies. ▪ Large-scale investigations using remote sensing methods may offer alternatives to up-scaling studies. ▪ Further investigation of the temporal effects of forest rotation and tree maturity on water yields are required to refine estimates of effects on stream flows, groundwater, and catchment water balances. ▪ Further investigation is required to determine the opposing effects of reduced water availability and increased CO2 concentration and temperature under different climate scenarios on forest water use and catchment water yields. ▪ The role of atmospheric coupling of evapotranspiration and precipitation on distribution of rainfall and runoff, is poorly understood and is not well captured in models of forest water use and projected climate change scenarios. ▪ A comparative assessment of the outlook for forestry under different economic scenarios including the operation of a CPRS is required to identify future possible impacts on catchment water balances under selected climate scenarios.

Table 9 : Cumulative effect of changes in precipitation, evaporation, storm depth, root depth, and plantation area on runoff in the Murray-Darling Basin.

(Water use from McVicar et al 2010, plantation area from Hafi et al 2010).

Catchment	Historic runoff (mm)	Median 2030 scenario			Dry 2030 scenario		
		Runoff (mm)	Runoff including plantation effects (mm)	Net plantation effect (%)	Runoff (mm)	Runoff including plantation effects (mm)	Net plantation effect (%)
Condamine	40	37	34	-7%	32	29	-7%
Border Rivers	53	52	44	-14%	40	34	-12%
Warrego	21	18	18	-3%	16	16	-3%
Paroo	29	26	26	0%	22	22	0%
Namoi	46	44	39	-10%	35	31	-8%
Macquarie-Castlereagh	55	52	46	-11%	39	34	-9%
Moonie	38	34	29	-13%	30	25	-11%
Gwydir	67	67	59	-13%	52	45	-11%
Barwon-Darling	18	17	16	-7%	13	12	-6%
Lachlan	43	39	37	-4%	27	26	-3%
Murrumbidgee	78	74	72	-3%	49	47	-2%
Ovens	229	208	208	0%	138	138	0%
Goulburn-Broken	167	152	151	0%	102	102	0%
Campaspe	97	89	85	-4%	61	58	-3%
Wimmera	34	29	29	0%	20	19	0%
Loddon-Avoca	42	38	38	-1%	28	27	-1%
Murray	36	33	33	0%	21	21	0%
EMLR	52	46	43	-6%	31	29	-4%

increased plantation area. Under the dry extreme 2030 climate scenario, plantations have a slightly smaller effect, reducing runoff by 0% to 12% among catchments, with an unweighted average of 4% across the basin.

Using a different approach to models based on forest physiology, catchment hydrology models estimate small reductions in stream flow as a result of small increases in plantation area (CSIRO 2008). The estimated effect on end-of-system flows of a 52,000 ha increase in traditional plantation area is very small compared to estimated effects of climate change scenarios (Figure 11).

Neither type of model attempts to account for changes in land suitability for forest plantations under future climate scenarios. Within the high rainfall zone, regions that receive between 600 mm y^{-1} and 800 mm y^{-1} tend to be marginal for plantation growth, and several respondents suggested that under a drier climate, plantations within this zone may be abandoned and replaced by plantations in areas with greater water availability.

Water security is not the only factor to affect expansion of forest plantations under future climate change scenarios. Potential impacts from fire were raised as a significant concern, leading to potential changes to forest species that will grow on marginal land, and a change in competition from alternative land uses such as growth of biofuel crops.

A major source of uncertainty in the future area of plantations and potential impacts under different climate scenarios is existing and future government policy on climate change and the possible introduction of a carbon trading system that places an economic value on carbon sequestered by forest plantations. Several studies have attempted to model the effects of different carbon prices on conversion of other land uses to plantations, and resulting implications for catchment water yields (Lawson et al 2008, Schrobback et al 2009; Hafi et al 2010), but the scenarios available at this time are largely hypothetical and are intended to allow comparisons between scenarios rather than to provide estimates of likely changes in land use for plantations.

One respondent suggested that predicted global population growth and emergence of a drier climate regime in many agricultural regions may place any land with regular, reliable rainfall under increased pressure to be used for food production. Under these circumstances, increased value of agricultural land is likely to marginalise other land uses, including forestry, with the result that changes in catchment water yield may be driven more strongly by agricultural demand rather than by expansion in plantation forestry.

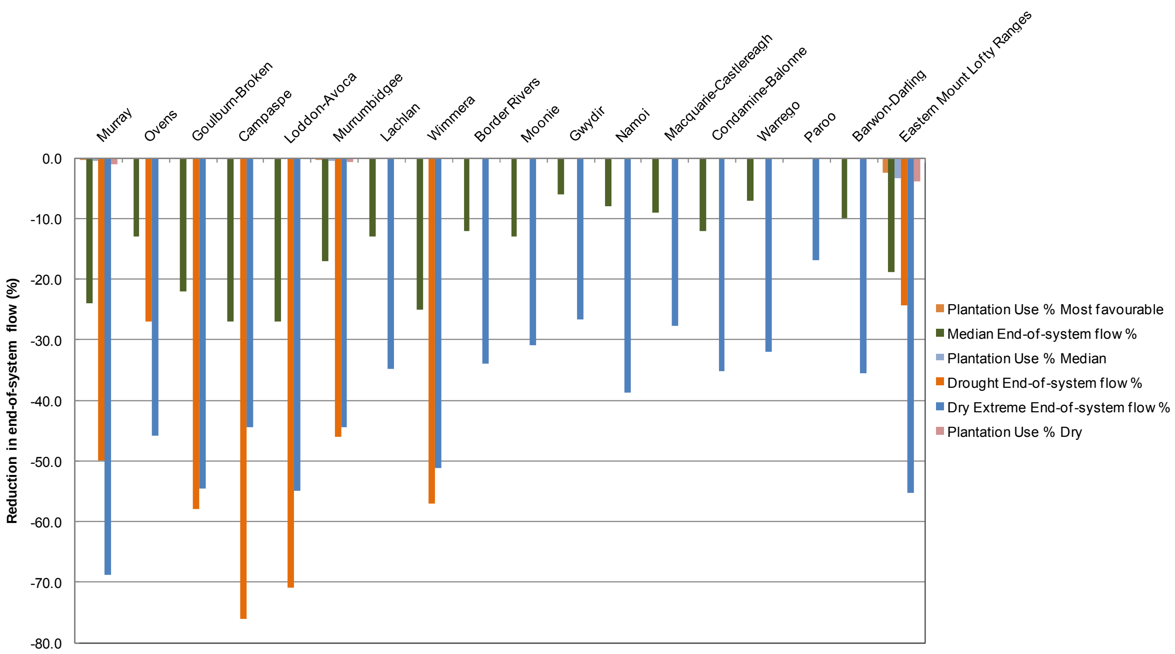

Figure 11 : Projected effects of increased plantation area relative to effects of different climate change scenarios on end-of-system flows in the Murray-Darling Basin.
Increases in plantation area are estimated for the Murray, Murrumbidgee and Eastern Mount Lofty Ranges regions. Based on data from CSIRO (2008).

4.3 Knowledge gaps

This study has identified a number of important knowledge gaps regarding the effects on catchment water yields of forestry plantations in the context of climate change. Other gaps were identified by people interviewed during the project. Whilst these issues provide opportunities to improve the accuracy and precision of estimated water yield impacts of forest plantations, they need to be considered in regard to the relative impact of plantations on water availability compared to the risks posed by interception processes.

Estimating effects at large catchment scales

Extrapolating results of plantation-scale and smaller plot-scale field experiments to assess whole catchment effects has identified a number of discrepancies that over-estimate impacts on water yields. Several sources of error have been identified that, if propagated through models to larger scales, may lead to exaggerated impacts at the catchment scale. The difficulty of measuring rainfall, interception rates and throughfall through forest canopies to ground level at the appropriate scale, and the variability in meteorological conditions, contributes to problems in definitively assessing water balances at the plantation-catchment scale.

Treatment of variability in hydrological models

Spatial variability among catchments, especially in paired catchment studies, and other sources of variability, contribute to high levels of stochastic variation that is not considered in more deterministic modelling approaches. This approach may contribute to some of the discrepancies between modelled estimates and empirical assessments at large scales. Greater emphasis of variability and confidence in model outputs may aid interpretation of effects at multiple scales, especially with regard to the range of values that might reasonably be expected.

Improved predictive models of plantation water use

The two most commonly used models in Australia were recently compared and found to either overestimate annual plantation water use by an average of 17%, or to under-estimate by an average of 37% (Benyon et al 2008). Models developed recently by McVicar et al (2010) based on forest physiology estimate that climate change effects on forest water use would reduce runoff in the MDB by between 8% for the median 2030 scenario and 31% under the dry extreme 2030 scenario. Hydrological models developed by CSIRO (2008) estimate plantation expansion to reduce end-of-system flows by between 0.6% and 1.6% under selected climate scenarios. This range of results indicates that better integration of information on physical hydrological, physiological, and other factors is required to develop models that provide reliable results at all relevant spatial scales.

Relative contribution of plantations compared to effects of land use change

Some of the hydrological effects commonly attributed to forestry are potentially more a reflection of changed land use, rather than explicit impacts of plantations. In these cases, other forms of land use change may result in similar changes to those caused by plantations. Examples may include replacement of soil compaction by grazing land use with other forms of land use that improve soil permeability and infiltration rates. The critical knowledge gap in this respect is the additional impact of forest plantations compared to alternative land uses.

Atmospheric coupling

A number of models applied in the Murray-Darling Basin and elsewhere in Australia do not take into consideration the degree of coupling between evapotranspiration and precipitation, and the role of forests and other land uses in contributing to atmospheric moisture and precipitation. This coupling will become increasingly important at large spatial scales that influence meteorological processes, including the effects of afforestation and deforestation on the spatial distribution of rainfall and runoff.

Improved monitoring of plantation water use and impacts

Most monitoring of water balance components relevant to plantation water use is undertaken at a relatively small scale, and involves only a small number of tree species. Additional investment in monitoring, at both plot scale and regional scale is required to support improved water accounting and prediction of impacts. Remote sensing methods show some potential, but require further development (Polglase and Benyon 2009). Other approaches might include a requirement for plantation managers to collect standardised data as part of their water access entitlements under the Basin Plan.

Significance of plantation water use

This study concurs with earlier assessments that report scale-dependent effects of plantation water use, ranging from small or undetectable effects at large spatial scales, to dramatic effects at smaller scales where 100% afforestation cover is possible (Polglase and Benyon 2009; Andreassian 2004). Better appreciation of the scales at which plantation water use becomes significant in hydrological, ecological, sociological and economic terms, is required to allow impacts that do occur to be managed and minimised. For example, the current trend for plantations to occupy smaller blocks spread across a number of catchments should, in principle, reduce the incidence of significant impacts in individual catchments. But the outcomes of this practice remain to be confirmed.

Net benefits of plantations

The viability of forest plantations, potential for expansion, and impacts on water yields within the MDB are strongly influenced by external economic drivers. Optimisation of land use involves environmental, social and economic considerations, including benefits that have no readily-definable market value. It would be instructive to consider plantations and other land uses in a cost-benefit analysis expressed as benefits per unit volume of water, and as dollars per unit volume of water (Polglase and Benyon 2009). Such an analysis would need to also consider the value of ecosystem services.

Impacts of climate change

Projecting the effects of climate change on forest physiology, plantation water use, and catchment water yields is made difficult because of the fragmentary nature of existing research. Existing models identified during this study use different approaches to assess responses to climate change, and provide different results. There is clearly a need for better assessment of the effect of selected climate scenarios on plantation water use, as well as the prospects for changes in plantation area.

Uncertainty of future outlook

The existence of multiple lines of uncertainty, spanning climate change impacts, environmental variability, economic drivers including a possible price on carbon, pricing of water entitlements and opportunities for water trading, long-term investment prospects, demand for wood products, and changing community attitudes makes it difficult to speculate on future plantation areas within the Murray-Darling Basin, and potential impacts on water availability. Whilst the consensus among specialists interviewed for this project is that a large-scale increase in plantation area is unlikely, and accordingly, risks to water yields in the Basin are small, plausible scenarios exist that suggest significant reductions in water availability. Further investigation of options to manage potential impacts of increased plantation area may be warranted as a contingency in the event of increased investor confidence, the introduction of a high price on carbon emissions, or other unforeseen circumstances.

5 SYNTHESIS OF WATER YIELD IMPACTS OF PLANTATIONS

5.1 Plantation water use

It is well established that trees intercept more water than cleared land, however, effects of plantation water use on catchment water yields are difficult to measure where plantations cover a relatively small proportion of the catchment, typically less than 20% of catchment area.

Consequently, at the basin scale and catchment scale where percentage plantation cover is typically in the range of 0.4% to 4%, effects of plantation water use on catchment water yields will also be small and may be below detection limits for practical purposes.

In small sub-catchments less than 100 km^2, where plantations may cover significantly more than 20% of the total area, effects on local stream flow may be significant, leading to reduced stream flow and increased drying of small streams during dry seasons.

Based on experience in the Murrumbidgee catchment, significant reductions in local stream flow in the order of 8% are likely to result in a reduction in mean annual water allocation to irrigators of 0.4%.

5.2 Changes in plantation area

The 2020 Vision to treble the area of plantation forests across Australia has been interpreted as translating into a total increase of 141,400 ha of plantations in the Murray-Darling Basin, compared to current plantation area of 284,000 ha. Recent estimates have adopted a more modest target of 52,000 ha by 2030, although the forestry industry believes that even this target is ambitious. Maintenance of existing plantation area, perhaps with a small increase of around 5%, is considered more likely under current climatic and economic conditions.

Historical clearing of catchments has resulted in a doubling of catchment water yields, based on studies in the Macquarie catchment. The small envisaged increases in plantation area will only have a small reversal of this effect.

Increased investment in plantation expansion requires increasing rainfall from recent drought conditions, greater global financial stability for long-term investment, and potential financial incentives, such as tax concessions or a price on carbon. Potential increases in the value of agricultural land in the high rainfall zone present a disincentive for forestry expansion.

As a result of these requirements, a significant increase in plantation area is unlikely in the foreseeable future, and consequently, the risk to water yields in the Basin is low.

5.3 Effects of climate change

Projections for a drier climate under the median 2030 scenario, with 9.7% less inflows to the MDB under the median 2030 scenario with current levels of development, may see a contraction of plantations to higher rainfall zones that receive greater than 800 mm y^{-1} mean annual rainfall.

Projected end-of-system flow under median 2030 climate change models suggests a reduction in water yields of 25% across the Basin, ranging from an increase of 20% in wet extremes to a possible decrease of 69% in dry extremes. Against this range of changes, the estimated reduction in end-of-system flow of 0.8% attributable to a 52,000 ha expansion in plantations is small, and actual change is expected to be even smaller if industry projections for a smaller increase are maintained.

The adaptive capacity of forests to climate change factors including precipitation, evapotranspiration, precipitation intensity, rooting depth, vegetation seasonality, and CO_2 enrichment suggest that catchment water yields may not be affected to the extent predicted by hydrological climate change models. The corollary to these results is that although increased plantation area might be expected to increase water interception and reduce stream flow, interactions between climate change and forest physiology may offset some of the anticipated effects of plantation expansion on water yields. The probability of these outcomes has not been determined.

5.4 Risks to water yields

The risk to water yields in the Basin if the projected increase of 52,000 ha in plantations is achieved, is a 0.8% reduction in end-of-system flows, or a 0.12% reduction in total water resource availability.

Under the median 2030 climate change scenario, this effect is likely to be masked by uncertainty in this projection, and other sources of variation.

Under the wet extreme 2030 climate scenario, the 0.6% reduction in flow from the projected 52,000 ha increase in plantations will be obscured by the 20% increase in end-of-system flows, combined with the interactions between climate and tree water use.

Under the dry extreme 2030 climate scenario, the 1.6% reduction in flow from a 52,000 ha increase in plantations will again be insignificant compared to the 69% reduction in end-of-system flows. Interactions between tree water use and climate change may reduce the magnitude of the total reduction to a small extent.

Basin-wide projections of the impacts of plantation expansion are consistent at the scale of individual catchments (Murray, Murrumbidgee and Eastern Mount Lofty Ranges) where plantation expansion is most likely to occur, although the relative impacts are greater in the smaller Eastern Mount Lofty Ranges catchment.

The likely risk to water yields will be much smaller than these estimates if industry projections of less than 5% expansion in plantation area are achieved. Taking an opposing view, if the unlikely expansion of 141,400 ha in plantations is realised, then the effects on water yields may be roughly three times greater than these estimates, equivalent to approximately a 2.4% reduction in end-of-system flows, and a 0.36% reduction in total water resource availability. These changes are still small compared to the magnitude of other sources of variability, including the range of possible outcomes between climate scenarios, and external factors such as the estimated 4.9% reduction in stream flow from increased development of farm dams.

5.5 Sources of uncertainty and knowledge gaps

The projected risks to catchment water yields posed by potential increases in plantation area are subject to several key sources of uncertainty and knowledge gaps. The greatest source of uncertainty is the actual increase in plantation area. The other critical source of uncertainty is the most likely climate trajectory. Current stream flow estimates at the catchment scale are much more strongly influenced by climate than by changes in plantation area.

Other sources of uncertainty include:

- Difficulties in extrapolating effects of plantation increase at large catchment scales;
- Methods for dealing with variability in hydrological models;
- Different processes represented in predictive models used to estimate plantation water use;
- The contribution of plantations to water use within catchments compared to other land uses;
- The role of forests and plantations in atmospheric coupling between evapotranspiration and precipitation;
- Approaches to monitoring plantation water use and impacts on water yields;
- The significance of plantation water use at different spatial scales;
- Net benefits of plantations in relation to water use;
- Impacts of climate change on plantation water use; and
- Uncertainty in the global economic outlook.

PART B

EFFECTS OF CARBON SEQUESTRATION PLANTATIONS

6 EFFECTS OF AFFORESTATION FOR CARBON SEQUESTRATION

6.1 Introduction

Effects of water use by trees on catchment water balances are broadly similar, irrespective of the purpose of plantations. However, plantations for carbon sequestration differ in several important ways from traditional forestry plantations.

Firstly, carbon sequestration plantations are most likely to be established in regions with lower rainfall, since areas with greater than 600 mm y^{-1} rainfall are in demand for more valuable forms of production, such as agriculture or traditional forestry (Crossman et al 2009).

Regions with rainfall suitable for carbon sequestration plantations tend to lie in lower gradient parts of the Basin, where the proportion of rainfall that forms runoff to rivers is low. Consequently, effects of plantations on surface water are less than effects of plantations in regions with higher rainfall (Zhang et al 2001).

Thirdly, the lower water availability to plantations in low rainfall areas means that different tree species, with different water requirements, are likely to be favoured in plantations intended to provide carbon sequestration benefits.

This section focuses on ways that carbon sequestration plantations differ in their water use requirements from traditional forestry plantations. It also addresses the effects of carbon sequestration plantings on salinity, biodiversity and riparian management and investigates the probability of the expansion of environmental plantings throughout the MDB, using data gathered from interviews with regional catchment management and natural resource management bodies. The legislative, economic and environmental drivers for the establishment of carbon plantings are also addressed, to identify knowledge gaps relating to this relatively new type of forestry in the Murray-Darling Basin.

6.2 Differences between carbon plantations and traditional forest plantations

6.2.1 Geographic range

The primary driver of the geographic range of plantations primarily for carbon sequestration or environmental plantings is economic, based on a function of carbon price and opportunity cost (A van Dijk pers comm).

Areas of high rainfall, good soil depth and topography attract high prices for commercially valuable products such as crops and traditional forestry and at this stage the economic incentives for plantations to be established primarily for carbon sequestration benefits are not competitive with such land uses. In low rainfall zones, land acquisition and establishment costs of environmental plantings are lower, but growth rate is also lower, therefore less carbon sequestered. It is assumed that landholders will switch land uses when estimated returns of the new land use outweigh those of the current agricultural use (Hafi et al 2010), however, it is recognised that other factors may contribute to a rate of plantation establishment that is lower than predicted.

So far, plantations for carbon sequestration have been established in lower rainfall zones where land prices are lower, and are often planted primarily for other benefits such as salinity management, or habitat restoration, with carbon sequestration an additional benefit. Early projections suggest that up to 90% of new plantations will be situated in the 600-800 mm y^{-1} rainfall zone (Hairsine and Polglase 2004).

These projections were made when the likelihood of a CPRS was high and the rural managed investment scheme (MIS) was funding the expansion of plantations, primarily in coastal regions but parts of the MDB were also targeted. Since April 2009, major investment companies in MIS schemes have collapsed, essentially stalling expansion from this sector.

