Native Forest Management in Silvicultural Systems and Impacts on Catchment Water Yields

Part 1: An Analysis of Hydrologic Impacts of Native Forest Management in the Murray-Darling Basin System

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October 2010

Published by Murray-Darling Basin Authority
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This report may be cited as: *Native forest management in silvicultural systems and impacts on catchment water yields-Part 1: An analysis of hydrologic impacts of native forest management in the Murray-Darling system,* Murray-Darling Basin Authority, Canberra.

MDBA Publication No. 125/11

ISBN 978-1-921783-84-5

Report Volumes and Authorship

Project Title: Native Forest Management in Silvicultural Systems and Impacts on Catchment Water Yields

Volume 1: An analysis of Hydrologic Impact of Native Forest Management in the Murray Darling Basin System.
Leon Bren, Stuart Davey, and Jeya Jeyasingham with contributions from Associate Professors Patrick Lane and Richard Benyon. Dr's Davey and Jeyasingham particularly contributed the analysis of Chapter 8.

Volume 2: A Critique of the "ACF Document "Woodchipping Our Water"
Leon Bren, with contributions from Professor Emeritus Ian Ferguson and Associate Professors Patrick Lane and Richard Benyon.

Although specific authors contributed their skills on specialized chapters, all authors contributed to comments in the document.

Photographs on Title Page

To Left: The upper reaches of the Dandongadale River.
To Right: Ice forms on a mountain lake at the head of the Ovens River.

Produced as Part of the "Risk Assessment Program" of MDBA,, October, 2010

List of Abbreviations

ABARE-BRS	Australian Bureau of Agricultural and Resource Economics – Bureau of Rural Sciences
ACF	Australian Conservation Foundation
BISY	“Bushfire Impact on Stream Yield”
GHA	General harvest areas
GL	Gigalitre (1000 ML or 1 billion litres)
MDB	Murray–Darling Basin
MDBC	Murray Darling Basin Commission
MDBA	Murray Darling Basin Authority
MMBW	Melbourne and Metropolitan Board of Works – a forerunner of Melbourne Water.
NFI	National Forest Inventory
ML	Megalitre (1 million litres)
SKM	Sinclair Knight Merz

Executive Summary

The possible impact of native forest harvesting through changes in catchment water yield is sometimes viewed as a potential risk to inflows into the Murray-Darling River. The purpose of this report is to review the knowledge-base on this matter, to define suitable models for evaluation of this risk over the Murray-Darling Basin, and to apply these to examine the impacts of such silviculture. An ACF report “Woodchipping Our Water” concluded that the value of water transpired by eucalypt harvesting in the Goulburn River catchment exceeds the value of wood products produced by the forest harvesting. A separate report providing a critique of the ACF report forms part of this review.

Concern about changed water yields associated with eucalypt regrowth were first articulated after the 1939 fires by the Melbourne and Metropolitan Board of Works. Forest fires in 1926 and 1939 led to replacement of large areas of old-growth with regrowth in Melbourne’s water catchments. This led to a program of water research starting in the 1950’s. The culmination of this were a number of single catchment and paired catchment experiments that have formed the knowledge base of today.

The single catchment work started with a data analysis by Langford (1974, 1976) using routine gauging data. This showed a depression of water yield in regrowth water catchments relative to old-growth mountain ash. The early work of Langford was augmented by the sophisticated analysis of Kuczera (1985) who used much the same data. This fitted a simple model to the bushfire response. The model suggested that, after burning, there was a two year period of stability followed by a substantial water yield decline. Streamflows reached a minimum about 25 years after the fire and then slowly increased. An elegant equation which has come to be known as “the Kuczera Curve” was formulated. The data, from burnt catchments, showed little sign of a flow increase after burning.

Subsequent work adopted a “paired catchment” approach. The useable data from the Coranderrk Paired Catchment Project started in 1968. In this work, one catchment was clear-felled in 1971 and a second catchment was “thinned” in 1972. The methodology followed was that of conventional paired catchments, as pioneered at Coweeta in North Carolina. The results of this, updated to mid- 2007, showed a clear initial increase in flows, followed by a sustained and prolonged decrease in flow. The decrease in flow had some similarity to the Kuczera Curve.

The success of the Coranderrk work led to two other groups of experimental catchments in the northern area of Maroondah catchment – the “North Maroondah experiments.” Myrtle2 catchment was a repeat of the Coranderrk experiment, except that it was located in a much wetter mountain ash environment. The Monda group looked at the impact from logging 1939 regrowth and replacing these with forests of varying density. Some partial results of these have been published in a paper looking at the methodology of data analysis (Watson *et al*, 2001). Unfortunately detailed analyses of the results of either of these have not been published. Similar experimental work by other Victorian Government agencies was discontinued and produced no results.