There are potential advantages to carbon sequestration plantations over timber plantations, given appropriate market incentives and environmental conditions. Carbon plantations are cheaper to establish and manage. They generally consist of multispecies plantings so the risk of disease is spread among species, reducing the total risk. The diversity of species also improves biodiversity outcomes and could potentially provide further economic incentives for landholders to convert part of their land to environmental plantings. A study by Crossman et al (2009) shows that reforestation for the supply of carbon permits under a CPRS scheme would be more profitable than agricultural production for 50% of South Australia's agricultural landscapes if the carbon price reached \$20 $tonne^{-1}$. A study in the south eastern part of the MDB concluded that a carbon price of \$50 $tonne^{-1}$ or more would be required for landholders to convert productive agricultural land to plantation forest (Schrobback et al 2009).

Many species, such as oil mallees, can be grown in areas with very low reliable rainfall, however, carbon sequestration is probably not viable in areas with less than 300 mm y^{-1} (D Bush pers comm). This contrasts with timber plantations which are generally most lucrative in areas with an annual rainfall of 1,000 mm y^{-1} or more and certainly are confined to areas with rainfall of at least 800 mm y^{-1} (Oil Mallee Company 2010).

6.2.2 Water requirements

Water use and carbon sequestration are closely associated (D Barrett pers comm; Schrobback et al 2009). In order to maximise carbon storage through tree growth, water use must also be maximised. In this way, environmental plantings are the same as traditional forestry plantations, in which maximum sequestration is achieved by maximising growth.

In the LRZ, where carbon plantations have historically taken place, not only is rainfall lower, but due to the generally flatter topography, run-off is also low, so the impact on runoff will be low (Zhang et al 2001). In regions that receive less than 500 mm y^{-1} rainfall, there is little practical difference between the effects of grasslands and forests on surface water resources.

In order to maximise the carbon sequestered and minimise water use, plantations need to consist of tree species that are most suited to the local environmental conditions. These are usually native species, however multispecies plantings and hybrid varieties also offer enhanced sequestration and other environmental benefits (eg Dale and Dieters 2007).

Studies of water use among a number of different species of eucalypts have been unable to find significant differences in water use (Hatton et al 1998). However, this is considered to be a complex issue with differences between absolute water use and water use efficiency, which can be thought of as units of carbon stored for units of water used. Paradoxically, drought tolerant species are often less efficient users of water, because through long dry periods they still must use some water but do not grow (and therefore do not sequester more carbon) (D Bush pers comm).

Mallee species, often used in low rainfall areas for environmental plantings, have an added benefit for carbon sequestration. Mallee eucalypts have multiple stems arising at ground level from a large woody structure known as a lignotuber or mallee root. If the plantation is burnt, the lignotuber, which stores much of the (carbon-based) food of the plant, is retained underground, therefore reducing the loss of carbon stores due to fire (Oil Mallee Company 2010).

Traditionally plantations have been viewed as only negatively influencing water availability in a catchment. However, recent studies show that clearing vegetation may influence local climatic conditions, increasing temperature and reducing rainfall (McAlpine et al 2007). Targeted afforestation could form part of a strategy to restore previous climatic conditions in heavily cleared landscapes (McAlpine et al 2007; Vanclay 2009).

The relative effects of plantations on catchment water yields under a hypothetical carbon price of \$28 tonne^{-1} are presented in Table 10 (Hafi et al 2010), interpolated to the year 2030.

Table 10: Estimated impact on water yield by 2030 attributable to plantations and climate change. (Hafi et al 2010).

Catchment	Forested land area % of total land area *a*		Impact on water yield %		
	Base	With sequestration plantations	Climate change 2030	Effect of plantations	Climate change and sequestration combined
Condamine-Balonne	22	29	-8	-6	-14
Border Rivers	29	44	-10	-13	-23
Warrego	28	31	-6	-2	-8
Paroo	16	16	-3	0	-3
Namoi	28	38	-5	-8	-13
Macquarie-Castlereagh	19	31	-3	-5	-8
Moonie	15	27	-11	-11	-22
Gwydir	16	29	-10	-10	-20
Barwon-Darling	17	23	-8	-9	-17
Lachlan	17	21	-11	-2	-13
Murrumbidgee	15	19	-9	-5	-14
Ovens	55	55	-13	0	-13
Goulburn- Broken	33	33	-14	-1	-15
Campaspe	17	23	-16	-11	-27
Wimmera	15	15	-21	-1	-22
Loddon-Avoca	12	13	-18	-3	-21
Murray	27	27	-12	-1	-13
Eastern Mt Lofty Ranges	9	15	-18	-11	-29
MDB	22	27	-11	-7	-18

6.2.3 Salinity effects

Deep-rooted woody vegetation can often be used to reduce groundwater salinity, and many plantations that provide carbon benefits were originally planted for this purpose. Upland recharge and infiltration zones are most prone to salinity problems in damaged agricultural catchments and benefit considerably from environmental plantings to reduce salinity (Bell 1999; Stirzaker et al 2002).

Australian plant species are particularly resourceful in accessing available water, and have annual evapotranspiration rates as much as seven times the rate of grazing pasture (Bell 1999).

Bell (1999) identified 32 species of eucalypt that can tolerate moderate to high levels of sodium (up to 300 mM). Species that are used for environmental plantings and have high salt tolerances include South Australian blue gum *Eucalyptus leucoxylon;* river red gum *Eucalyptus camaldulensis*; swamp yate *Eucalyptus occidentalis*; and forest red gum *Eucalyptus tereticornis.*

Eucalypt species that both reduce salinity and sequester high amounts of carbon for timber production are likely to come from targeted breeding programs. Hybrids of *E. camaldulensis*, *E. grandis* and *E. globulus* show increased carbon sequestration of up to 2.5 the average rate of pure stands, while maintaining the salt tolerance levels of *E. camaldulensis* (Dale and Dieters 2007).

6.2.4 Biodiversity and riparian effects

Carbon sequestration plantations are more amenable to multispecies plantings and afforestation of appropriate areas on existing farmland can also be targeted to include a diversity of species, thereby reducing the risk of failure due to pests and disease.

Studies in Western Australia suggest that species such as oil mallees that are used for carbon sequestration in low rainfall areas provide important resources for biodiversity. Food and shelter are enhanced using multispecies plantations, especially if situated next to existing native woodland (Smith not dated; Salt et al 2004).

Landscapes are generally heterogeneous so permanent carbon plantings that are targeted and contain a number of species will make greater contributions to biodiversity goals than monocultures that are not planted to maximise biodiversity benefits (Salt et al 2004; Crossman et al 2009).

Spatial optimisation methods are being developed to examine how environmental benefits can be maximised with minimum impact on sequestration capacity (Barrett et al 2010)

6.3 Knowledge gaps

Much of the knowledge on environmental plantings has been derived from studies of traditional forestry plantations, or based on theoretical studies and modelling. In comparison, there is still limited information on carbon sequestration and other environmental plantations from empirical studies.

Researchers interviewed who worked in the area of empirical analysis identified the limited research on environmental plantations as an important knowledge gap. Additional empirical research is required to strengthen deterministic models commonly used to extrapolate findings from traditional forestry plantations, and to reduce reliance on forecasts with assumptions and multiplicative errors generated by scaling up smaller scale studies. This conclusion was supported by scientists involved in scenario modelling and analysis at catchment scales. Previous studies where catchment-wide predictions have been based on extrapolating from data obtained from small, localised studies have been shown to over-estimate effects of plantations on stream flow (van Dijk et al 2007; see Part A for further discussion).

The rates of carbon sequestration of different species under different environmental conditions have been modelled and studied (eg England et al 2006; Fortunaso et al 2008), but there is still debate about the reliability of these methods, due mainly to a reliance on assumptions about the tissue:root ratio in the equations used for calculating the amount of carbon stored. This measure is subject to variability, making calculations unreliable (D Ellsworth pers comm).

If environmental plantings are to be established more widely, it is important that their multiple costs and benefits are better understood. For example, whilst it is well established that catchment water yields are likely to be reduced when cleared land is reforested, there is a specific need to improve biophysical modelling of runoff and stream flow in low rainfall, low gradient catchments where the effects of plantations on catchment yields may be negligible and where carbon plantations are most likely to be established.

Agroforestry, by integrating environmental or timber plantations into the agricultural landscape, was supported by most interviewees as a way for landholders to spread risk and increase salinity mitigation, biodiversity and riparian benefits. But proven methods of designing landscapes to maximise benefits and minimise costs require spatial optimisation methods which are currently being developed for this purpose (Barrett et al 2010).

Trade-offs between water balance and carbon sequestration and how to maximise water use efficiency and other environmental benefits are only beginning to be studied in detail (Barrett et al 2010). Developing methods that reliably predict both carbon sequestration and impacts on water balance at the small, local scales of many on-farm and remediation activities, as well as catchment wide scales, will be important to support decision-making regarding increased environmental plantings.

6.4 Summary

Responses to interviews conducted on carbon sequestration plantations are summarised in Table 11.

Table 11: Summary of interview responses.

Issue	Responses		
	Timber industry	Research scientists	Natural resource managers
Approaches used in the MDB for afforestation, primarily to provide carbon sequestration benefits	MIS had big impact on approaches, but more on coast than MDB. Legislation allows for limited carbon only plantations. Carbon price not at a level that it is profitable over other uses. Carbon plantations require less management and therefore generate less employment for communities. Government funding or carbon price is required for viable plantations, especially in low rainfall areas. Viability of carbon-only plantations is questionable.	Current investments in carbon sequestration are small. Several companies brokering land for biosequestration. Brokers buy land, establish carbon sequestration plantations and then sell property rights. Forest Productivity Index is used to identify potentially suitable land. Australian Carbon Schemes do not currently recognise below ground storage.	Treated coal seam gas water used to irrigate environmental plantations on private holdings. Carbon price increase would potentially drive an increase in afforestation, with potential for negative overall effects.
Species currently used or recommended for carbon sequestration plantations	Current policy places timber production as primary objective with other benefits maximised where possible. Native local species reduce risk of disease and more likely to cope with variability in water availability. Carbon plantings usually more diverse, diversity can spread risk. Good timber species sequester maximum carbon. Multipurpose forests can give a higher return in LRZ. Most mallees well-suited to MDB. Oil mallees eg blue-leaved mallee (*Eucalyptus polybractea)* perform well in low rainfall areas.	Silvicultural species used in general provide confidence in future projects. Species grown in lower rainfall areas less than 800 mm y^{-1}, have carbon sequestration as primary goal. Local species most appropriate for area. Blue-leaved mallee used for commercial oil production may flood market. Tall, dense, high energy, high density and good biomass species include: Chinchilla white gum (*Eucalyptus argiphoilea*), flat top or swamp yate (*Eucalyptus occidentalis*) and red ironbark (*Eucalyptus fibrosa*). Research on hybrids promising eg *Eucalyptus tereticornis* x *Eucalyptus grandis* grows well in Western Sydney (avg rainfall 800 mm y^{-1}).	Multiple NRM objectives ie erosion control, biodiversity and salinity management. Native local species preferred. Non-native plantings can have positive NRM outcomes in agroforestry setting. Carbon-only plantings not generally supported by CMAs.

Issue	Responses		
	Timber industry	Research scientists	Natural resource managers
Viability of carbon sequestration plantations across the MDB, contrasting high rainfall and low rainfall regions	HRZ – carbon-only plantations determined by competition between alternative land uses. LRZ – Carbon-only plantations more attractive because of low forest productivity. For similar land tenure, land costs strongly influenced by rainfall. Lower value crop requires lower land values.	Timber production only viable in HRZ. Best sequestration performance above 600 mm y^{-1}, but HRZ not viable for carbon-only because of high land values for other uses. Potential for Integrated agroforestry in HRZ. Most suitable area is 400-600 mm y^{-1} zone just below the traditional forestry zone. LRZ down to 300 mm y^{-1} attractive but low reliability of plantation establishment. Less carbon stored than in high rainfall zones. Mallees well suited to dry areas. Faster growing species better suited to wet areas. All plantings e non-viable below a rainfall threshold. Viability driven by combination of growth rates and opportunity costs (cf current value of land and agricultural production).	Monocultures of highly productive tree species will almost always sequester more carbon than local habitat species (even in low rainfall environments). Lack of data for most species in LRZ makes use of models such as NCAT/FullCAM less reliable.
Anticipated trends in carbon sequestration plantations	Depends on introduction of an emissions trading scheme. Long term revenue stream required to maintain healthy forests. Integrated approach preferred over large scale carbon-only plantings, to reduce risks. Carbon-only plantations more attractive in the future.	Increase in drivers to sequester carbon In the next 5-10 years, especially in international markets. Biosequestration and plantations are cheapest and immediately available methods for greenhouse gas mitigation. Carbon capture methods, such as geosequestration, unlikely to be available within 10+ years. Areas with additional biodiversity or salinity benefits will expand as will low rainfall zones.	Coal seam gas water likely to support increased establishment of irrigated carbon sequestration forestry. Changes in offset market treatment of regrowth (i.e. REDD, NCOS) may encourage increase in managed regrowth carbon sequestration rather than plantings. Capacity of carbon sequestration markets to value other environmental benefits may drive an increase.
Existing land use most amenable to conversion to carbon sequestration	Least potential in irrigated zone and high value areas such as dairy farming land. Collapse of MIS will allow some	Trade- offs to carbon sequestration, eg reduced runoff. Location to reduce impact on run-off reduces carbon	Data required to determine best land use, particularly regarding climate change

Issue	Responses		
	Timber industry	Research scientists	Natural resource managers
plantations	plantations to convert back to agriculture. Broad acre cropping in LRZ benefits from trees for diversification. Larger scale plantations on grazing land because of lower land prices, better rainfall and soil. Preference to integrate high value timber species into existing farms (agroforestry).	sequestration. Feasible to design landscapes and plant to reduce impacts on water. Marginal wheat land, grazing land, degraded land, portions of properties which are low yielding or inaccessible in HRZ suitable for carbon plantings. Potential multiple-benefits increase value of plantations and allow conversion of higher-value land.	impacts on land use. Net Carbon and Net Environmental cost and benefits for changing land use require further investigation. Suitable lands include marginal cropping land, sandy hillsides in Murray. Recent mapping undertaken by SAMRIC (SA M-DB Resource Information Centre) has identified best areas based on soil type and rainfall.
Current scientific knowledge on the impacts of carbon sequestration plantations on: a) Catchment water yield b) Salinity management c) Biodiversity d) Riparian management	b) Local impacts- groundwater seepage debate regarding upland management of groundwater. Localised control using salt tolerant species near saline seepages has declined in last 10 years. c) carbon plantations usually more diverse than traditional plantations, better for biodiversity.	a) Water yield impacted by plantation type, locality and rainfall. Increasing carbon assimilated requires more water. Knowledge gap in LRZ. b) Healthy forests typically reduce salinity impact. But use of groundwater by trees may reduce or increase salinity depending on local conditions. c) Establishment of plantations does not necessarily mean loss of biodiversity, but monocultures do not enhance biodiversity. Planting to improve biodiversity will require trade-offs against carbon sequestration . Inter-planting mixed species such as acacias and eucalypts create positive interactions that improve nitrogen-fixing. Limited field studies. d) Riparian plantings provide maximum value because of other environmental benefits.	a) Trees may increase local rainfall Runoff will either increase or decrease depending on soil condition, ground cover and tree density. b) Native plantings preferred as habitats for native species and have less stress on water resources. Plantations in recharge zones could affect deep drainage and offsite downstream dryland salinity. c) Biodiversity benefits depend on species selected and type of planting. Results strongly influenced by placement of planting in landscape. d) Plantations promote riparian revegetation and weed control.

Issue	Responses		
	Timber industry	Research scientists	Natural resource managers
Limitations in knowledge or knowledge gaps	Biggest gaps concern effects of carbon sequestration plantations on biodiversity and riparian management. Limited knowledge of where species grow best. Implications for disease management at local scales, for selected species.	Ability to optimise multiple costs and benefits. Understanding of landscape design to maximise benefits and minimise costs-using spatial and temporal optimisation methods. Flow-on effects of environmental plantations not well documented, and largely based on theoretical development. Limited empirical data. Uncertainty in the amount of sequestered carbon that ends up as soil or humus. Consequences of disturbing soil to create plantation may negate benefits of sequestration. Modelling studies do not adequately address assumptions and propagation of errors when up-scaling results of smaller studies to catchment scales. Trade-offs between water balance and carbon sequestration to maximise efficiency are inadequately understood.	Limited knowledge regarding local species carbon sequestration values limits their use in carbon plantations.

7 REVIEW OF LEGISLATION AND POLICIES ON AFFORESTATION FOR CARBON SEQUESTRATION

7.1 Introduction

This chapter reviews current legislation and policy of relevance to afforestation for carbon sequestration in the Murray-Darling Basin, highlighting legislation relating to the implications of carbon sequestration plantations on water use and management.

The review covers all State and Territory jurisdictions in the Murray-Darling Basin, making regional references where important. It also reports on relevant overarching Commonwealth legislation. However relevant Commonwealth documents are limited as the activities assessed are traditionally the responsibility of State jurisdictions.

The findings highlight growing strategic efforts by government in the area of greenhouse gas mitigation and the role of vegetation, through carbon sequestration. As this is a growing area of governance, a lot of discussion is contained in climate policy, with only some States beginning to develop legislation or strategy specifically related to afforestation for carbon sequestration. Carbon sequestration is however often highlighted as a benefit of general forestry activities by most agencies and documents.

In addition, the changing water use management framework in Australia and the MDB is evident. The overarching Commonwealth *Water Act 2007* guides the States toward a more sustainable allocation of water between consumptive users and the environment. It also highlights the balancing of water use in the MDB and focuses on frameworks for integrated catchment management. Accounting for the indirect use or interception of water by planted vegetation is treated inconsistently between jurisdictions. Afforestation results in the uptake of groundwater, and interception of overland flow and rainfall. Only some legislation (for example, the *Water Resources Act 2007* in the ACT) refers specifically to this form of water use (flow interception) – but the specifics of how this is assessed and managed under an entitlement framework are unclear. In Queensland water use by planted crops or vegetation is not accounted for in the entitlement framework, and is an issue that needs to be addressed (M Hill pers comm, Senior Water Planner, Queensland Department of Environment and Resource Management).

Afforestation for carbon sequestration includes a diversity of practices, for example, traditional plantation activity, private on-farm forestry, and native forest practices. Overall, each afforestation activity will need to be assessed on a case-specific basis to determine the exact application of legislative requirements.

7.2 Methods

This chapter is an overview of the relevant legislation and policy, highlighting the purpose and relevance to afforestation, carbon sequestration and associated water use. It does not constitute an in-depth analysis; however the methods have been developed to allow a rigorous assessment across jurisdictions. Legislation and policy of the Commonwealth and the MDB States of Queensland, New South Wales, Australian Capital Territory, Victoria and South Australia are reviewed.

The project scope restricted the review to high level, overarching Acts. Regulations and Codes beneath these Acts were not explicitly considered, however some key documents have been discussed. Further analysis of these secondary pieces of legislation would be beneficial for a more in-depth analysis.

Where policy directions appeared particularly important, or no key legislation could be identified, policy or strategy was also identified and outlined.

After a preliminary search it was determined that the overview should be defined by six categories of legislation and policy. These six categories allowed review of the major areas of legislation related to afforestation, carbon sequestration and water use. The categories also allow the regulation of a range of different commercial and non-commercial afforestation activities, including timber plantations, State forest reserves, private farm forestry and native forest activities to be assessed. The six categories are:

- *Forestry* – Legislation and policy directly relating to forestry activities, including plantation, State forest reserves, and private forestry. Generally, these documents provide guidance on where forestry development is expected, what forestry regulations apply to afforestation, and any relevant carbon sequestration provisions.
- *Water* - This section is focused on water use implications, rather than water quality. The focus here is water use by afforested areas and how this is factored into the water use management framework. Generally this involves an analysis of whether interception or uptake of water by vegetation is included in the definition of water use, take or interference, and whether it requires an entitlement.
- *Climate change* – The main driving factor of carbon sequestration activities is the mitigation of climate change. Statutory legislation in this arena is sparse however policy and strategy are quickly developing and frequently consider the benefits of afforestation for carbon sequestration.
- *Land Use and Planning* – Afforestation usually constitutes a type of development under State planning legislation (which frames local development assessment processes). Afforestation may also require environmental assessments to be carried out under these Acts.
- *Environment* – This category was not always relevant. It relates mainly to conservation and dedication of national park areas.
- *Vegetation* – This category was not always relevant. Primarily, these regulations consider clearing of forest and native forest operation, and how afforestation and carbon sequestration may interact.