The work of the Melbourne and Metropolitan Board of Works led to a stimulating period in forest hydrology. This was manifested in some fine physiological work and a collection of somewhat similar paired catchment projects in other parts of Australia; the results from these studies have provided the bulk of information for this report. Two of these – the Karuah Project looking at water use of moist eucalypts and the Yambulla project looking at the water use of mixed species forest have been continuing for many years. However over time there has been a change in commitment to such research and momentum of the work has faded. Thus, although many of these projects have large amounts of data there are relatively few published results from them. Analysis of data from such projects is a focus of recommendations.

The work in general found that when ash type eucalypts were harvested there was a period of enhanced flow due to the lack of transpiring vegetation. This could last for five to ten years. Typically the increased flows would “build up” rather than increase dramatically; this can be interpreted as reflecting catchment water storage. Then, after a period of water flows similar to that of old-growth control catchments, the flow would decline by perhaps 200 mm annually. There is considerable year to year variation in the magnitude of both the increase and the decrease in water yield. The longest-running data set is that of Picaninny catchment, with the post-logging sequence being 35 years. Although there are some similarities to the well-known “Kuczera curves” the results have substantially greater variation. Unlike the Kuczera curves, it takes about ten years before the water yield decline starts.

The results were less specific with respect to mixed species forests. The early work of Langford and Kuczera could find no indication of water yield decline over time when mixed species forest was burnt. Although various models have large declines in water yield inherent in them, we could find little evidential basis for this (with the possible exception of the Yambulla paired catchment experiment). Our recommendations include paired catchment work in mixed species forest.

At the same time as forest hydrology work was declining, there was an increased interest in logging and water yields in the Australian environment. The result was the development of a number of models for consultancies or research purposes. These models have formed the basis of many reports and considerations of water yield. However, the origins and data-backing of these models is not always clear. This report summarises the available data, gives an account of such models, and tests the ability of these models to reproduce annual streamflow changes. The testing uses the well-known Nash-Sutcliffe coefficient of efficiency, and single mass plots of the data. Most commonly the models appear to over-estimate the "depression phase" of regrowth water use. Many of the models do not reproduce the enhanced flows experienced for five or more years after logging. The best-performing model was the SKM-MDBA "Bushfire Increase in Streamflow Yield" (BISY) model. This model was used in subsequent phases of this study.

An input to this report was an analysis of the distribution of native forest and native forest under potentially harvestable management within the Murray Darling Basin was made by ABARE-BRS. The majority of the forests in the Murray-Darling Basin are non-commercial or of low commercial value with low rates of increment. However, three major catchments – the Goulburn/Broken, the Ovens/Kiewa, and the Upper Murray catchments have high rainfall, high increments, and well-developed and long-standing forest harvesting. Using the known location of the 700 mm and 900 mm rainfall isohyets, the forests were categorised into areas receiving <700 mm, 700-900 mm, and >900 mm annual rainfall historically. The total area of commercial forests in these catchments was 608,800 ha, this being about 44 percent of the total forest areas in the catchment.

Given the long-standing history of forest management in the above areas, the forests were assumed to have approximately equal areas of all age classes present. The selected models were applied to compute both the increase in yield that would occur if all the forests in the catchments were old-growth, and the rate of transition to these if logging should cease. The results showed that the water yield in such areas might be expected to double, although because of the action of forest harvesting in increasing water yield initially, cessation of harvesting would lead to decreased yields initially. The total maximum annual volume "liberated" was computed as around 500 GL per annum, distributed over the three catchments, although it would take 1-2 centuries for this to be realised. Of these catchments, the greatest potential for yield increases would appear to be from the forests within the upper Goulburn catchment, reflecting the largest area of high-rainfall managed forests

Although the computations followed an objective procedure, interpretation of the results requires consciousness of issues with the model and the inadequacies of both the model and the long-term data on which the analysis is based. The results of the computations indicate that if logging ceased today, it would be ten to twenty years before there was any net gain in water yield. Since logging has been embedded in these catchments for probably a century or more, it is likely that current water resource utilisation has developed with a background of logging. The view can also be taken that, like all biological products, water is a resource required for wood production, and it may well be an entirely economic and sensible use of water to grow wood. Finally, it is likely that recent fires in the forests of the area will lead to large stands of regrowth that will be heavy water users. Thinning regimes may be required to increase water yields.