The review of each document began by conducting a general overview of the document's framework, parts, and overall intent. A key word search was then undertaken on each document. The following key words were searched (* indicates that longer versions of these words would be picked up in the search, examples of these additional words are included):

Afforestation	Forest* (eg *forestry*)	Take
Reafforestation	Sequest* (eg *sequestration, sequester*)	Flow
Reforestation	Carbon	
Plant* (eg *plantation, planting*)	Water	

Hits for key word searches were then investigated in detail to determine their relevance to carbon sequestration afforestation and water use implications.

Finally, much of the information compiled needs to be applied on a case-specific basis. Assessment and approval processes cannot always be generalised and further approval through Regulations and Codes will also be necessary.

7.3 Findings

The findings of this review are presented in Table 12 according to jurisdiction and legislation category. The table indicates which legislative or policy documents are relevant, and describes the purpose of the document and relevant sections.

Table 12: Legislation and policy review of afforestation for carbon sequestration, and associated water use implications in the Murray-Darling Basin.

COMMONWEALTH of AUSTRALIA		
Category	Act of Policy	Intent
FORESTRY	*Regional Forests Agreement Act 2002*	This Act gives the Commonwealth certain obligations under Regional Forest Agreements (RFA). RFAs are 20 year plans for the conservation and sustainable management of Australia's native forests. RFAs in Victoria and New South Wales extend into the Murray-Darling Basin. These agreements aim to integrate Commonwealth and State forest management and balance conflicting forest uses, including meeting goals of forest growth for carbon sequestration.
	Income Tax Assessment Act 1997	From 1st July 2007, forest growers can claim a tax deduction for the expense of establishing trees in a carbon sink forest (Subdivision 40 – J).
	National Forests Policy Statement	This is a strategic policy document aiming to ensure the sustainable management of forests across Australia by Commonwealth and State governments. Includes policy discussing reforestation (for example, methods of reforestation) and indicating that the carbon sequestration properties of plantations and other forestry (private, conservation) are positive benefits of reforestation.
WATER	*Water Act 2007*	The *Water Act 2007* provides for the overall integrated management of the Murray-Darling Basin water resources by the Commonwealth and Basin States. The aim is to ensure the sustainable allocation of water resources which are currently over-allocated or overused and to protect the ecological values and ecosystems services of the basin, whilst allowing for economic and social uses of water. The Act sets up a framework for the Basin States to manage and sustainably allocate water. Specific water use provisions which relate to the use of water by forests for carbon sequestration are contained within State legislation. The Act provides for the development of a Basin Plan to manage water taken from the MDB. The take of water is defined below. Clarification is required to determine whether water use by planted trees is considered as "take" under these definitions, and whether this form of water use is therefore regulated under the Act. However it appears that the *impeding* of water flow by afforested areas *into* the water resource is captured under s4 (b) below – and therefore would require entitlement for water interception by afforested areas. *s4 Definitions – "take"* water from a water resource means to remove water from, or to reduce the flow of water in or into, the water resource including by any of the following means: (a) pumping or siphoning water from the water resource; (b) stopping, impeding or diverting the flow of water in or into the water resource; (c) releasing water from the water resource if the water resource is a wetland or lake; (d) permitting water to flow from the water resource if the water

COMMONWEALTH of AUSTRALIA		
Category	Act of Policy	Intent
		resource is a well or watercourse; and includes storing water as part of, or in a way that is ancillary to, any of the processes or activities referred to in paragraphs (a) to (d).
CLIMATE CHANGE	Carbon Pollution Reduction Scheme (CPRS)	Currently, the introduction of a CPRS has been delayed until the end of the current Kyoto Commitment, at the end of 2012. The possible timing of introduction is not known and may be affected by political changes. Reforestation is defined under the CPRS as 'forests established by people since 1990 on land that was clear of forest on 31 December 1989.' (DCCEE 2010) When in force, the CPRS is expected to include provisions for the management of reforestation for carbon sequestration. Eligible persons will be able to participate in the CPRS through holding emissions units or carbon sequestration rights.
LAND USE PLANNING	Not applicable. Land use planning is regulated by State jurisdictions.	
ENVIRONMENTAL	*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)	The *Environment Protection and Biodiversity Conservation Act 1999* provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places — defined in the Act as "matters of national environmental significance" (MNES). There are seven MNES to which the EPBC Act applies, these are: ▪ world heritage sites; ▪ national heritage places; ▪ wetlands of international importance (Ramsar wetlands); ▪ nationally threatened species and ecological communities; ▪ migratory species; ▪ Commonwealth marine areas; and ▪ nuclear actions. Generally, activities which may affect MNES require self-assessment to determine whether referral for further assessment is triggered. This is captured under Chapter 3 of the EPBC Act. The EPBC Act (s40) defines *forestry operations*. This means any of the following done for commercial purposes: (a) the planting of trees; (b) the managing of trees before they are harvested; (c) the harvesting of forest products; and includes any related land clearing, land preparation and regeneration (including burning) and transport operations. For purposes of paragraph (c) forest products means live or dead trees, ferns or shrubs, or parts thereof. Forestry operations captured under a Regional Forest Agreement (RFA) do not require approval under Chapter 3 of the EPBC Act (RFAs capture assessment of significant environmental impacts). The need for approval under the EPBC Act would be determined on a case-specific basis.
VEGETATION	No provisions relevant to afforestation for carbon sequestration or associated water use.	

QUEENSLAND		
Category	Act of Policy	Category
FORESTRY	*Forestry Act 1959*	The purpose of this Act is "to provide for forest reservations, the management, silvicultural treatment and protection of State forests, and the sale and disposal of forest products and quarry material, the property of the Crown on State forests, timber reserves and on other lands; and for other purposes". It does not identify specific future intent for afforestation, or carbon sequestration. Carbon sequestration is only discussed in terms of plantation forestry, as the selling of a carbon sequestration right is considered included in the commercial purpose of plantation forestry. Carbon sequestered within a tree or vegetation is considered a natural resource product. The Act considers the management of natural resource products, for example entering into agreements about selling the land on which natural resource products exist.
	Queensland Timber Plantation Strategy 2020	The purpose of this strategy is to indicate the Queensland government's objective to encourage new, sustainable private investment in the timber plantation sector. It outlines key strategies and actions to deliver sustainable plantation growth over the coming decade. Aspects relevant to afforestation for carbon sequestration include: ▪ Notes the environmental benefits of plantations including removing carbon dioxide from the atmosphere. ▪ Indicates Queensland government support for the development of large industrial timber plantations, including existing ones – for a range of purposes including carbon sequestration. ▪ Expansion of the plantations in certain areas – only area in Queensland relevant to the MDB is the planned expansion of plantation in the south east corner of Queensland (primarily around and south of Toowoomba). ▪ The intent that Queensland plantation develops based on market trends to determine the composition, size and location of plantation. Consistent with a move to transfer plantation management to the private sector in Queensland. ▪ It is a Queensland government priority to continue research into carbon sequestration outcomes and promoting small-scale timber plantations as part of integrated farming enterprises.
	Forestry Plantation Queensland (FPQ) Strategic Plan 2009 – 2013	The Plan notes some management goals of relevance to the water use implications of forestry. These would be carried out at a management level and are guided by the following (s6.3): *The forest manager shall manage forest operations to ensure hydrological flows are in accordance with authorised regional catchment goals, where they exist. Where regional catchment goals do not exist, the forest manager shall liaise with the relevant catchment management authorities and minimise adverse environmental impact of changes in hydrological flows.*
WATER	*Water Act 2000*	The *Water Act 2000* provides for the sustainable management of water use in Queensland, including the allocation of entitlements for use and environmental purposes. To take or interfere with water, an entitlement is required under the Act, (through the relevant water resource plan). An owner of land who is actively *taking or interfering* with water requires such an entitlement, and an owner of land includes 'the plantation licensee of

QUEENSLAND		
Category	Act of Policy	Category
		a plantation license under the *Forest Act 1959*' (s203). However, *taking or interfering* with water does not include the planting of vegetation which may intercept the flow of water into the watercourse. Direct irrigation, or the storing of water to do so, does however need an entitlement.
CLIMATE CHANGE	South East Queensland Climate Change Management Plan (Draft) (SEQ CCMP) (June 2009)	Includes policies to reduce greenhouse gas emissions, including through increased carbon storage (Policy 1.3.5). Discusses draft actions to meet these goals (Draft action 15 and 16): *Policy 1.3.5* *Increase stored carbon through retention of planting of trees or other vegetation, and other land management practices that also provide sustainability and amenity outcomes.* *Draft Action 15. Identify and map areas suitable for carbon sequestration through vegetation retention or enhancement.* This is considered of immediate priority for action. Currently investigations are being made through local governments and the SEQ Regional Carbon Sink Task Force to develop bio-sequestration on a regional scale, including integration of sequestration actions with other natural resource and water management outcomes. *Draft Action 16. Increase carbon sequestration through vegetation retention or enhancement.* This action will follow on from Draft Action 15. The intention is to amend planning schemes to reflect mapped areas as suitable for revegetation or rehabilitation. The SEQ CCMP encourages total water cycle management to minimise impacts of land use and climate change on the natural water cycle, including aquatic ecosystems. The final SEQ CCMP will have statutory force.
LAND USE AND PLANNING	*Sustainable Planning Act 2009*	Forest practice, including the planting and management of trees, is considered "operational work" (s10). Carrying out operational work may require development assessment; however this would need to be assessed on a case-specific basis.
ENVIRONMENTAL	*Nature Conservation Act 1992*	s70 A, 70 C, 70 F Assists in the dedication of areas within State forests, timber reserves, *Land Act* reserves or unallocated State land as protected areas. A forest reserve may be managed to protect conservation values, or to provide for the continuation of any lawful existing use. A lawful existing use only applies to the purpose of commercial logging if the purpose of the logging is to remove plantation trees to restore the land's conservation values.

NEW SOUTH WALES		
Category	Act or Policy	Intent
FORESTRY	*Forestry Act 1916*	The purpose of this Act is to provide for the dedication, reservation, control and use of State forests, timber reserves, and Crown lands for forestry and other purposes. It also provides for the management of timber and forestry activities, including the selling forestry products. The Act has some provisions which relate to tree growth

NEW SOUTH WALES		
Category	Act or Policy	Intent
		for carbon sequestration purposes. The Act defines carbon sequestration and rights to carbon sequestration - s33B. Through s87A of the *Conveyancing Act 1919* carbon sequestration is defined as the process by which the tree or forest absorbs carbon dioxide from the atmosphere. A person may be a holder of a carbon sequestration right - a person who is entitled to exercise (or who in the future may be entitled to exercise) to the right (s33B). s33C indicates the powers of the Forestry Commission in respect of carbon sequestration rights. The commission may: a) acquire, hold, sell or otherwise deal with or trade in carbon sequestration rights, and b) exercise the powers referred to in section 11(1)(m3) [see below*] for the benefit of investors in carbon sequestration rights, and c) provide services in request of the verification of the quantity of carbon sequestration by any tree or forest *s11(1)(m3) The commission may – (i) procure the use of land on behalf of investors under a forestry right or by purchase, lease or otherwise, (ii) establish and maintain timber plantations on behalf of investors or other persons, (iii) harvest and market timber grown on behalf of investors or other persons
	Forestry and National Parks Estate Act 1988	Sets out forest agreements and other mechanisms for the joint management of forest areas between the Department of Environment, Climate Change and Water, and Forests NSW.
	Plantations and Reafforestation Act 1999	This Act facilitates reafforestation of land and establishment of timber and other forest plantations. A plantation is defined as an area of land on which the predominant number of trees or shrubs forming, or expected to form, the canopy are trees or shrubs that have been planted (whether by sowing seed or otherwise), and include trees for the purpose of acquiring or trading in carbon sequestration rights. A natural forest is not considered under this Act. The Act establishes the Plantations and Reafforestation Code which provides a framework for managing plantations under the Act, including protecting rivers and lakes and preventing operations that obstruct or detrimentally affect the flow of waters (s27(2)(c)).
	Private Native Forests Code (under the *Native Vegetation Act 2003*)	The Code regulates private native forestry operations. It highlights the importance of private native forestry for sequestration of greenhouse gases. Harvesting operations under the Code need to be carried out in accordance with a Property Vegetation Plan which constitutes an agreement between the landowner and the Department of Environment, Climate Change and Water. This includes regulation of harvesting activities to prevent impacts to water quality.
WATER	*Water Management Act 2000*	The purpose of this Act is to provide for sustainable and integrated management of New South Wales water sources for the benefit of present and future generations. Interception land uses, such as plantation forestry, which are assessed as over an agreed threshold

NEW SOUTH WALES		
Category	Act or Policy	Intent
		size may require a water access entitlement in the future; however this is not yet incorporated into a management framework. As discussed in Section 4.0 below, recognition of the need to incorporate interception land uses in water management has occurred under the National Water Initiative (NWI).
CLIMATE CHANGE	*NSW State Plan 2010* and NSW Climate Change Action Plan (under development)	The NSW State Plan 2010 is directing the development of the NSW Climate Change Action Plan, which is currently under development. The Climate Change Action Plan will aim to increase the extent and improve the condition of native vegetation and habitats.
	The Electricity Supply Act 1995 and the associated *Greenhouse Gas Benchmark Rule (Carbon Sequestration) No. 5 of 2003.*	The *Electricity Supply Act 1995* sets up the Greenhouse Gas Abatement Scheme (GGAS) which includes afforestation for carbon sequestration (see rule below) activities. The objective of the Act (s97A) is (1) The objects of this Part are to reduce greenhouse gas emissions associated with the production and use of electricity and to encourage participation in activities to offset the production of greenhouse gas emissions. (2) For those objects, this Part: (a) establishes State greenhouse gas benchmarks and individual greenhouse gas benchmarks for the reduction of greenhouse gas emissions that are to be met by retail suppliers, market customers and certain other persons who supply or consume electricity, and (b) provides for greenhouse gas benchmarks to be complied with by acquiring certificates relating to the carrying out of activities that promote the reduction of greenhouse gas emissions, and (c) provides an economic incentive to undertake activities resulting in the reduction of greenhouse gas emissions by imposing a penalty on greenhouse gas emissions above the specified benchmark.
LAND USE PLANNING	*Environmental Planning and Assessment Act 1979 No. 3*	This Act is the primary legislation governing land use and development in New South Wales. Development approval under the Act would need to be sought on a case-specific basis. Consideration of the environmental impact of an activity may be required – s111 Duty to consider environmental impact - (1) For the purpose of attaining the objects of this Act relating to the protection and enhancement of the environment, a determining authority in its consideration of an activity shall, notwithstanding any other provisions of this Act or the provisions of any other Act or of any instrument made under this or any other Act, examine and take into account to the fullest extent possible all matters affecting or likely to affect the environment by reason of that activity. Potentially, this Duty (s111) could be interpreted to include the hydrologic impacts of plantations on watercourses. Some activities may require an Environmental Impact Statement (EIS) - s112 Decision of determining authority in relation to certain activities (1) A determining authority shall not carry out an activity, or grant an approval in relation to an activity, being an activity that is a prescribed activity, an activity of a prescribed kind or an activity that is likely to significantly affect the environment (including critical habitat) or threatened species, populations or ecological communities, or their habitats, unless:

NEW SOUTH WALES		
Category	Act or Policy	Intent
		(a) the determining authority has obtained or been furnished with and has examined and considered an environmental impact statement in respect of the activity
ENVIRONMENT	*National Parks and Wildlife Act 1974 No. 80*	This Act plays a role in the management of State forests, including the development of management plans.
	Catchment Management Authorities Act 2003	This Act establishes catchment management authorities and devolves to them certain natural resource management functions in their regions. This includes managing 'catchment activities' including planting trees. Other management areas under the Act include natural resource planning, and integrated catchment and local land use decision-making.
VEGETATION	*Native Vegetation Act 2003*	This Act provides for the management of native vegetation in a sustainable and regional manner which considers the social, environmental and economic interests of the State. The Act prevents broad-scale clearing of native vegetation and aims to conserve its environmental value.

VICTORIA		
Category	Act of Policy	Intent
FORESTRY	*Forestry Rights Act 1996*	This Act provides for ownership of trees to be separated from the ownership of land on which the trees grow. It facilitates investment in plantations on private land, including third party investments for the purpose of carbon credit trading (State Government of Victoria 2008). A number of provisions are important in regard to afforestation for carbon sequestration purposes. *s1 Purpose* The purpose of this Act is to provide for the creation of forest property rights. A *carbon sequestration right* means a right to commercially exploit carbon sequestered by trees *s5 Agreement creating forest property right* (1) An owner of land may enter into an agreement with a person— (a) to grant to that person a right to— (i) plant, maintain and harvest forest property on that land; or (ii) maintain and harvest forest property planted on that land or derived from forest property planted on that land; and (b) to grant to that person a carbon sequestration right in relation to forest property on that land; and (c) to vest the ownership of the forest property in that person; and (d) subject to the agreement, to permit the person— (i) to enter the land which is subject to the agreement; and (ii) to carry out any works which are necessary for the purposes of planting, maintaining or harvesting the forest property; and (iii) to monitor and measure carbon sequestered by trees on that land. *s12 Carbon rights agreement*

VICTORIA		
Category	Act of Policy	Intent
		(1) A forest property owner may enter into an agreement with a person to grant the forest property owner's carbon sequestration right to that person. (2) A carbon rights agreement must— (a) be in writing; and (b) specify the following— (i) the parties to the agreement; and (ii) the land to which the agreement applies; and (iii) the rights and duties of the parties to the agreement; and (iv) the date or circumstances under which the agreement terminates. (2) A carbon rights agreement may specify any other matters consistent with the matters set out in subsection (2) to which the parties agree. s4 indicates that carbon rights do not constitute an interest in land, or a forest property agreement under this Act.
	Forests Act 1958	The Act sets out the management framework for forestry and plantation activities including tree planting. There are no specific provisions for afforestation for carbon sequestration.
	Sustainable Forests (Timber) Act 2004	This Act provides a framework for the sustainable management of forests considering the whole forest estate. There are no specific provisions for afforestation for carbon sequestration.
	Code of Forest Practice (2007)	This Code provides guidance for forest operation to deliver sound environmental performance when undertaking commercial timber production. The Code applies to forest management and operations on land that is used for timber production.
WATER	*Water Act 1989*	This Act provides for the protection and management of underground and surface water resources, water catchments and the provision of allocations for domestic, industrial, agricultural, and environmental water use. No particular provisions are made for water use by afforestation purposes. Direct water use, for example through irrigation, of afforested areas would require an entitlement under the Act. Water use for these purposes would be assessed on a case-specific basis. If the afforested area interferes with the flow of water in a waterway, this may require an entitlement, but would need to be assessed on a case-specific basis. Whether the natural uptake of water by planted vegetation is considered to constitute interference with the flow of a waterway is not made clear.
	Catchment and Land Protection Act 1994	This Act indicates general landowner duties. These include ensuring that his or her land (including soil, water, vegetation and fauna on land) protects water resources. It is unclear whether this extends to the impact of afforestation on water use.
CLIMATE CHANGE	Victorian Climate Change Green Paper (2009)	Indicates that the forestry sector is important in reducing greenhouse gas emissions and that forestry land uses should be fostered to ensure continued reduction in emissions. It is questioned whether, without the implementation of a CPRS, the market will provide opportunities for carbon sequestration and farm forestry activities.
LAND USE PLANNING	*Planning and Environment Act 1987*	The purpose of this Act is to establish a framework for planning the use, development and protection of land in Victoria in the present and long-term interests of all Victorians. There is no mention of afforestation, forestry or plantation land uses. The definition of

VICTORIA		
Category	Act of Policy	Intent
		"development" does not appear to factor in these land uses.
ENVIRONMENT	No provisions relevant to afforestation for carbon sequestration or associated water use.	
VEGETATION	Victorian's Native Vegetation Management Framework (2007)	Under this framework, certain management goals are identified. Two of these support afforestation for carbon sequestration purposes: ▪ Enhanced amelioration of the impact of climate change by significantly increasing Victoria's carbon sinks through revegetation and regeneration. ▪ Increased carbon sinks and provision of a range of other benefits through development and expansion of private forestry in a way that complements native vegetation retention. Regional Native Vegetation Plans will be developed to outline priorities, responses, targets and minimum standards for successfully achieving the above goals within frameworks of sustainable catchment-wide management.

SOUTH AUSTRALIA		
Category	Act of Policy	Intent
FORESTRY	Guidelines for Plantation Forestry in South Australia 2009	This document guides plantation forestry development in South Australia and provides an outline of legislative requirements for such developments. This document indicates that commercial scale forest activity in South Australia is mainly confined to three regions. Two of these are within the Murray-Darling Basin area – the South East region, and the Mount Lofty Ranges/Mid North. Farm forestry plantings also exist in these regions. Of the total amount of farm forestry within South Australia 86% exists in the South East region and 11% in the Mount Lofty Ranges/Mid North.
	Forest Property Act 2000	This Act provides for the separation of ownership of land, forest vegetation and carbon rights for improved investment security and transferability. *3A—Carbon absorption capacity of the forest vegetation to be a form of property* (1) The capacity of forest vegetation to absorb carbon from the atmosphere is a form of property (a *carbon right*) in the nature of a chose in action. (2) A carbon right attaches to the forest vegetation to which it relates, and ownership of the right passes with ownership of the forest vegetation unless ownership of the right is separated from ownership of the forest vegetation under a forest property agreement. (3) A forest property agreement may relate to carbon rights in respect of the past absorption of carbon from the atmosphere as well as to those in respect of the absorption of carbon from the atmosphere during the currency of the agreement. *s5 Types of forest property agreements* (1) Forest property agreements are of 2 types – (a) forest property (vegetation) agreements; and, (b) forest property (carbon rights) agreements. (2) A forest property (vegetation) agreement separates ownership of forest vegetation from ownership of the land on which the

SOUTH AUSTRALIA		
Category	Act of Policy	Intent
		vegetation is growing, or is to be grown, by transferring ownership of the forest vegetation from the owner of the land (the transferor) to another (the transferee) without severance of the vegetation from the land. A forest property (carbon rights) agreement separates ownership of carbon rights from ownership of the vegetation (the transferor) to another (the transferee).
	Forestry Act 1950	This Act applies to the creation, management and protection of public owned state forests, including state forest reserves and native forest reserves. It does not apply to forestry activities on freehold land. This Act includes provisions for the declaration, control and planting of forests: s12 indicates the ability to plant in forest reserve areas – *s12 Planting and milling of timber* The Corporation may - (a) plant any forest reserve with trees; (b) take any action necessary or convenient to be taken to protect any trees in a forest reserve and ensure their proper growth; establish, maintain, and operate mills, plant and machinery for the milling and treatment of such trees and timber.
	Local Government (Forestry Reserves Act) 1944	This Act provides for the establishment and management of forests by municipal and district councils. s3 provides for any Crown land which has been dedicated or reserved as a forestry reserve and used for forestry purposes to be declared a local government forestry reserve.
WATER	*Natural Resources Management Act 2004*	Provides for restrictions which regulate the impact of plantation forestry on water resources, for example through Water Allocation plans, or Natural Resources Management Plans by declaration of plantation forestry as a water affecting activity that requires a permit for development. In addition, s133 indicates that it is the duty of the landowner whose land is adjacent to a watercourse or waterbody to take reasonable measures to prevent or minimise harm to the resource. Afforestation developments would need to be assessed on a case-specific basis to determine specific restrictions applicable, or whether water impacts by the proposed afforestation where regulated under s133.
	South Eastern Water Conservation and Drainage Act 1992	Specific water management in the rural land of the south-east of the State.
	River Murray Act 2003	Under the Act, s23 indicates a General Duty of Care that all persons must take to prevent or minimise harm that the activities they have undertaken may have on the River Murray. This includes risk of harm, harm in the future, and temporary or permanent harm. Under this duty, persons must consider the potential environmental, social and economic consequences their actions may have, and consider the environmental and economic significance of the River Murray.
CLIMATE CHANGE	*Climate Change and Greenhouse Emissions Reduction Act 2007*	This Act encourages actions which will reduce or limit the emission of greenhouse gases into the atmosphere, and aims to reduce the impact of climate change on the region. Therefore, targets within this legislation generally support activities such as afforestation for carbon sequestration.
LAND USE PLANNING	*Development Act 1993*	Under this Act, a change of land use requires a development application to be submitted through the local government and assessed against the planning guidelines of the relevant authorities. Planting of trees or forestry development is considered a change of land use which requires development approval (unless it is the

SOUTH AUSTRALIA		
Category	Act of Policy	Intent
		replanting of an existing site). Planning authorities can impose design requirements upon the developer of forestry or plantation developments.
ENVIRONMENT	*Natural Resources Management Act 2004*	This Act sets out provisions for the management and protection of natural resources, including vegetation. It may relate to the establishment of trees for carbon sequestration, for example through provisions requiring the alignment with regional Natural Resource Management plans, and restrictions on the clearing of areas of native vegetation.
VEGETATION	*Native Vegetation Act 19991*	This Act provides for the preservation of native vegetation and includes legislative controls for native vegetation clearance. Depending on afforestation activities, this may be relevant on a case-specific basis.

7.4 Legislative or policy motivation for afforestation for carbon sequestration

There is a growing strategic requirement by government for greenhouse gas mitigation via afforestation for carbon sequestration purposes. Table 13 highlights the specific legislative and policy documents identified in Table 12 which actively encourage the planting of trees for the purpose of carbon sequestration.

7.5 Comparison with National Water Commission report

The National Water Commission (NWC) released a report in May 2010 discussing the impact of certain land use activities on water availability due to the interception of water by these activities (SKM, CSIRO, and Bureau of Rural Sciences 2010). The National Water Initiative (NWI) explicitly recognises that water interception activities can reduce water availability. State governments have committed (under the NWI) to the recognition of water interception in water management and allocation by 2011 (SKM, CSIRO, Bureau of Rural Sciences 2010). Of relevance to this discussion is the report's review of policy and legislation as it relates to plantation forestry as a water interception activity.

The legislation and policy component of the NWC report has a different scope to this chapter. Firstly, it refers specifically to water use policy and legislation, rather than the range of forestry and other environmental legislation considered within this chapter. Secondly, it considers only commercial plantations, rather than also considering other afforestation practices such as on-farm forestry or native forest practices. This chapter however endeavours to overview legislation as it relates to all forms of potential afforestation. Thirdly, the NWC report does not consider Commonwealth legislation, and covers all States, not only Murray-Darling Basin States. Finally, this chapter focuses mainly at the *Act* level of legislation; however the NWC report includes more thorough consideration of an additional level of subordinate legislation and associated management plans.

Table 13: Current policy and legislation that specifically encourages afforestation for the purpose of carbon sequestration.

State	Act or Policy	Motivation to plant for carbon sequestration purposes
Commonwealth of Australia	*Income Tax Assessment Act 1997*	This Act encourages the planting of trees as carbon sink forests by providing tax deductions for these activities.
	CPRS	If enacted, the CPRS will allow eligible persons to own and trade carbon rights. The economic advantage of holding these rights for a carbon sequestration plantation may actively encourage the planting of trees for carbon offset purposes.
Queensland	*Queensland Timber Plantation Strategy 2020*	The Strategy indicates an intention to expand plantations in the south-east corner of Queensland (around and south of Toowoomba); and, in addition, the intention to encourage planting in the form of small scale timber plantations as part of integrated farming enterprises.
	South East Queensland Climate Change Management Plan (Draft, June 2009)(SEQCCMP)	As part of the South East Queensland Regional Plan 2009 – 2031, the SEQ CCMP directs the identification and mapping of areas suitable for vegetation planting for the purposes of carbon sequestration. It also aims to develop mechanisms within planning schemes which encourage this planting.
New South Wales	*The Electricity Supply Act 1995* and associated *Greenhouse Gas Benchmark Rule (Carbon Sequestration) No. 5 of 2003*	This Act aims to reduce greenhouse gas emissions associated with the production and use of electricity and encourages activities which offset the production of Greenhouse Gas Emissions, including afforestation for carbon sequestration.
Australian Capital Territory	*Weathering the Change*	This policy encourages the extension of urban forestry across the ACT as a means of achieving carbon sequestration goals.
Victoria	*Victorian Climate Change Green Paper (2009)*	This policy indicates that forestry should be fostered and increased to ensure continued reduction in greenhouse gas emissions.
	Victoria's native Vegetation Management Framework (2007)	This policy supports increased afforestation to significantly increase Victoria's carbon sinks, including expansion of private forestry.
South Australia	*Climate Change and Greenhouse Emissions Reduction Act 2007*	This Act generally encourages mitigation activities which reduce the amount of greenhouse gases in the atmosphere, including afforestation for carbon sequestration.

The overall finding of the NWC report is that aside from South Australia's process for dealing with forestry water use, there is no formal, nor comprehensive, recognition of significant water interception activities by the other Australia States and their water allocation and management frameworks (SKM, CSIRO, Bureau of Rural Sciences 2010). The findings of the NWC report and this study are compared in Table 14.

7.6 Conclusion

A broad range of policy and legislation exists that is relevant to afforestation for carbon sequestration purposes, and the associated water use implications. This study has assessed the main categories of legislation that may drive changes in land use through forest plantations for the purpose of carbon sequestration, and which may regulate effects of plantations on water quality and quantity. Any further investigations should delve further into subordinate legislation provisions and strategic policy directions, and highlight any newly developed legislation or policy in the arena. This further investigation should intend to build upon knowledge gained from the NWC report, including investigation of changes in water policy at management level as States move to comply with the NWI requirements to recognise water interception through legislative changes.

Carbon sequestration plantations are currently encouraged by a raft of legislation and supporting policies in the all of the MDB states. However, only South Australia appears to recognise the potential effects of plantations on water supply and stream flow under existing legislation. Legislation in the Australian Capital Territory, Victoria, and the Commonwealth has provisions which could be interpreted to capture certain aspects of forestry water use. However, responsibilities for implementing legislation are diffused across different levels of government and among multiple agencies, potentially resulting in inconsistent interpretation and implementation.

The future introduction of a CPRS may provide additional incentives for carbon sequestration plantations where potential risks to water supply are inadequately managed by existing safeguards.

Table 14: Comparison of legislation and policy drivers relevant to managing water interception activities of carbon sequestration plantations identified by the NWC report, and this study (Table 12).

State	NWC Report	This study
Queensland	No current policy. Interception of water by commercial plantations in Queensland is not considered a concern by the NWC report.	Water interception by all forms of vegetation is not included in a water management framework (indication by State government is that this is a concern and should be recognised).
New South Wales	No current policy. Groundwater management plans acknowledge that plantations should be included as a water use; however licenses for groundwater extraction are not currently required. In the future, water sharing plans will assess whether individual plantation developments will significantly intercept water and therefore require a license to be managed under the *Plantations and Reafforestation Act 1999.*	The NWC report provides further detail at a management plan level.
Australian Capital Territory	No current policy. Interception of water by commercial plantations in the ACT is not considered a concern.	The Water Resources Act 2007 recognises the interception of water by vegetation through s11(a)(iii). This indicates that the definition of “taking water” which requires an entitlement includes ‘do[ing] anything else that results in a reduction of flow of surface water in a waterway’. Water interception by afforestation may be captured under this clause.
Victoria	No current policy. However the issue has been recognised and policy is being developed in the 12 months following May 2010.	There is a lack of clarity in the legislation. It is unclear whether interception of water by vegetation constitutes interference with water which therefore requires an entitlement. *The Catchment and Land Protection Act 1994* also highlights a general landowner duty to ensure water resources are protected. It is unclear whether the impact of afforestation on water use is captured by this requirement.
South Australia	Recent policy developed. Through revision of the existing groundwater allocation plan, new plantations now need to acquire a water license for groundwater extraction. Licensing depends on the amount of interception of groundwater recharge and the depth of groundwater below the surface.	*The Natural Resource Management Act 2004* indicates that water allocation plans are developing ways of accounting for interception activities.

*SKM, CSIRO, Bureau of Rural Sciences (2010).

8 ASSESSING RATES OF CHANGE IN AFFORESTATION

8.1 Introduction

Estimates of changes in afforestation rates in the MDB have been made by a number of authors (eg Ferguson et al 2002; Hairsine and Polglase 2004; Lawson et al 2008; Parsons et al 2007; Schrobback et al 2009; Hafi et al 2010,). This section assesses rates of afforestation based on survey of regional catchment management and natural resource management groups within the Murray Darling Basin. Respondents were questioned about current plantations, any environmental plantings or proposed plantings within their regions, and their interest in future afforestation initiatives for carbon sequestration. Six major tree planting organisations were also contacted to obtain information on their plantings within the MDB.

This section provides a base case scenario of current plantations to allow estimation of a minimum rate of change for primarily carbon plantations.

8.2 Environmental plantings by CMAs

Nineteen Catchment Management Authorities (CMA's) and natural resource management groups lie fully or partially in the MDB (Figure 12). The total area of the CMA's occurring within the MDB is over 106 million hectares, with approximately 284,000 hectares under plantation of one kind or another. Only about 14,000 hectares of this has been planted primarily for carbon sequestration.

Each CMA received a score of current activities or likelihood of expanding their carbon-only planting (Table 15), based on:

- Current area under carbon sequestration plantings;
- Proposed or fully funded programs for future plantings; and
- Level of interest in environmental plantings by the CMA's and incentives provided to landholders.

Scores were allocated as:

0 – limited current plantings, no programs and no interest in pursuing programs for carbon plantings.

1 – Some current carbon-only plantings or some proposed programs or interest in pursuing carbon plantations; or

2 – Relatively large current plantings and or current programs to plant and actively pursuing further opportunities for planting.

CMA's varied markedly in the current planting, level of interest and knowledge about environmental plantings. The Goulburn-Broken CMA had over 7,000 hectares under primarily environmental plantings and many of their plantations had been the subject of studies into carbon sequestration (eg England et al 2006). Other groups had no current forestry plantations at all and no plans or interest in establishing plantations or pursuing environmental grants to encourage landholders to plant for environmental return.

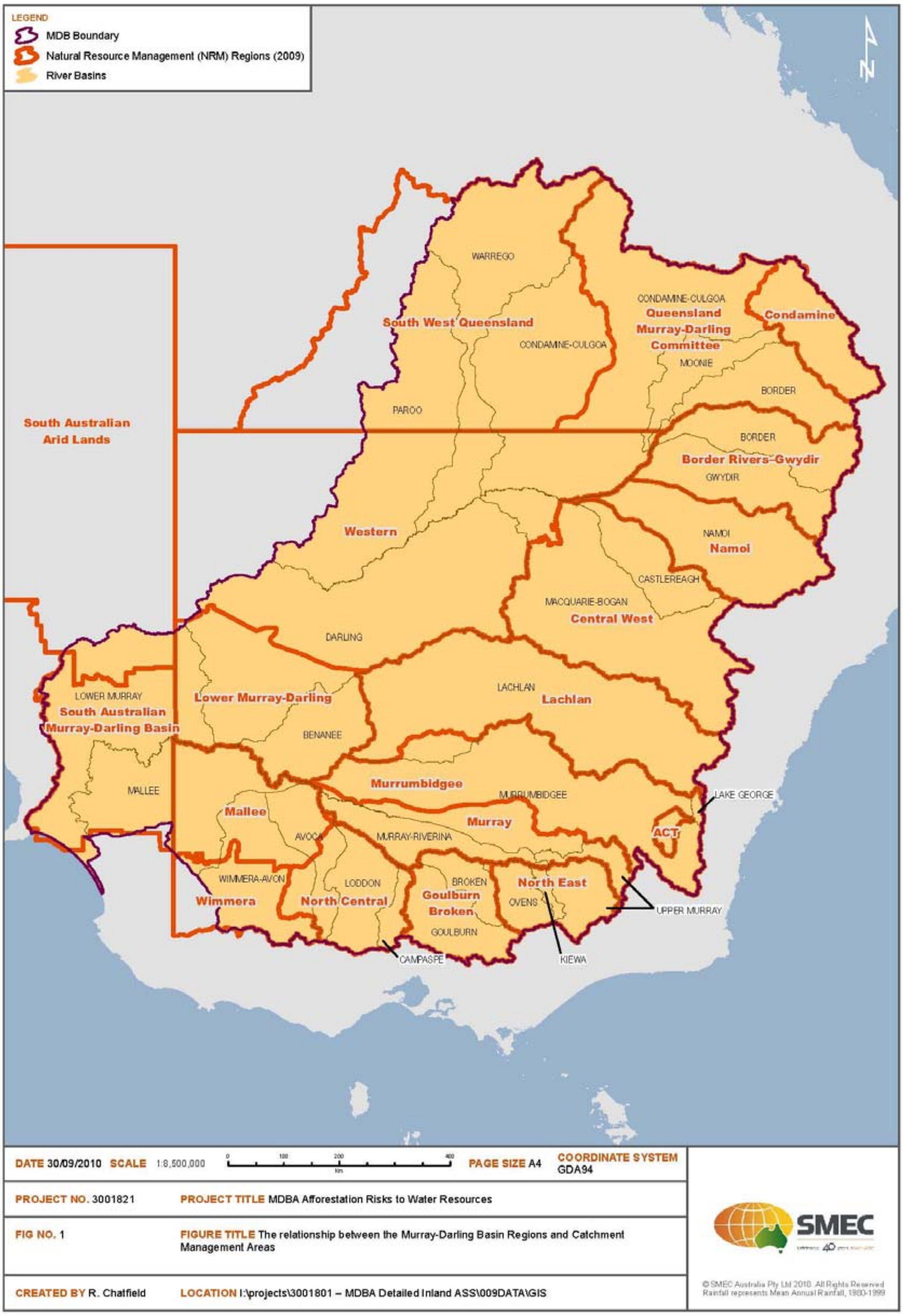

Figure 12: Catchment and natural resource management regions in the Murray-Darling Basin.

Table 15: Summary of current plantation area, potential change and ranking for change, particularly in relation to carbon sequestration plantations for each of the Catchment Management Authorities in the MDB.
See section 5.2 for explanation for future plantation scores.

Catchment management region	Area of catchment in MDB (ha)	Area currently under plantations (ha)	Area primarily carbon sequestration (ha)	Comments*	Future plantation score
ACT	235,987	16,240	-	No current plans. Potential limited interest in carbon sequestration programs relating to primary production and nature conservation.	0
Border Rivers/ Gwydir	5,073,980	9,307	1,500	A total of 9307 ha for revegetation of native species (generally locally indigenous) in terrestrial and riparian areas. One major plantation of around 1500 ha planted with native (but not local) species for timber production. Areas associated with revegetation for salinity mitigation purposes were not included in these figures.	2
Central West	8,492,572	39,919	-	No current plans. Soil carbon incentive program is running that encourages landholders to undertake certain land management practises to try and build soil carbon. It focuses on farming techniques and pasture grazing methods.	0
Condamine	2,436,369	948	<2	Limited number of projects due to lack of funding. Plantings in the last 12 months have been limited to small site restoration activities totalling less than 2 ha. Catchment is an identified priority area for increasing soil carbon under the Caring for our Country program, established investment projects of this type target mainly cropping land. Condamine Alliance open to tree/vegetation planting activities, for both biodiversity and sequestration outcomes, if opportunities arise.	1+
Goulburn-Broken	2,405,567	24,476	7,445	See case study in Section 8.3.2.	2
Lachlan	8,624,722	30,319	-	Proposed project seeks to revegetate 5000 ha of riparian land to enable cost effective carbon sequestration. Additional benefits for biodiversity, threatened species and water quality. Studies have been undertaken to assess the carbon sequestration potential of environmental tree plantings in the Lachlan area.	2
Lower Murray-Darling	6,288,458	-	-	No current plans. Little interest as catchment has 90% native vegetation retained and plantations have a low success rate in the	0

Catchment management region	Area of catchment in MDB (ha)	Area currently under plantations (ha)	Area primarily carbon sequestration (ha)	Comments*	Future plantation score
				area due to low rainfall. Funding incentives exist for management of native vegetation.	
Mallee	3,925,720	-	-	Currently, there are no native species of local provenance accredited for use in a carbon sequestration program. There is significant community interest in increasing carbon sequestration (particularly bio-sequestration) to align both with the private carbon industry and any future Government carbon scheme. Funding is required to quantify the potential to use indigenous species to sequester carbon in the region.	0
Murray	3,535,857	22,280	-	No current plans. There have been several thousand hectares of revegetation targeting recharge control and biodiversity outcomes, but nothing directly aimed at carbon.	1
Murrumbidgee	6,969,826	86,833	1,837	Project has been running since 2004, included revegetation (mixed species) of 1,837 ha. Perennial pasture revegetation of 1,065 ha (mainly lucerne, phalaris and cocksfoot pastures). No plans to increase formal plantations due to lack of funding, CMA is offering land managers incentives to conserve and connect native vegetation corridors which will also have carbon sequestration benefits. Murrumbidgee CMA will pay landholders to engage in contracts to manage native vegetation corridors for either 10 or 15 years and provide funding for protection and enhancement of existing remnant native vegetation and enhancing linkage of vegetation corridors with locally indigenous native trees and shrubs.	2
Namoi	4,199,642	4,480	400	No current plans for carbon sequestration. The closest relevant project is increasing revegetation for woody native vegetation.	1
North Central	2,963,289	6,249		CMA contacted but unable to provide any information. Amalgamation with Goulburn-Broken planned for 2012.	N/A
North East	2,405,567	38,183		CMA contacted but unable to provide any information. Amalgamation with Goulburn-Broken planned for 2012.	N/A
Queensland Murray-Darling	10,268,164	1,769	-	Currently in policy development stage regarding role in carbon sequestration in the region. The impact of by-product water from coal seam gas mining activities is likely to support increased establishment of irrigated carbon sequestration forestry.	1

Catchment management region	Area of catchment in MDB (ha)	Area currently under plantations (ha)	Area primarily carbon sequestration (ha)	Comments*	Future plantation score
				Various private plantings have occurred mainly for bio-diesel production. Limited knowledge of local species carbon sequestration values limits their use in carbon plantations.	
South Australian Arid Lands	1,156,893	-	-	No current or future plans. Plantations would not be viable as most of the catchment is pastoral land.	0
SA Murray-Darling Basin	5,570,653	3,000+	3,000+	A $5.7 million project exists to establish a River Murray Forest in a corridor area extending 20 km either side of the Murray River, from the SA-Victorian border to the Coorong. The project focuses on revegetation for carbon sequestration and long-term landscape-scale biodiversity benefits. To date, the SA Government has developed collaborative arrangements with other organisations to implement the project. An innovative market-based tender approach has been used, enabling the establishment of over 3,000 hectares of native vegetation on private land.	2
South West Queensland	13,221,005	-	-	No current plans. Plantings not considered viable in arid to semi-arid climate.	0
Western	16,599,453	-	-	No current plans. The catchment retains around 95% of its area under natural native vegetation. There is a significant interest in carbon sequestration from improved/changed grazing and land management practices.	0
Wimmera	169,0882	541	Unknown	No current plans. Carbon sequestration has been referenced as an outcome for contracts with landholders for revegetation projects.	1
Total	106,232,886	284,604	14,184		

Five CMA's received a score of two, with active plantings, current grants and a keen interest in expansion of environmental plantings:

- Border Rivers;
- Goulburn-Broken;
- Lachlan;
- Murrumbidgee; and
- South Australian Murray-Darling Basin.

Approaches adopted by Goulburn-Broken and Lachlan CMA's to environmental plantings are further detailed in Section 5.3. Although these CMA's had active projects and interest in further carbon plantings, none were likely to significantly increase environmental plantings, primarily because of funding constraints. The introduction of a CPRS or other scheme to establish a price on carbon sequestration would have an impact on the magnitude of these potential increases.

Eight CMA's received a score of 0, and are unlikely to expand their environmental plantings. Most of these CMA's are in areas with marginal rainfall or other land use restrictions. In some areas, this was because the CMA is currently 95% under native vegetation, so plantation establishment would be contrary to Kyoto protocols (eg Western CMA). Representatives from other CMA's primarily in marginal pastoral land with unreliable rainfall (eg South West Queensland), believed that environmental plantings would not be viable in their area. While it is likely that plantings in the 300-600 mm y^{-1} rainfall zones may be marginal, more research is required to examine both the carbon sequestration properties of indigenous species in this area (England et al 2006) and to determine whether selected species and hybrids can be bred to further improve drought tolerance and carbon sequestration (D Bush pers comm; Dale and Dieters 2007).

The ACT has over 16,000 hectares currently under plantation (timber plantations) but has only limited interest in environmental plantings, despite receiving greater than 600 mm y^{-1} rainfall. Conversely, the Lachlan CMA is actively pursuing grants for environmental plantations and is providing incentives for landholders to plant trees that would qualify for carbon sequestration benefits.

8.3 Case studies

8.3.1 Lachlan CMA

The Lachlan CMA in consultation with CSIRO Sustainable Ecosystems, DECCW, I&I NSW and GHD, has developed a tool for estimating carbon sequestration by trees used in environmental plantings. The project addressed critical knowledge gaps relating to the quantification of sequestered carbon in environmental plantings. The project has improved methods to quantify carbon stock which will assist future trading of sequestered carbon from environmental plantings, potentially generating an income stream from environmental plantings, reducing net greenhouse gas emissions and assisting in State-wide NRM targets (Fortunasso et al 2008).

Specific project objectives were to:

- Quantify the temporal change in carbon stock for a diverse range of planted woody vegetation systems established through afforestation and reafforestation activities;
- Develop robust models and inventory methods for these woody vegetation systems to assist in the creation of offset credits as part of an emission trading scheme; and
- Develop inventory methods to assist in carbon trading and provide a framework for enhanced implementation of carbon sequestration.

An empirical growth curve for carbon stocks in environmental plantings was generated for the Lachlan catchment. Rates of sequestration of carbon were found to be influenced by rainfall, planting geometry (block or linear) and the species composition planted. The dataset derived was used to generate recommended National Carbon Accounting Toolbox NCAT defaults for prediction of carbon stocks under linear and block environmental plantings of various tree:shrub mixtures in the Lachlan Catchment (www.lachlan.cma.nsw.gov/ourprojects/pages/carbseq.aspx).

8.3.2 Goulburn-Broken CMA

No revegetation with the primary goal of carbon sequestration has been undertaken in the Goulburn-Broken region, however in the last four years, 6,662 hectares of native revegetation and 413 hectares of timber plantations have been established.

The CMA currently devolves government funding for on-ground works to landholders via a range of programs. These programs include Environmental Management Incentives (EMI) for terrestrial areas and Waterway grants for riparian areas, as well as tender programs from time to time, such as Bush Returns, which targets a stewardship approach to encourage natural regeneration of native vegetation.

Investigation into opportunities and challenges associated with carbon markets has occurred over the past two years. The main focus in the short-term will be mitigating potential negative effects on biodiversity, such as monocultures or forest type plantings being established in areas that are historically grasslands or grassy woodlands.

8.4 Private company plantings

Six of the largest providers of carbon offsets in Australia were interviewed by phone regarding their plantations in the MDB (Table 16). A number of companies either did not work in the MDB or were unwilling, for commercial reasons, to disclose the information on the extent of their current plantations. Landcare, Greening Australia and Trees for Life do work throughout the MDB, usually in conjunction with local CMAs. Plantations of this nature are currently relatively small at less than 100 ha.

8.5 Summary

The MDB has approximately 284,000 ha under plantation, approximately 14,000 ha (5%) is environmental plantings, which is less than 0.01% of the area of the MDB. Interest and opportunity for environmental plantings primarily for carbon sequestration varies markedly across the CMA's, with many of the active programs primarily designed for salinity or biodiversity benefits that have carbon sequestration as a secondary benefit. Significant private investment in environmental plantings has not yet occurred in the MDB, with private plantations restricted to 100 ha or less and usually in association with local CMAs.

Interest and capacity to develop environmental plantations differs markedly across the MDB, with many CMA's in arid areas seeing little opportunity for plantation development in their catchment, regardless of carbon price (see Section 3 for discussion of mallee species and hybrids that may be suitable). Most CMA's cited the lack of investment as a major obstacle to environmental plantation establishment, and some were ambivalent about encouraging landholders to convert some of their farms to environmental plantations. Overall, even in areas where there was intense interest in establishment of carbon plantations, the area covered or likely to be covered was small and is unlikely to grow significantly in the short to medium term.

Table 16: Organisations involved in establishing carbon sequestration plantations.

Organisation	Projects	Comment
Green Fleet Australia	Murray-Darling Rescue Project 2001-2008 in SA, VIC, NSW and the ACT.	Details unavailable
Greening Australia	Involved in Boorowa River Recovery campaign, part of Greening Australia's nationwide River Recovery program. Campaign seeks to reduce sedimentation and salt loads from Boorowa River into the Lachlan. Also involved in the River Murray Forest project (South Australia Murray Darling Basin).	Details unavailable
$C0_2$ Australia	Projects running in Murrumbidgee and Lachlan regions.	Details unavailable
Landcare Australia	Plantings (less than 100 ha each) under CarbonSMART program undertaken in Wimmera, North Central, Murray, Namoi, Murrumbidgee, Goulburn-Broken catchments.	Total plantings much more substantial but information not provided.
Trees for Life	Involved in the River Murray Forest project (South Australia Murray Darling Basin).	Details unavailable
Water and Carbon Group	No plantations in the MDB.	Details unavailable

9 ASSESSMENT OF POTENTIAL EFFECTS OF AFFORESTATION FOR CARBON SEQUESTRATION

9.1 Framework development

Vulnerability assessments are commonly used to provide a qualitative approach to combining different types of information in risk assessments for hazards and human health contexts. The technique has recently been applied successfully in the climate change domain to assess risks to systems such as the Great Barrier Reef (Johnson and Marshall 2007), and aquatic ecosystems and fisheries in the Pacific region (Bell et al. in press).

Vulnerability assessments draw on all available sources of information, including published and unpublished scientific information, professional and local knowledge, and expert opinion. Outcomes from this approach are commonly used to link public knowledge to policy and governance agendas to assess potential risks and opportunities for intervention (Kok et al 2006).

The Intergovernmental Panel on Climate Change has defined climate change vulnerability as “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity”.

This report has adopted the vulnerability assessment framework (Figure 13) to allow potential effects of afforestation for carbon sequestration to be combined with potential responses to climate change scenarios to provide a method for assessing the risks and implications for water quality and quantity, salinity, biodiversity, riparian management, and related effects of land use change.

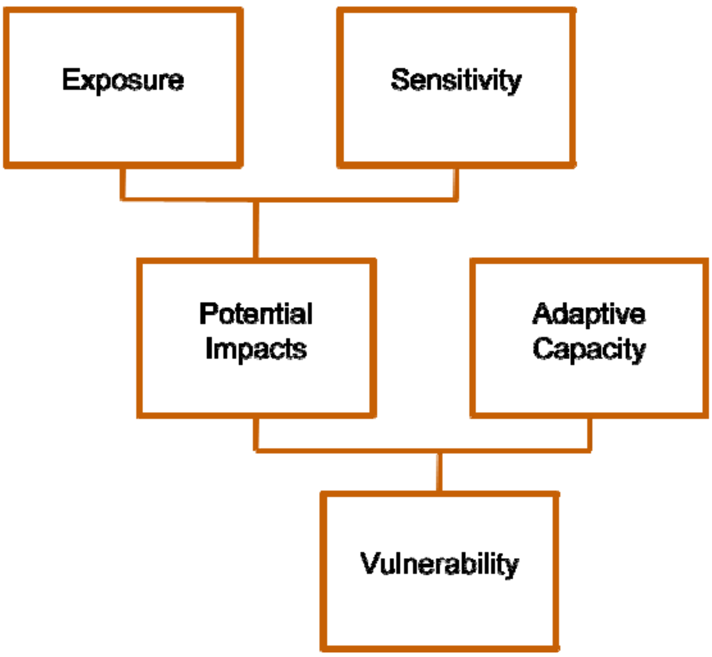

Figure 13: Vulnerability assessment framework.

The usefulness of vulnerability assessments to inform policy depends on the reliability of the information on which they are based (Johnson and Marshall 2007). The approach adopted in this study draws on sources of information that include opinions of interviewed experts, synthesis of published and unpublished scientific research, existing legislation and policy, local community knowledge derived from Catchment Management Authorities and NRM groups within the Basin, and professional experience.

Uncertainty is unavoidable in undertaking assessments of this nature, especially considering the small number of consultations possible within the project scope, and the quality of available information. This assessment describes a process for assessing the risks posed by the combination of climate change and carbon sequestration plantations, and provides a basis for refining the resulting assessment in the future as information on climate change improves, and as policies and incentives for climate mitigation become more established.

9.2 Climate change scenarios

Three climate change scenarios were considered in the vulnerability assessment, based on projections to 2030 (Table 17). Historical climate, with current levels of water resource development (most favourable 2030 scenario) was used to generate mean annual end-of-system flows for each region, based on CSIRO (2008). The second scenario drew on the median model of all global climate models considered by CSIRO (2008) (median 2030 scenario) to generate mean annual end-of-system flows for each region, based on rainfall and runoff projections under the median model, with current levels of water resource development. The third scenario (least favourable 2030 scenario) considered the effects of the last 10 y of drought in the Basin to project mean annual end-of-system flows for each region, with current levels of development, based on CSIRO (2008).

9.3 Carbon sequestration scenarios

Several scenarios have been established for possible establishment of carbon sequestration plantations. The hypothetical scenarios of Hafi et al (2010), and Lawson et al (2008) present hypothetical assessments of the possible extent of carbon sequestration and other environmental plantations in response to the introduction of a price on carbon, for the year 2050. These authors estimated that over 10 million ha of cleared land in the Basin could be converted to plantations, mostly for environmental purposes (Figure 14). We applied a linear interpolation between 2008 and 2050 to derive an estimated increase by 2030 of over 5 million ha distributed across all sustainable yields regions (Table 18). This is referred to as the maximum sequestration scenario.

The alternative scenario based on recent trends and existing plans for plantations within individual CMAs and NRM regions suggests that nearly 19,000 ha has been identified for establishment of carbon sequestration or multipurpose plantations, and that planting of this area has already commenced. Several additional regional groups consulted indicated a willingness to pursue carbon plantations, if funding was available for that purpose. Some CMAs have recently advertised the availability of funding to support climate change plantations by landholders. Other organisations involved in environmental and carbon sequestration plantations were unwilling to provide quantitative information on the extent of plantings. In view of the uncertainty regarding current and projected rates of change, we have assumed a subjective increase of 5,000 ha per year, over 20 years as the minimum scenario by 2030, which is equivalent to a total increase in environmental plantings of 100,000 ha. This increase was arbitrarily allocated across catchment regions based on land suitability for plantations as used by Hafi et al (2010).

Table 17: Summary of project effects of climate change scenarios on end-of-system flows, compared to the most favourable climate change scenario, assuming current levels of development. (CSIRO 2008). The most favourable scenario represents a continuation of the long-term (1895 to 2006) averages for rainfall and runoff, with current levels of development.

Sustainable yields region	Most favourable 2030	Median 2030		Least favourable 2030		Wet extreme		Dry extreme	
	Gl	Gl	%	Gl	%	Gl	%	Gl	%
Murray	4733	3575	-24%	2367	-50%	5662	20%	1476	-69%
Ovens	1752	1518	-13%	1278	-27%	1779	2%	947	-46%
Goulburn-Broken	2092	1713	-18%	1042	-50%	2007	-4%	950	-55%
Campaspe	418	367	-12%	239	-43%	402	-4%	232	-44%
Loddon-Avoca	54	42	-23%	21	-60%	50	-8%	24	-55%
Murrumbidgee	1481	1222	-17%	800	-46%	1789	21%	823	-44%
Lachlan	209	182	-13%	209	0%	228	9%	136	-35%
Wimmera	21	16	-24%	9	-56%	19	-8%	10	-51%
Border Rivers	539	476	-12%	539	0%	680	26%	356	-34%
Moonie	72	62	-13%	72	0%	91	27%	50	-31%
Gwydir	189	178	-6%	189	0%	251	33%	139	-27%
Namoi	583	538	-8%	583	0%	889	52%	357	-39%
Macquarie-Castlereagh	583	531	-9%	583	0%	819	41%	422	-28%
Condamine-Balonne	247	218	-12%	247	0%	298	21%	160	-35%
Warrego	143	133	-7%	143	0%	217	52%	97	-32%
Paroo	326	324	0%	326	0%	498	53%	271	-17%
Barwon-Darling	1783	1603	-10%	1783	0%	2612	47%	1150	-35%
Eastern Mount Lofty Ranges	111	89	-19%	84	-24%	107	-3%	49	-55%
MDB	4733	3575	-24%	2367	-50%	5662	20%	1476	-69%

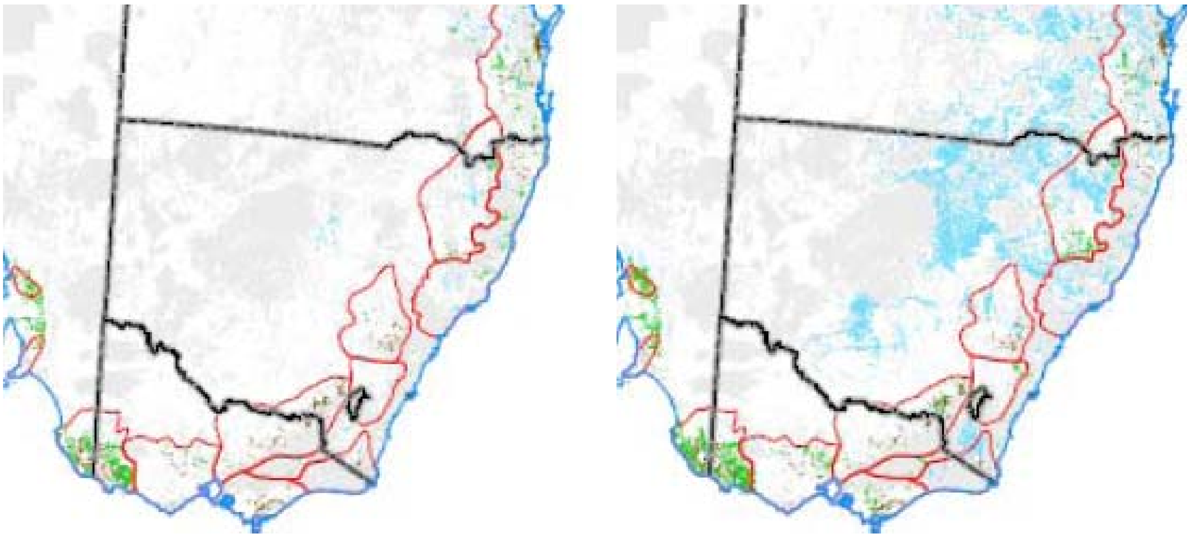

Figure 14: Effect of carbon price on the extent of afforestation plantations in south-eastern Australia. Left panel: \$20 tonne^{-1}; Right panel: \$28 tonne^{-1}.
(Lawson et al 2008). Blue depicts environmental plantations; green shows plantations for wood and wood products.

9.4 Vulnerability assessment

A qualitative procedure was applied to score the exposure of each region to expansion of carbon sequestration plantations under each scenario (Table 18). It was assumed that exposure to plantations was constant under all climate change scenarios. Sensitivity of end-of-system flow to increased carbon sequestration was estimated by linear interpolation of changes attributable to sequestration alone, presented by Hafi et al (2010) to 2030. Sensitivity of end-of-system flow to the median 2030 climate scenario and the dry extreme 2030 scenario was assessed by adding the effect of each scenario (CSIRO 2008) to the change attributable to sequestration plantations alone.

Impacts on end-of-system flows were estimated qualitatively as the product of exposure and sensitivity. The adaptive capacity of catchments to offset impacts on end-of-system flows was assessed qualitatively as two conditions, defined as Low or High adaptive capacity. Vulnerability was then estimated by dividing the impact score by the adaptation score.

This process created a total of 12 scenarios that were assessed for each of water quantity; salinity management; biodiversity; riparian management; and combined positive and negative responses (Table 19). These scenarios represented three climate scenarios, maximum and minimum estimated extent of sequestration plantations under each climate scenario, and maximum and minimum adaptation capacity for each climate and plantation scenario.

Vulnerability of water quantity to carbon sequestration plantations is typically negative, reflecting the increase in water use by plantations. However, in the case of water quality, salinity, biodiversity, and riparian management, the effects of tree planting are typically positive. Rather than attempting to model effects of sequestration plantations on each of these objectives in this high-level approach to setting priorities, it was assumed that plantations that comply completely (100% compliance) would maximise benefits to water quality, salinity, biodiversity, and riparian management. To allow for plantations that do not achieve 100% compliance because of specific objectives and constraints, a 50% compliance scenario was also applied to estimate benefits in cases where plantations do not meet all published guideline requirements.

Table 18: Exposure of each region to carbon sequestration plantations, under the maximum scenario described by Hafi et al (2010). Scores allocated as: (1) 0 – 10%; (2) 10 – 30%; (3) 30 – 60%; (4) 60 – 100%; (5) >100%. Sensitivity to changes in end-of-system flows scored as: (1) >0%; (2) 0 – -10%; (3) -10 – -30%; (4) -30 – -60%; (5) >-60%.

Catchment	Base forested area (,000 ha)	Forested area with 2030 sequestration (,000 ha)	2030 exposure Change (%)	Exposure score	2030 sensitivity Change in end-of-system flow %	Sensitivity score
Condamine	2,966	3,945	33	3	-7	2
Border Rivers	1,254	1,904	52	3	-14	3
Warrego	2,153	2,354	9	1	-3	2
Paroo	567	569	0	1	0	2
Namoi	1,123	1,518	35	3	-9	2
Macquarie	1,428	2,329	63	4	-6	2
Moonie	226	400	77	4	-12	2
Gwydir	406	748	84	4	-10	2
Barwon-Darling	2,474	3,341	35	3	-9	2
Lachlan	1,417	1,768	25	2	-2	2
Murrumbidgee	1,350	1,697	26	2	-5	2
Ovens	429	430	0	1	0	2
Goulburn-Broken	732	740	1	1	-1	2
Campaspe	69	92	33	3	-12	3
Wimmera	446	456	2	1	-1	2
Loddon	303	324	7	1	-3	2
Murray	5,514	5,618	2	1	-4	2
Eastern Mt Lofty Ranges	42	71	70	4	-12	3
MDB	22,899	28,306	24			

An integrated ranking of catchments was achieved by summing all estimated vulnerabilities, and then reducing the scores to ranks, to identify which catchments are likely to receive the greatest, or least, combined environmental benefit from carbon sequestration plantations.

9.5 Water quantity

Vulnerability of regions to reduced end-of-system flow as a result of carbon plantations is shown in Figure 15. Under the minimum plantation scenario represented as a continuation of the current rate of planting to 2030, climate change has a stronger effect on stream flow than increases in plantation area. Under the maximum plantation scenario (Hafi et al 2010), the north-eastern catchments are most vulnerable to reductions in stream flow. The greatest vulnerability occurs in the dry extreme scenario in the Moonie and Gwydir catchments under the assumption of low adaptive capacity. Vulnerability of stream flow to sequestration plantations in the southern regions of the Basin is typically low because of the low returns on non-harvestable trees compared to agricultural production, and the low price required for land to be attractive to convert to plantations. However, under an

Table 19: Scenarios used to assess vulnerability to increase in plantation area.
Shaded scenarios (three climate scenarios x two plantation scenarios) were applied to maximum and minimum scenarios for each environmental effect, giving a total of 12 scenarios.

Climate Scenarios	Carbon plantation increase	Environmental effects		Combined ranking
		Water impact – end-of-system flows	Salinity, biodiversity, or riparian management	
Most favourable 2030	Minimum (100,000 ha)	Minimum (14% flow enhancement)	Minimum (50% compliance with guidelines)	Combined minimum conditions
Median 2030	Maximum (10 million ha)	Maximum (52% flow enhancement)	Maximum (100% compliance with guidelines	Combined maximum conditions
Dry extreme 2030				

alternative hypothetical scenario, Schrobback et al (2009) estimated that a carbon price of \$100 tonne^{-1} would stimulate a higher rate of conversion from other land uses to carbon plantations in the south-eastern catchments. In the western regions that receive less than 400 mm y^{-1} mean rainfall, rainfall is typically too low to support significant plantation areas.

9.6 Water quality, salinity, biodiversity and riparian management

Extensive guidelines are available to assist planning to achieve the greatest benefits from planting trees and other revegetation for the purposes of erosion control and transport of sediments and nutrients into rivers; salinity management (Stirzaker et al 2003; Robins 2004); biodiversity management; and riparian management (Lovett and Price 2007). It is not the purpose of this report to review those guidelines directly. Rather, we have assumed that if existing guidelines are followed, the benefits of carbon plantations for other environmental purposes can be maximised. The qualitative scoring process used to rank regions according to the benefits provided was relatively coarse, so that the resulting vulnerability assessments were the same for each set of benefits (Figures 16 – 18).

This result can be interpreted as indicating that if trees are planted at current rates for carbon sequestration, then the potential benefits for other purposes will be small and water quality, salinity, biodiversity and riparian management programs will maintain their vulnerability to existing land use drivers. However if the price set for carbon is high

enough, and if plantations are established with 100% compliance with current guidelines, then on the basis of agricultural land values, maximum benefits will be achieved from plantations in the Moonie, Gwydir and Macquarie-Castlereagh catchments. Under progressively drier climate scenarios, the relative ranking of catchments remains the same, but the benefits are noticeably reduced under the dry extreme 2030 climate scenario because reduced rainfall constrains the establishment of plantations. Where plantations only achieve 50% compliance with current guidelines, the anticipated environmental benefits are diminished, but the catchments that derive the greatest benefits are still the Moonie, Gwydir and Macquarie-Castlereagh.

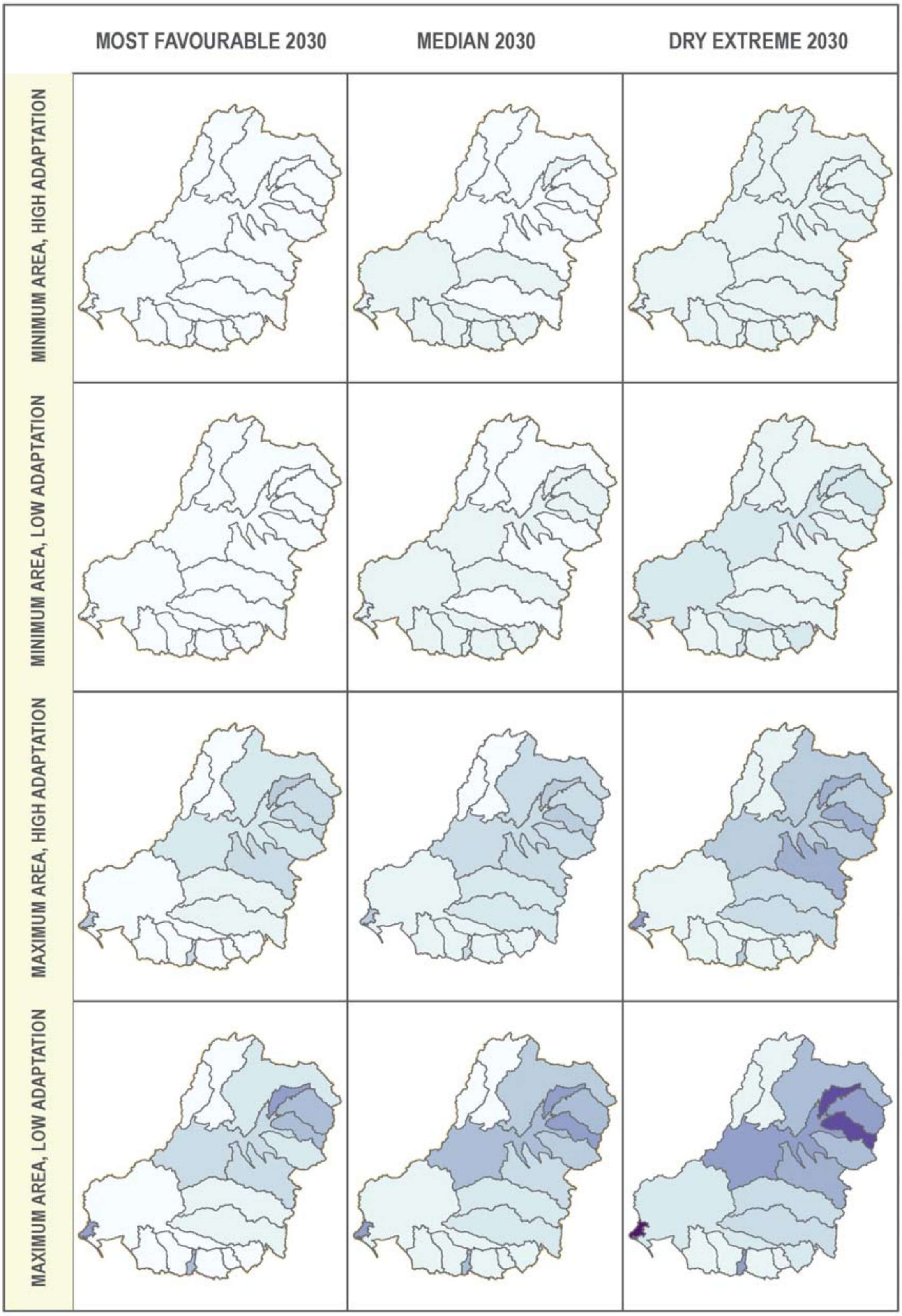

Figure 15: Vulnerability of regions by potential effects on water quantity. Darker regions are most vulnerable.

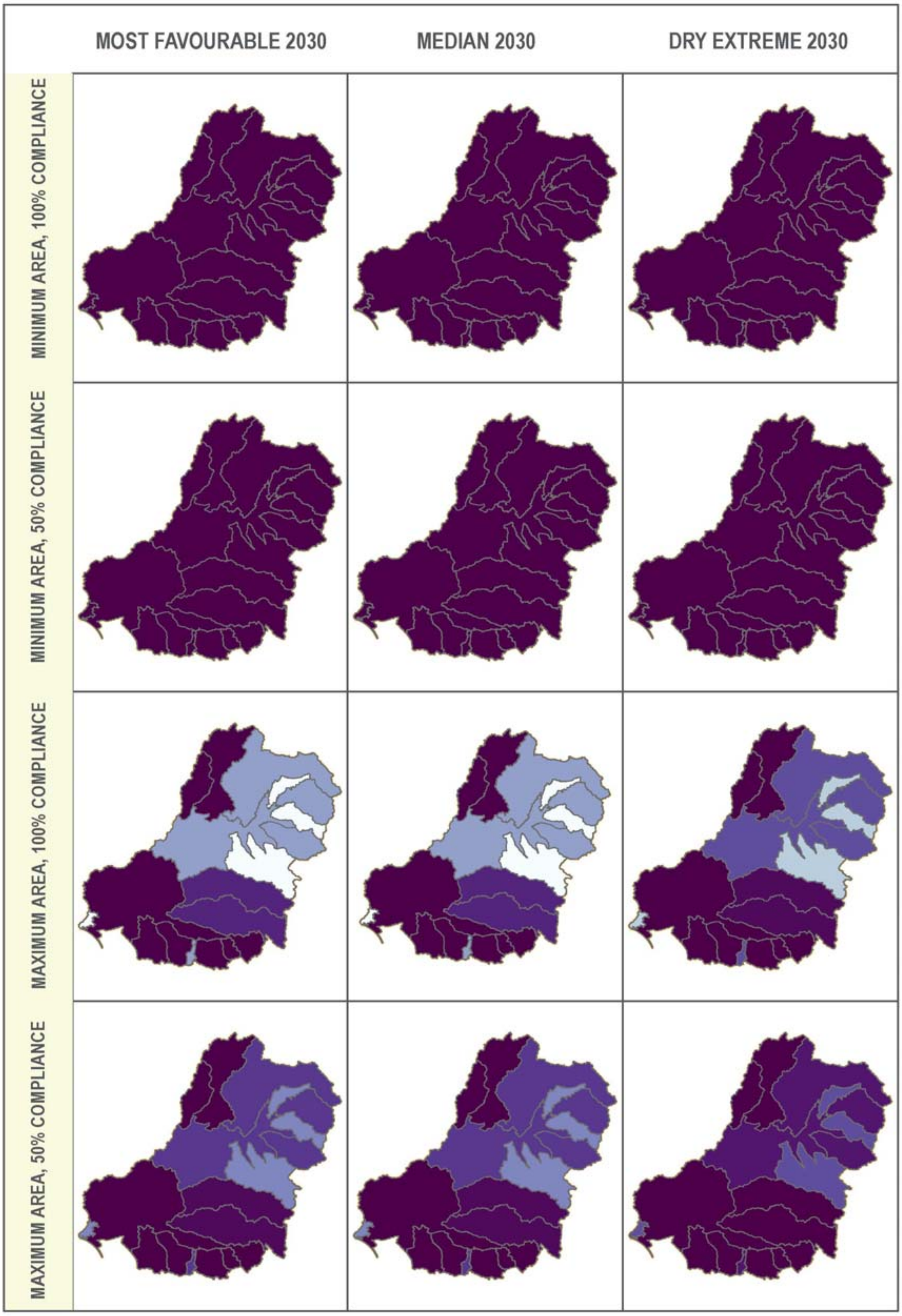

Figure 16: Vulnerability of regions by potential effects on salinity management. Lighter shaded regions have the greatest potential for positive benefits.

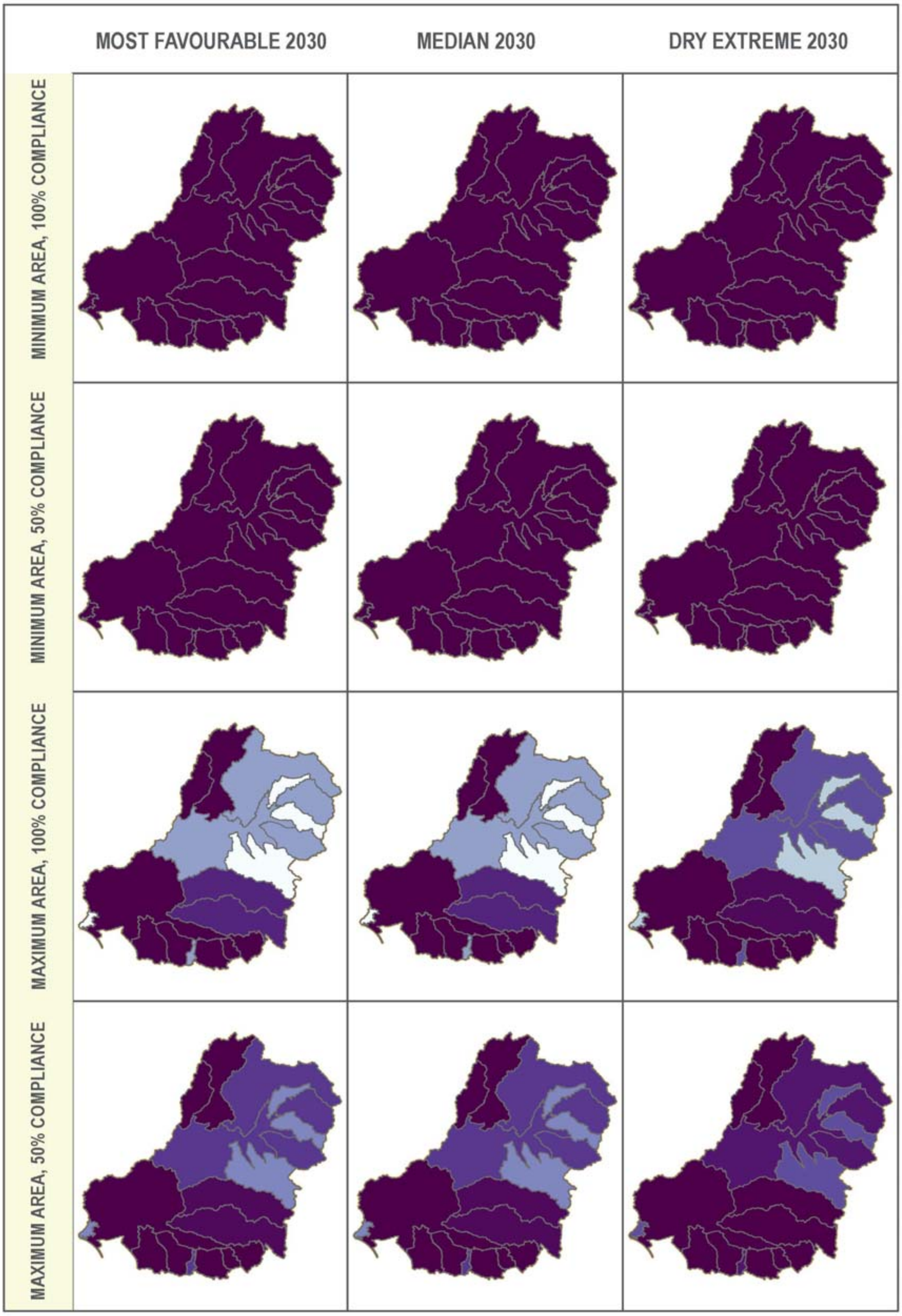

Figure 17: Vulnerability of regions by potential effects on biodiversity management. Lighter shaded regions have the greatest potential for positive benefits.

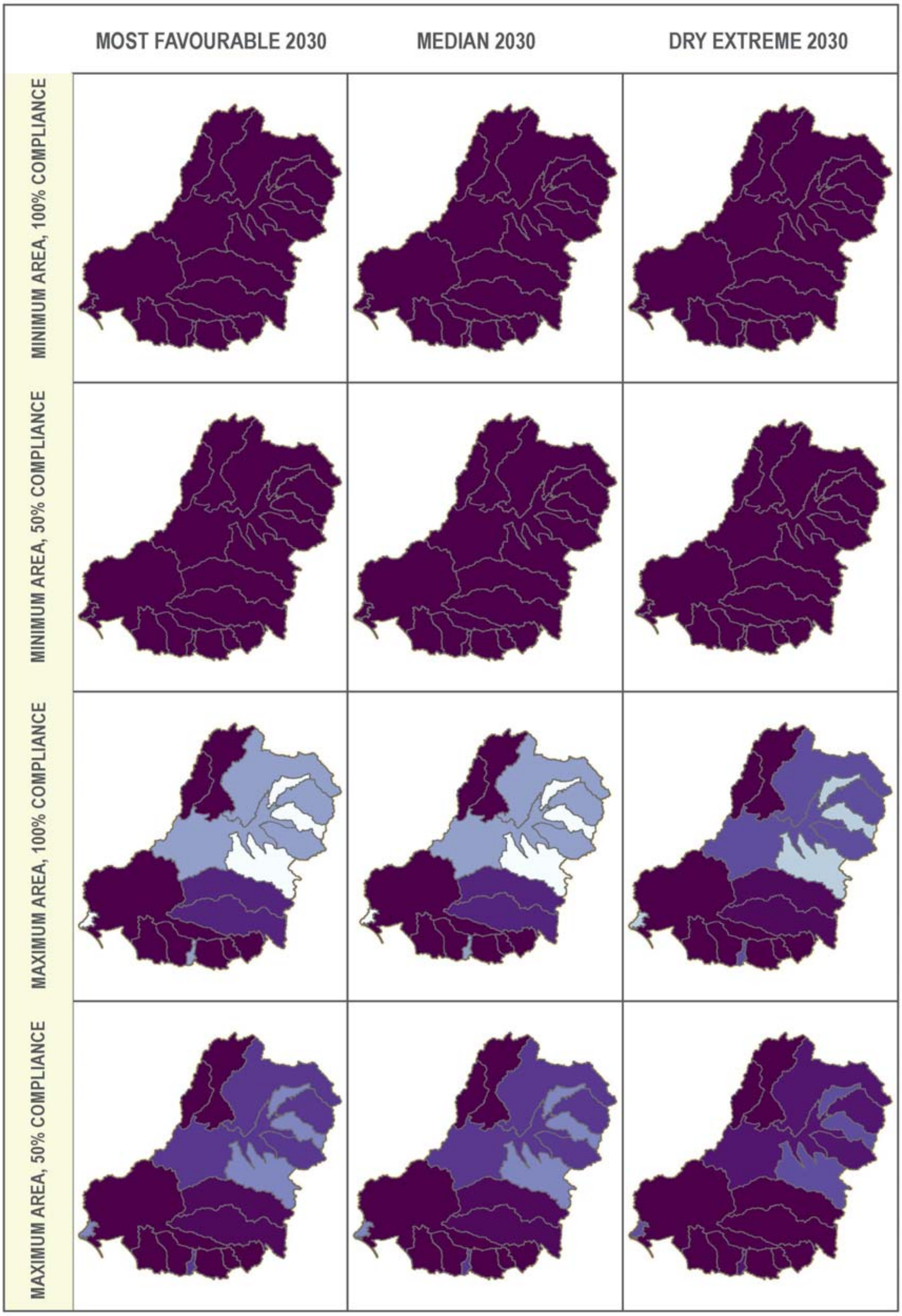

Figure 18: Ranking of regions by potential effects on riparian management.
Lighter shaded regions have the greatest potential for positive benefits.

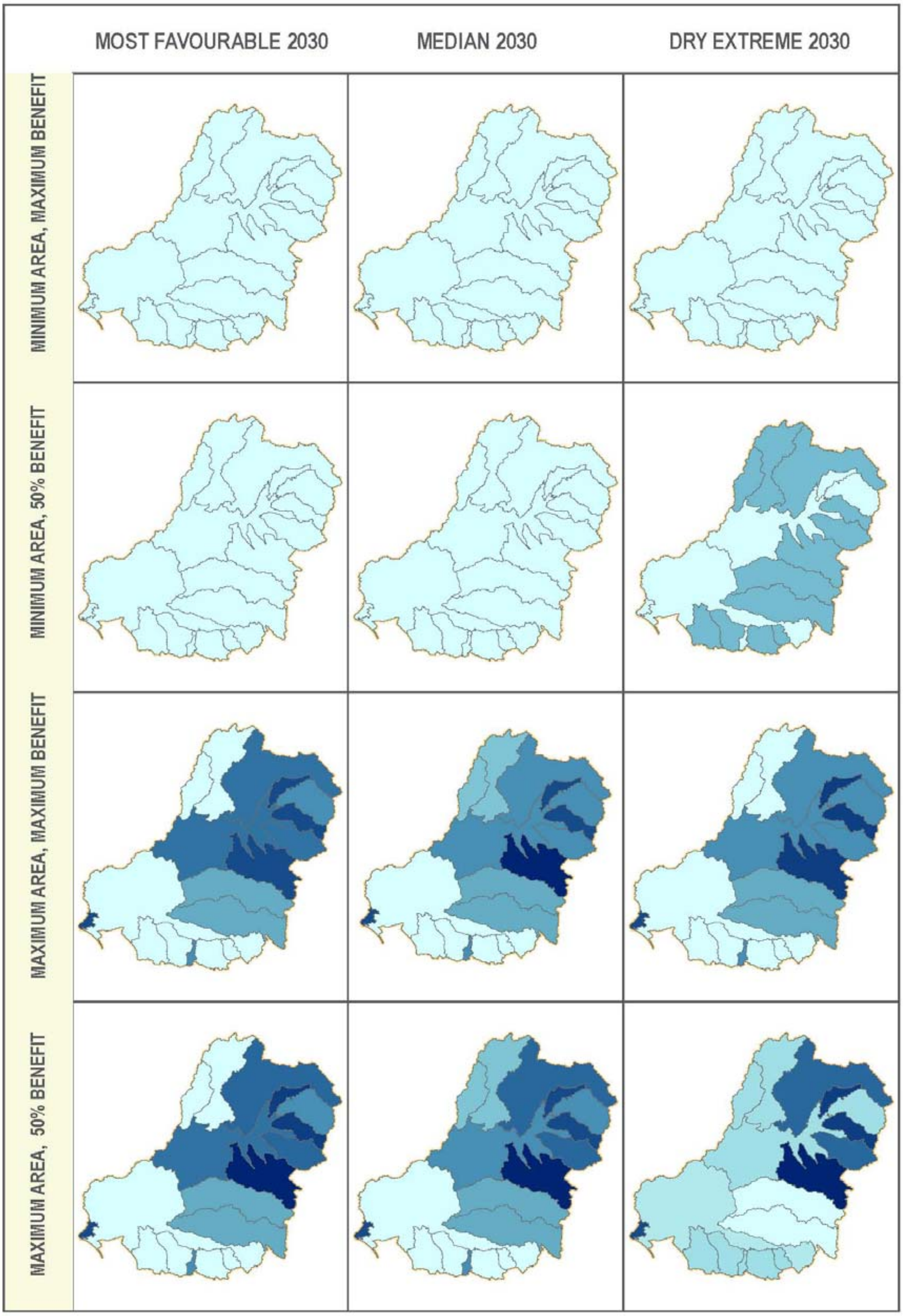

Figure 19: Integrated vulnerability of regions to potential effects of carbon sequestration plantations on combined effects on water quantity and quality, salinity management, biodiversity management, and riparian management. Darker regions are expected to receive the greatest benefit.

9.7 Ranking of priority catchments

As a general observation, risks to catchment water yields by 2030 are limited at the catchment scale under scenarios where plantations increase at the current rate. In this example, stream flows will only be vulnerable at the local scale where plantations cover more than 20% of the subcatchment area. Even so, plantations of species such as *Calitris* or acacias that typically grow in low rainfall regions that generate little or no runoff, and which typically grow along sand ridges away from riparian areas, will have little effect on stream flow or regional groundwater.

In contrast, under any scenario where the price of carbon is high enough to provide incentives for landholders to convert marginal agricultural land to carbon plantations, effects on water yields, and benefits to other environmental purposes will be greatest in the Eastern Mount Lofty Ranges, Moonie, Gwydir and Macquarie-Castlereagh catchments (Figure 19). Rankings of all catchments under most favourable, median, and dry extreme climate scenarios for 2030 are presented in Table 20. In this table, regions with the lowest ranked value are expected to receive the greatest net benefit from carbon sequestration plantations.

In drier catchments such as the Paroo and Warrego, other management strategies will be required to address emerging environmental issues because neither current nor future climate scenarios provide sufficient rainfall to allow large-scale expansion of plantations.

Table 20: Priority ranking of regions within the Murray-Darling Basin for the contribution of carbon sequestration plantations to provide environmental benefits and to reduce stream flows. Lowest values indicate where benefits are likely to be greatest. Larger values indicate that where water quality, salinity, biodiversity or riparian management threats exist, additional measures other than carbon plantations will most likely be required to mitigate impacts and to remediate affected regions. This table shows only results for the maximum plantation scenario based on a carbon price of \$28 tonne^{-1} (Hafi et al 2010).

Region	Most favourable 2030 climate	Median 2030 climate	Dry extreme 2030 climate
	Maximum area, maximum benefit	Maximum area, maximum benefit	Maximum area, maximum benefit
Macquarie-Castlereagh	1	1	1
Moonie	1	2	1
Gwydir	1	2	1
Eastern Mount Lofty Ranges	1	2	4
Namoi	5	5	5
Condamine-Balonne	5	5	5
Barwon-Darling	5	5	5
Campaspe	8	5	5
Border Rivers	8	5	5
Murrumbidgee	10	10	10
Lachlan	10	10	10
Warrego	12	12	12
Paroo	12	12	12
Murray	12	14	12
Ovens	12	14	12
Goulburn-Broken	12	14	12
Loddon-Avoca	12	14	12
Wimmera	12	14	12

10 MAXIMISING BENEFITS OF CARBON SEQUESTRATION PLANTATIONS

10.1 Benefits

The potential range of carbon sequestration outcomes, in terms of projected plantation coverage by 2030, is large. The low estimate adopted for this study suggests carbon plantations may cover 100,000 ha, equivalent to a 35% increase compared to the current area of traditional forestry plantations. Even this estimate is approximately twice the maximum increase estimate for traditional forestry plantations adopted in Part A (CSIRO 2008).

In contrast, upper range estimates vary widely depending on the introduction of a price on carbon, and the actual price set for carbon. Based on a carbon rice of \$28 tonne^{-1}, Hafi et al (2010) estimated an increase in all forested land area of over 10 million ha across the Basin by 2050. In the south-eastern catchments alone (Murrumbidgee, Upper Murray and Murray Riverina, Goulburn-Broken, North East and North Central regions), Schrobback et al (2009) estimated that a carbon price of \$100 tonne^{-1} would result in 1.14 million ha additional carbon sequestration forestry plantations by 2050 under current climate conditions, reducing to 0.53 million ha under an average climate change projection that increased the value of agricultural land.

In both economic studies, the increase in plantation area was estimated to replace agricultural land use, so that the land value and income derived from agricultural business were taken into account. The conclusion from these studies is that a low price on carbon provides little financial incentive for commercial plantations for the purpose of carbon sequestration. A low price on carbon may however provide strong incentive for conversion of low-value agricultural land to plantations for a combination of environmental benefits. Following the assessment of traditional forest plantations in Part A of this report, a high carbon price in the vicinity of \$100 tonne^{-1} may encourage establishment of plantations in areas with marginal rainfall and soil types where growth of commercial tree species is poor.

It is not possible to accurately predict the price of carbon into the future, however recent prices of greenhouse gas abatement certificates in New South Wales have fluctuated from \$8 – \$10 tonne^{-1} carbon in 2004 to \$14 tonne^{-1} in 2006, to around \$5 tonne^{-1} in 2009 (Grieve et al 2009). These prices indicate that the hypothetical prices used in some studies may differ substantially from actual price-based incentives.

Examples of potential benefits and disbenefits of plantations are listed in Table 21. Local rural economies may benefit significantly from traditional forest plantations. In the Green Triangle region in South Australia, forestry on less than 10% of the total land area generates around 29% of the gross regional product and 25% of regional employment (Hairsine and Polglase 2004).

Reduction in groundwater recharge as a result of plantation water use typically results in lowering of the water table, subject to time lags associated with groundwater dynamics (Stolte et al 1997; McJannet et al 2000; Hairsine and Polglase 2004). Associated with the reduction in recharge, mobilisation of salt into rivers is also reduced, leading to improved water quality by reduced conductivity in rivers with significant groundwater inflows. However in some locations salt mobilisation is reduced to a lesser degree than stream flow, resulting in increased water salinity. (Hairsine and Polglase 2004).

Table 21: Potential benefits and disbenefits of plantations established on agricultural land. (Hairsine and Polglase 2004).

Potential benefits of new plantations	Potential disbenefits of new plantations
Enhanced rural economies	Reduced stream runoff volume for downstream use
Reduced local recharge assisting in salinity control	Reduced low flows for streams
Reduced stream pollutant loads	Increased stream salt concentrations through reduction of dilution flows (for plantings in high rainfall areas)
Decreased stream salt concentrations (for plantings in low-medium rainfall areas)	Degraded soil physical and chemical properties
Carbon sequestration	Competition for water, nutrients, and light with agricultural crops
Biodiversity enhancement	
Improved soil physical and chemical properties	
Improved soil structure	
Other on-farm benefits such as stock shelter and wind-breaks	

By reducing rain-splash erosion and surface runoff, plantations typically reduce the sediment and nutrient load entering rivers, leading to improvement in water quality compared to agricultural land (Chiew et al 2002, Hairsine and Polglase 2004).

Carbon sequestration rates by plantations account for carbon stored in above-ground vegetation, roots, the litter layer, and carbon entering the soil. Commercial plantation species such as Tasmanian blue gum and radiata pine grown in high rainfall areas sequester between 6 and 13 tonnes carbon ha^{-1} y^{-1} (Paul et al 2002), but in low rainfall areas receiving around 400 mm y^{-1} rainfall sequestration rates may average less than 4 tonnes carbon ha^{-1} y^{-1} (Schrobback et al 2009). Actual rates will vary depending on species planted, soil type, water availability, climate and other factors (Fortunasso et al 2008).

The benefits of plantations for biodiversity depend on spatial and temporal heterogeneity of species and habitats provided. Optimising biodiversity benefits requires consideration of issues including:

(i) Location of the plantation with regard to adjacent landscapes, connectivity with other habitats, landscape context and protection of water courses;

(ii) Configuration with respect to the size and shape of plantings;

(iii) Species composition including mixed-species plantings and use of local species;

(iv) Complexity, including multiple vegetation storeys, trees of different ages, and patchiness of plantings; and

(v) Ecological management, which includes monitoring, adaptive management, simulating natural disturbances, and variability in management actions (Salt et al 2004).

Stirzaker et al (2004) provide guidelines for optimising plantations to manage salinity. To achieve the maximum hydrological effect with the minimum loss of agricultural land requires consideration of (i) the location of plantings in relation to recharge; (ii) moving wood lots around the landscape to reduce leakage from subsequent crops; (iii) planting trees in belts on sloping land; (iv) planting trees in belts to access soil water from cropping land and pastures; and (v) planting trees to access the water table. Plantations for salinity management need to recognise the scale of landscape hydrological processes, since the benefits of planting trees may be realised on the same farm at a local scale, or hundreds of kilometres away. Revegetation at the catchment scale needs to be tailored to annual rainfall, lateral flow patterns of groundwater, and catchment topography. Different plantation strategies are appropriate for different zones in catchments depending groundwater conditions and geology.

Riparian vegetation provides multiple environmental benefits, including stabilising river banks, improving water quality by intercepting runoff that carries sediments, nutrients and other contaminants into rivers, providing structural habitats for aquatic biota and organic carbon for aquatic food webs, terrestrial habitat and habitat corridors along river banks. Shading of the water surface to reduce warming, promoting soil carbon to support soil micro-organisms that reduce nitrogen concentration in shallow groundwater, and slowing river flows to reduce erosion and sediment transport, especially during floods. Detailed guidelines for management of riparian vegetation are provided by Lovett and Price (2007).

Optimising the requirements of plantations to achieve multiple environmental benefits for carbon sequestration, salinity management, water quality, biodiversity, riparian zone management, and increasing rural land values, whilst minimising effects on catchment water balances and the reduced availability of valuable agricultural land, requires complex balancing of trade-offs. A number of optimising processes have been developed that explicitly score and weight multiple objectives using a combination of scientific and economic indicators. Methods for assessing multiple outcomes simultaneously may involve multi-criteria analysis (MCA) or mutli-attribute utility theory (MAUT) (Hajkowicz et al 2003). Hairsine and van Dijk (2006) describe an application of this technique to optimise the outcomes of environmental and traditional plantations.

Barrett et al (2010) describe a robust framework to maximise return on conservation investments, identify biodiversity offsets and preserve a range of ecosystem functions by assessing costs and benefits of revegetation in terms of ecosystem services and social impacts. The spatial optimisation scheme allows variable weighting of cost and benefit objectives described by biodiversity metrics, runoff to streams, carbon sequestration, revegetation opportunity costs and management costs, and draws on landscape biophysical models to provide information on catchment hydrology and carbon pools. Social information includes costs of revegetation in terms of industry displacement and employment in the agriculture sector.

Optimisation processes like these have potential application to include environmental offsets and biobanking approaches, as well as use of environmental water in decision making on plantation establishment. The overall outcome of these and related optimisation approaches to achieve multiple environmental outcomes is that it is likely that the amount of carbon sequestered will be less than the maximum that could potentially be achieved, which may reduce the income stream generated by carbon plantations. In turn, a reduction in carbon revenue may limit the area of agricultural land that is converted to plantations.

10.2 Knowledge gaps

The vulnerability assessment framework provides a robust process for evaluating priorities to manage risks from afforestation and climate change. However, the application described here will benefit from better information on the likely increase in plantation area, and catchment water impacts of plantations of species likely to be grown for environmental purposes in low rainfall areas.

The multiple-use plantation optimisation systems described here require further development and evaluation (Hairsine and van Dijk 2006) with regard to:

- Practical evaluation of their usefulness in the field to assess the net benefits of optimised plantations;
- Evaluation of the compatibility of optimisation methods with existing incentive schemes, including a carbon price;
- Validating assumptions of the underlying models; and
- Validation that the method successfully meets the expectations of multiple stakeholders.

11 OPTIONS TO INCLUDE CARBON SEQUESTRATION IN WATER ACCESS ENTITLEMENT FRAMEWORKS

11.1 Introduction to water entitlement options for afforestation

A water access entitlement is the maximum amount of water authorised to be taken and used by a person under specific conditions. Categories of water entitlements currently available in the Murray-Darling Basin State jurisdictions (excluding the ACT) are listed in Table 22. The type of water entitlement is most easily identified by asking whether or not a trade involves only a change to the entitlement ownership (Shi 2005). Fundamentally entitlements are used to define access to pools of water and therefore it is logical to consider afforestation and water access entitlements within the three systems:

(i) Regulated surface water;

(ii) Unregulated surface water; and

(iii) Groundwater.

Hydrologically these three systems are linked, although the degree of linkage varies among and within catchments. For this reason, reallocation of water entitlements under the Basin Plan across these systems must be reflective of actual water availability from season to season. Incorporating activities that may affect water availability, such as afforestation, into water entitlement and accounting mechanisms becomes a critical step.

11.2 Afforestation impacts on water availability and entitlement security

Each catchment has a maximum water entitlement for consumptive use as determined by the MDB SDL's under the Basin Plan. Maximising the net benefits from water being made available for consumptive use, or take of water by afforestation, in a large interconnected system such as the MDB depends on water property rights being well specified and transferable (Hafi et al 2010). The primary issue in considering the water interception processes associated with afforestation and water entitlement is the possibility of attenuation of existing property rights to water (Groesch et al 2008). This is likely to result in an inefficient allocation of water because of the narrow definition of water property rights with these rights not taking into account the potential for intercepting activities such as afforestation for carbon sequestration, or farm dams (Hafi et al 2010). Therefore the critical basis for options for afforestation under water entitlements is a detailed understanding of afforestation impacts on water yield on a season to season basis concomitant with the allocation of water.

Increasing afforestation and resultant catchment water yield reductions could lead to reduced access to surface water and the activation of groundwater licences that are currently unused, or only partially used. Afforestation in high recharge areas of physically connected water systems (ie areas where surface water and groundwater have a high degree of connectivity) could lead to a reduction in the volume of surface water flows available for downstream use. Similarly, water losses through evapotranspiration are possible in areas where afforestation plantations are able to draw significant quantities of water from a perched aquifers or elevated water tables. Earth Tech Engineering (2003) suggest that groundwater management units in the Condamine, Lower Gwydir, Upper Namoi, Lower Macquarie, Upper Lachlan, Murrumbidgee and upland Victoria systems exhibit medium to high stream aquifer connectivity.

Table 22: Categories of water entitlements in Queensland, New South Wales, Victoria and South Australia. (Adapted from Shi 2005).

	System	NSW	Victoria	SA	Queensland
Entitlement categories	Regulated surface water	Domestic & stock access licence	Domestic & stock right	Stock & domestic licensed allocation	Interim resource operations licence
		Local water utility access licence	Town water supply	Metropolitan water licensed allocation	Interim water allocation
		High security access licence	Supply by agreement	Country town water licensed allocation	Resource operations licence
		Conveyance access licence	Water right	Industrial licensed allocation	Water allocation
		Environmental water access licence	Diversion licence	Recreational & environmental licensed allocation	Supplemented water
		Indigenous cultural access licence	Sales water	Irrigation licensed allocation	
		General security access licence		Wetlands licensed allocation	
		Supplementary water access licence		Water (holding) licensed allocation	Irrigation
	Unregulated surface water	Domestic & stock access licence	Direct pumping licence		Water harvesting
		Local water utility access licence	Winter fill licence		Unsupplemented water
		Unregulated river access licence	Farm dam licence		
		Runoff harvesting access licence			
		Indigenous cultural access licence			Riparian water right
		Research access licence			
	Groundwater	Local water utility access licence	Groundwater licence	Water (taking) licensed allocation	Artesian water
		Aquifer access licence	Groundwater licence (irrigation)	Water (holding) licensed allocation	Subartesian water
		Supplementary water access licence	Groundwater licence (non-irrigation)		Stock & domestic licensed allocation

Suitability of land for afforestation in the Basin corresponds closely with rainfall, with highly suitable areas typically having annual rainfall of 800 mm or more and moderate suitability down to about 700 mm per year (van Dijk et al 2006). Afforestation options for carbon sequestration in higher rainfall areas would need to consider the impacts of connectivity, interception and capture of water inflows to shared water resources. Presently the lack of recognition on hydrological connectivity is undermining confidence in the security of water access entitlements in the MDB. In this context, a possible option is the purchase of a groundwater access licence to account for diminished recharge of groundwater management units in higher rainfall areas with high connectivity. However, this is an option that is better considered beyond 2011 given the Basin Plan will set Sustainable Diversion Limits for groundwater as well as surface water, and will allow the two to be managed in conjunction (Productivity Commission 2010). It seems irrelevant to develop options specific to deep aquifers given the utilisation of surface water and shallow groundwater by trees, and the reliance on surface water by afforestation plantations.

Option 1: *Purchase of environmental allocation from the Commonwealth Environmental Water Holder (CEWH) through the 'Water for Future' program.*

The CEWH has amassed water entitlements across most catchments of the Murray-Darling Basin. Purchase from the CEWH is possible for the purpose of carbon sequestration because the Water Act includes provisions to enable the CEWH to trade to improve environmental benefit (Productivity Commission 2010). Furthermore, water held by the CEWH will not be limited by the SDL's meaning that the water will not be affected by the introductions of SDL's (MDBA 2009). Environmental entitlements yield a seasonal allocation in the same way as other entitlements dependent upon specific catchment factors. This is a key assumption of the management arrangements for environmental water entitlements under the Basin Plan. Because water use by afforestation plantations will vary from year to year, we have suggested two hypothetical ways to recover purchase of season allocations.

(i) Known quantity, in arrears. Purchase of the allocation would lag by one year. This would allow the purchased volume to be based on a known quantity (or calculated) water use per hectare of the afforested area for the previous year.

(ii) Expected estimate, current season. Purchase of allocation for the current season at market prices. This is the same as the above only the quantity purchased would be based on the previous year's water use per hectare of afforested area.

Further research is required to optimise a purchasing strategy specific to the target catchment and afforestation area.

This option gives some flexibility for afforestation proponents in that they are effectively recognised as a user of water with equivalent rights, albeit there is no tangible product or delivery requirement. This in itself offers proponents a larger area for afforestation because water delivery is not constrained by infrastructure or other physical constraints. This argument introduces the question of equity for afforestation proponents to be charged transaction costs, administrative charges and other costs related to physically securing allocations. Herein lies an incentive for proponents to purchase water from the CEWH assuming costs associated with water delivery and transaction can be excluded.

Option 2: *Water licence tender.*

In unregulated systems water for afforestation could be secured through the purchase of water licenses by afforestation proponents. This option has been based on the stream flow tender process used in Melbourne catchments in which the Victorian Government purchased water in unregulated parts of the Yarra system to increase environmental flows (DSE 2007). In the case of afforestation the option is concerned not with flow characteristics (as for environmental flows) but rather the end-of-system water quantities. A tender process could be used whereby diverters (water licence holders) submit bids offering to sell or modify part, or all of their water licence. This may include changes to the timing of diversion, quantity diverted by the licence holder. Willing participants who have subscribed to the tender are then selected based on the volume of water required to offset the afforestation water use in the appropriate location in the catchment. Conditions would need to be developed around the process, however, the outcome could be positive for existing licence holders in unregulated catchments and for afforestation proponents. Willing licence holders could reduce the quantum of their entitlement by detailing how much is being offered and their diversion location within the catchment. This option may appeal to water entitlement holders who do not take up their full allocation, or who are willing to sell part or all of their licence.

Option 3: *Afforestation of land with existing bundled water rights.*

This option focuses on the acquisition of land suitable for afforestation that includes bundled water rights of sufficient quantity to offset water use. A large-scale example of such a purchase by the Australian Government is Toorale Station for $23.75 million which holds entitlements to extract 14Gl of water from the Warrego and Darling rivers, and the right to harvest water from the floodplain (see Table 22.). The execution of this option is in the acquisition of land by the afforestation proponent. A number of considerations make this option viable:

(i) Land and water right must not be unbundled at the time of acquisition;

(ii) Both the land and water assets are needed for afforestation;

(iii) Typically the volume of entitlement attached to the land parcel will be more than required for the growth of trees at all growth stages and therefore the impacts on water yield will be offset;

(iv) From (iii), the afforestation proponent could trade excess entitlements;

(v) Other positive externalities such as biodiversity and salinity credits could be captured depending upon the prudent location of afforestation; and

(vi) The MDBA could have significant control over (v).

Option 4: *Payments for environmental services (or contracts for afforestation services).*

This option reframes a known policy tool applied in various forms for pursuing environmental outcomes all over the world. In Australia the policy tool has been applied to remnant native vegetation management through the BushTender program in Victoria, the Liverpool plains program in New South Wales and the Onkaparinga Catchment conservation program in SA (Productivity Commission 2010). The fundamental concept is providing payment for an environmental service or maintaining an environmental asset. In the context of water entitlements, this option allows landholders to lease their land and water allocation through a service contract to afforestation proponents for the plantation period. As for the other options the quantum of water allocation would need to be determined based on water use of the plantation. The terms and conditions of the lease need to determine the responsibilities of each party for costs of plantation establishment, maintenance and operation, as well as entitlements of each party to revenue for carbon credits and other possible environmental services payments.

The carbon credits generated by the plantation, biodiversity benefits and other environmental services that are generated (depending on the composition and nature of the plantation) are quantified and valued. The afforestation proponent may either own the credits outright if invested throughout the afforestation process, or purchase credits from the landholder.

There is significant scope to tailor the agreement to suit both the landholder and afforestation proponent. Fundamentally this option explicitly recognises the generation of environmental benefits and provides a mechanism for payments for those benefits.

Some considerations include:

(i) For landholders that are in marginally productive areas it provides a source of steady income for the period of the service contract;

(ii) The proponent can lease land and water allocation for a defined period of time without the cost of purchasing the land and entitlements. This is an advantage in the sense that the proponent is not left with assets it might not want after the plantation has generated its carbon credits;

(iii) There are potential biodiversity, water quality and salinity credits depending upon afforestation location; and

(iv) The option could be applied to both unregulated and regulated systems.

This option is an application of an existing policy tool that has been used for the protection and enhancement of ecosystems in the EU, USA and Australia. The rigour and clarity of the service contract and agreement between the parties will be key to the success of this option.

Option 5: *A new afforestation entitlement across the Murray-Darling Basin.*

Development of a new entitlement would explicitly address water use by afforestation plantations. While administrative, this option would recognise the risk to water security and reliability of water access entitlements that large scale afforestation presents, including groundwater licences. The National Water Commission (NWC) has highlighted the potential for further erosion of security of existing entitlements and recommends significant water interception activities be identified and quantified ‘to enable jurisdictions to include any proposals for additional water interception activities above an agreed threshold size into existing water access entitlement regimes by no later than 2011.’ (NWC 2009, p 28).

A new entitlement, conceptually similar to the way Victoria and SA manage farm dam interception, could be introduced for afforestation activities extensive enough to influence water security at the sub-catchment scale. Some considerations include:

(i) Explicitly recognise the influence of afforestation plantations and provide a mechanism to plan and account for water security;

(ii) Speed up the identification and quantification of afforestation activities on interception of surface and groundwater and set measurable and meaningful targets; and

(iii) Enable jurisdictions to meet their policy obligations.

11.3 Conclusions

Afforestation for carbon sequestration purposes is likely to affect net water yields. It is a land use practice that may indirectly affect seasonal allocations of water to entitlement holders in all systems.

Further development of these options for afforestation for carbon sequestration purposes will need to consider:

- The carbon price (see Lawson et al 2008);
- Land suitability for afforestation for carbon sequestration purposes. This would include land value, soil type, water entitlements bundled with land, location within the catchment;
- Water yield impacts of afforestation for carbon sequestration purposes. This should include a more detailed analysis of the effects of scale and species composition on the water cycle and resultant impacts on water yields for the catchment;
- Compatibility with any proposed changes to water entitlement frameworks under the basin plan; and
- Influence of afforestation on compliance with Sustainable Diversion Limit's, especially focusing on catchments identified as least vulnerable (most suited) to afforestation for carbon sequestration.

12 CONCLUSIONS

12.1 Risks to water resources from expansion of traditional plantation forests in the context of climate change

The likelihood of significant expansion of commercial forestry plantations in the high rainfall zone of the Murray-Darling Basin, at a scale that will affect catchment water yields, stream flow and allocations to water users, is low. The maximum impact on end-of-system flows in the Basin occurs under the dry extreme 2030 climate scenario, and is estimated to be a 1.6% reduction in flow.

The greatest risks exist in small sub-catchments less than 100 km^2 where plantations may occupy more than 20%, and close to 100% of catchment area, and where seasonal reductions in stream flow resulting from interception by plantations may be hydrologically and ecologically significant.

Reduced rainfall under future climate scenarios may encourage plantation area to remain static or contract to higher elevations within the existing 800 mm y^{-1} rainfall zone.

An existing trend toward establishment of smaller plantations distributed more widely may spread effects on water yields among small catchments, potentially reducing the effects on individual streams.

The adaptive capacity of plantations to increase water use efficiency under a drier future climate may partially offset projections for increased water use by any expansion in plantation area.

Future introduction of a price on carbon, and charging for water used by plantations are likely to provide additional socio-economic drivers that may encourage expansion of plantations beyond the levels considered to be realistic in this assessment. The introduction of a carbon trading system, and the price set for carbon, are major sources of uncertainty in projections of expansion in plantation area.

12.2 Management implications and opportunities

Maximising the water efficiency of plantations is clearly important to minimise the effects of traditional forest operations on availability of water for other users and for the environment. However, this analysis has identified that effects of water use by plantations on stream flow and water availability at the Basin scale, and at the scale of major catchments, are small compared to other factors, and accordingly, the benefits of improved forest management for other water users are also likely to be small.

Opportunities exist to reduce the hydrological footprint of forestry plantations in catchments less than 1000 km^2, by reducing the concentration of operations through promoting an increasing number of smaller plantations. This approach may generate higher operating costs, but the benefits of reducing fire risks and insurance costs are attractive to the forestry industry. Smaller plantations will presumably have a smaller effect on water yields in individual catchments, especially if the plantation area is restricted to less than 20% of individual subcatchments. The forestry industry is already adopting this strategy in recent plantations.

The benefits of changing plantation management practices are likely to be evidenced through re-establishing perennial stream flow in small tributaries that become ephemeral during low rainfall seasons. This benefit will translate to local aquatic environments in catchments less than 1000 km^2 in the high rainfall zone, rather than delivering significant improvements in flow in lowland river reaches. The Sustainable Rivers Audit has identified ecosystem health in parts of the high rainfall zone as Poor, Very Poor, or in some cases, Extremely Poor, attributable to the presence of alien fish, effects of the drought, and alteration to river flow regimes (Davies et al 2008). An increase in permanence of small tributaries by improved forest management in catchments with high plantation cover is likely to contribute to improved ecosystem health, and conservation of threatened species in upper reaches.

An additional scenario has been proposed that may affect the capacity for plantation expansion. As water availability becomes more limited, and allocations for irrigation areas are reduced, a trend for increasing agricultural food production may emerge in higher rainfall areas of the Basin, resulting in increased value of agricultural land. If this scenario eventuates, forestry plantations may become a less attractive economic proposition, and expansion in plantations may become less likely.

12.3 Risks to water resources from carbon sequestration plantations

Water use by plantations established for the purpose of carbon sequestration follows the same principles as for traditional forest plantations. Water use efficiency of eucalypt and pine species used for wood production varies from 1 to 5 m^3 Ml^{-1}, with carbon sequestration rates ranging from less than 4 tonnes carbon ha^{-1} y^{-1} to 13 tonnes carbon ha^{-1} y^{-1} depending on tree species, rainfall, local site conditions, and management practices. The main differences in effects on catchment water yields between traditional plantations and carbon sequestration plantations lies in the capacity for sequestration plantations to be established in regions with lower rainfall where traditional forest plantations are not economically viable.

The low rainfall regions of the Murray-Darling Basin typically have lower gradients and lower runoff rates than the high rainfall zones preferred for traditional forest plantations. Consequently, the differences in runoff between grassland and mature plantations in the low rainfall zones are much smaller than in high rainfall zones, and from a practical perspective may be difficult to detect in areas that receive less than 500 mm y^{-1} mean annual rainfall. Notwithstanding these practical considerations, model scenarios that produce large increases in environmental plantings of the order of 10 million ha suggest a 13% reduction in catchment water yields, and an 8% reduction in end-of-system flow across the Basin by 2050, in addition to effects under the median 2030 climate change scenario.

Estimates for increases in plantation area across the Basin range widely from a minimum value of 100,000 ha to over 10 million ha, driven largely by the existence of a price on carbon emissions, and the actual price achieved. At low carbon prices, growth of plantation area is predominantly through traditional plantation forests, but as the price of carbon increases, carbon sequestration plantations account for most of the increase in projected area.

Carbon prices under the existing New South Wales greenhouse gas abatement certificate scheme have fluctuated around \$10 $tonne^{-1}$ in recent years, so that projections based on higher prices of \$28, \$50 and \$100 $tonne^{-1}$ present hypothetical scenarios that may not eventuate in the immediate future.

Existing State and Commonwealth regulatory frameworks encourage plantations to mitigate carbon emissions to varying degrees, but there is limited consistency or clarity among jurisdictions in the way that water use by plantations is considered, and in statutory provisions for managing potential impacts of plantations on catchment water yields and stream flow.

A vulnerability framework has been developed to identify regions within the Basin most likely to be affected by increased carbon sequestration plantings, in the context of end-of-system flows, water quality, salinity management, biodiversity and riparian management. Combining all the anticipated impacts and benefits for each region in the Basin suggests that under the most extreme plantation scenario, the greatest changes are likely to occur in the Macquarie-Castlereagh, Eastern Mount Lofty Ranges, Moonie and Gwydir catchments. Potentially negative effects on stream flow are greatest in the Eastern Mount Lofty Ranges, Moonie and Gwydir catchments. Changes are greatest under the dry extreme 2030 climate scenario. The minimum plantation scenario reflects negligible changes in stream flow as a result of increased carbon sequestration plantings. The combined assessment also demonstrates that under the minimum plantation scenario, carbon plantings will make little contribution achieving the environmental objectives of other natural resource management programs. However, under the maximum plantation scenario, carbon plantings may provide significant support to other environmental objectives in selected catchments.

The multiple objectives and requirements of environmental plantations with regard to stream flow, water quality, salinity management, biodiversity, and riparian management present a complex set of trade-offs that will require multi-criteria spatial optimisation decision support tools to identify best approaches at all but the smallest spatial scales.

The uncertainty surrounding the influence of economic and other drivers on the extent of conversion of other land uses to carbon sequestration plantations creates a wide range of possible impacts on water availability within the Basin. Under current rates of afforestation, the risk to catchment water yields and stream flow from carbon plantations is widely dispersed and very low. However, the potential for reduced water availability resulting from large-scale plantation establishment in some catchments exceeds the projected reduction under the median 2030 climate change scenario, and presents a significant but manageable risk to water resources and ecosystems.

Depending on the eventual price for carbon, the magnitude of potential impacts may require regulation of plantations to minimise the effects of tree water use on the availability of water for environmental and consumptive purposes.

Five options were identified for including plantation water use in water access entitlement frameworks:

(i) Purchase of environmental allocation from the Commonwealth Environmental Water Holder

(ii) Water licence tender.

(iii) Afforestation of land with existing bundled water rights.

(iv) Payments for environmental services (or contracts for afforestation services).

(v) A new afforestation entitlement across the Murray-Darling Basin.

12.4 Recommendations

The potential consequences for water resources and ecosystems arising from a high rate of land conversion to carbon sequestration plantations require further investigation to determine the likelihood of occurrence, the resulting risks, and to identify appropriate risk management strategies.

The scale of possible impacts is large enough to drive large-scale changes in land-use, with potential for unforeseen environmental, social and economic outcomes.

Accordingly, estimates of future carbon sequestration plantation area require considerable refinement to allow better planning for potential impacts and regulatory requirements to manage negative effects.

Economic modelling studies that consider a range of likely prices for water and carbon are required to reduce the large range in existing estimates of future plantation area. Estimates based on hypothetical high prices have limited value in informing the relative importance of multiple threats to catchments and aquatic ecosystems, and in providing guidance on the probability of different outcomes for formulating appropriate risk management profiles.

Additional research is required to improve confidence in estimates of water use by carbon sequestration plantations at a regional level.

There is a large range of permutations of factors that determine the negative effects and environmental and social benefits of afforestation. Better information is required on sequestration rates and water use of typical species used for environmental plantings, particularly regarding stochastic variation and the range of possible outcomes compared to modelled predictions.

Depending on the likelihood of large-scale expansion of plantations, the complexity of trade-offs between mitigating greenhouse gas emissions, minimising effects on water resources, maximising other environmental benefits, economic outcomes and social dimensions may require accelerated development of landscape optimisation tools to provide practical advice on development of carbon sequestration plantations.

Options to manage plantation water use through tradable water access entitlements require more detailed assessment of the combined effects of water prices and carbon prices on carbon sequestration plantations.

12.5 Target audience and communication strategies

Audiences for communication of information on forest plantations and catchment water yields cover a wide range of sectors, including forestry and forest product industries; agriculture industries; rural communities; competing water users within the high rainfall zone and further downstream; natural resource management groups, conservation groups, and regulatory authorities responsible for land-use planning and approval, water management, and environmental management.

Strategies that focus on the limited effects of forestry plantations on water availability at a large scale within the Basin, and the limited opportunities for expansion of traditional forestry plantations are likely to be valuable in communicating information on relative risks to water resources under future climate regimes. This approach will assist targeting plantation management to reduce local-scale effects, and setting priorities to address all issues that potentially affect catchment water yields and stream flows. Other key messages include the possibility that introduction of a carbon trading system may significantly increase the potential to increase plantation area and resulting impacts on water yields.

12.6 Repeatability to establish trends

The standardised questionnaire format used to obtain information for this report allows trends in plantation projections, industry perceptions, and knowledge of water yield impacts and management to be assessed over time by combining assessments from specialist organisations, industry, and recent literature. This approach is able to account for changing experience over time, improvements in scientific knowledge, variability in interpretations among individuals, and changes in external drivers.

This process seeks to identify the current state of knowledge by consulting acknowledged specialists in relevant disciplines, rather than attempting to obtain a consensus based on a statistically appropriate sample size. Despite the intentionally small sample size, there was a high level of consensus among views expressed by respondents from different professional and disciplinary backgrounds.

In view of recent hypothetical assessments that suggest a price on carbon may provide incentives to expand plantation area, it would be prudent to reassess the conclusions from this study when there is greater certainty of the introduction of a carbon trading system and a price of carbon.

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APPENDIX A - INTERVIEW QUESTIONNAIRE

Part A

For interviewer: The objective is to review and synthesise current understanding of the water yield impacts of traditional plantations in the high rainfall catchments of the MDB.

The following ranking system is used for a few specific questions.

Importance, on a scale of -2 to +2:		*Magnitude, on a scale of -2 to +2:*	
Not at all important	-2	Large reduction in water quality &/or quantity	-2
Not very important	-1	Small reduction in water quality &/or quantity	-1
Neutral	0	No change in water quality &/or quantity	0
Important	+1	Small increase in water quality &/or quantity	+1
Very important	+2	Large increase in water quality &/or quantity	+2

Respondent ____

Organisation and role ____

Interviewers ____

Date of Interview ____

Type of interview (Face-to-Face, Telephone, Email)

Questions

These question focus on traditional commercial-scale hardwood and softwood forestry plantations on cleared land, and on native forest land, in high rainfall areas (>600 mm y^{-1}) in the MDB.

1. What is your understanding of current scientific knowledge of the effects of traditional forestry plantations on catchment water balances, with regard to both surface water and groundwater?

2. Is this effect the same for softwood and hardwood plantations?

3. Are water balance impacts the same for plantations in cleared land and for plantations among native forest?

4. What are the principal factors that determine plantation affects on water yields? *(Only if required, prompt with information regarding e.g. plantation age; soil type; catchment gradient; density of planting and thinning practices.)*

Factor 1:					
Importance	-2	-1	0	+1	+2
Magnitude	-2	-1	0	+1	+2
Factor 2:					
Importance	-2	-1	0	+1	+2
Magnitude	-2	-1	0	+1	+2
Factor 3:					
Importance	-2	-1	0	+1	+2
Magnitude	-2	-1	0	+1	+2

5. The 1997 statement on *Plantations for Australia: the 2020 Vision* established a notional target of trebling the area of commercial tree crops by 2020. What level of increase or decrease in forestry plantation area in the Murray-Darling Basin is realistic and desirable?

6. What areas in the Murray-Darling Basin are likely to support large-scale expansion in forestry plantations (show on maps)?

7. How is the potential growth of forestry plantations affected by economic issues regarding land values and profitability of alternative land uses such as cropping and grazing?

Explain briefly current climate and projected climate scenarios provided by MDBA.

8. Considering growth projections for plantations in high rainfall areas, how will plantation areas be affected by the three climate scenarios?

b) What are the implications for water yield impacts and streamflow?

9. What are the main gaps in existing scientific knowledge regarding impacts of forest plantations on catchment water balances?

Significance of gaps in scientific knowledge

Importance	-2	-1	0	+1	+2

10. What key scientific documents is your knowledge/awareness of the issues based on?

Part B

For interviewer: The objective is to review and synthesise the knowledge available on multipurpose forest, commercial and non commercial afforestation, in all rainfall areas in the MDB, both current and proposed, that are planted specifically to provide carbon sequestration benefits. The impacts of these plantings, both positive and negative should be assessed, including impacts on water yield, salinity management, biodiversity and riparian management.

Respondent ____

Organisation and role ____

Interviewers ____

Date of Interview ____

Type of interview (Face-to-Face, Telephone, Email)

Questions

These questions specifically relate to commercial and non-commercial multipurpose forests planted specifically to provide carbon sequestration benefits, in all rainfall areas of the MDB.

1. What approaches are used for afforestation intended to provide carbon sequestration benefits in the Murray-Darling Basin?

2. What species of tree are currently used or recommended for carbon sequestration plantations?

3. How does the viability of carbon sequestration plantations vary among geographic regions in the MDB, especially between high rainfall and low rainfall regions?

Effect of rainfall on viability of carbon sequestration plantations

4. How are the different types of carbon sequestration plantations likely to increase or decline in the future?

5. Are any particular types of existing land use most amenable to conversion to carbon sequestration plantations?

6. What is your understanding of current scientific knowledge on the impacts of carbon sequestration plantations on:

   a) Catchment water yield

b) Salinity management

c) Biodiversity

d) Riparian management

7. Are you aware of any limitations or obvious gaps in knowledge to these studies? (List against items a – d above)

8. What key scientific documents is your knowledge/awareness of the issues based on?