Recommendations include revisiting past paired catchment projects and bringing the analysis of data up to high, uniform standards, commencement of new long-term projects to measure water use of mixed species forests, and proper economic analyses that take account of fire protection costs, the difficulties of growing stands to old growth in the present fire climate, and the joint production costs of wood and water. Work on how climate change will affect forest growth and water yield also needs to be undertaken.

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Chapter 1:

Introduction to Native Forest Water Use

Picaninny catchment thirty six years after clear-falling. This was part of the Coranderrk Paired Catchment Project.

1.1 Introduction

From about 1980, there has been discussion and controversy on the impacts of regrowth eucalypts on water supplies. This has been a quintessentially Australian debate – with minor exceptions, in other countries of the world there seems little evidence of an age-related difference between younger and older forest once the forest has gained occupancy of the site (Bosch and Hewlett 1982). Thus in these countries, after harvesting there is an increase in water yield for some years and then the water yield returns to the level characteristic of the species (or forests in that area generally), irrespective of age. This appears to not be the case in Australia; rather the water use of the forest (or the water yield of the catchment) appears to vary as the age (and growth rate) of the trees varies.

This effect appears to have first been articulated by officers of the Melbourne and Metropolitan Board of Works (MMBW) – the organisation that provided Melbourne with water until about 1992. The expansion of Melbourne's water supply involved acquisition of land and withdrawal of timber resources. An argument that developed after massive fires in 1926 was that the catchments of regrowth mountain ash (*Eucalyptus regnans*) did not yield the same water outflow as the catchments of old-growth mountain ash. This view was reinforced by substantial areas of regrowth in the water catchments of Melbourne resulting from fires in 1939.

The conflict between the wood harvesters and the water harvesters continued through the 1950's. In the 1950's the MMBW initiated a program of hydrology research, ultimately leading to a collection of studies that have become fundamental to this report. However research did not really commence until 1968 when the active phase of a paired catchment project at Coranderrk started after reconstruction of a failing weir. This work became associated with a number of other studies referred to below, and provided quantitative data regarding assertions of age-related water yield issues. In the 1970's to the present work has continued – albeit intermittently – in defining some aspects of the changes in water yield associated with forest harvesting.

During this time, native forest harvesting has become controversial. A common argument put forward against harvesting is that regrowth eucalypts will use "valuable water" and that the value of the water will exceed that of the wood (Hughes, 2006; ACF/Practical Ecology, 2009). A large amount of polemical material has been generated on this matter. The purpose of this review is:

1: To examine the available “scientific” information on the impacts of native forest harvesting on annual water yields in the Murray-Darling Basin

2: To consider the “value” or the “price” of water as a traded good.

3: To examine the impact of the rate of interest chosen on the results of economic analyses concerning wood and water issues.

The work is laid out in a more or less chronological sequence documenting the research developments.

It should be noted that this report is concerned only with the results relating to impacts of harvesting on water yields. The report does not cover issues such as stormflow, physiology, or groundwater processes. Emphasis is given to studies from areas at least close to the Murray Darling Basin. However some reference is made to excellent studies from Western Australia and overseas.

In general, the view of water in the report is as a priced good passing into the River Murray. An underlying assumption is that there is entirely adequate storage capacity to deal with any stormflow generated from forested catchments.

Criteria for Inclusion in the Literature Review

There is a vast world-wide literature on the impacts of tree growth on water resources, the impacts of logging, and the ecological and physiological processes involved. For this review the criteria for inclusion were:

1: Work should be based on direct measurement of water resources over a number of years.

2: Results should either be a time sequence of data or encapsulated in a formula.

3: If results are not based on direct measurement, they should have a clear connection to such primary measurement.

4: Data should be from a site relevant to Australian conditions generally and ideally within or close to the Murray-Darling Basin area.

Methodology of the Review

Figure 1.1 illustrates the methodology adopted for reviewing the impact of native forest harvesting on River Murray water resources. The procedure has been:

1: Extraction of the quantitative evidential base for impacts of native forest logging. The criteria for selection are given below.

2: Programming of the model as far as possible.

3: Extraction or obtaining of the “base data” of included studies. In some cases this was obtained by “digitizing” illustrations from publications.

4: Testing the models against available base data to find which ones gave the best agreement. Testing used two methods – “single mass plots” and “Coefficients of agreement.” Details are given below.

5: Model selection to use to make estimates for the appropriate situation.

6: Application of the model to the forest area estimates to compute the volumes of water involved.

The rationale for this methodology was to find an objective way to “rank” the various models.

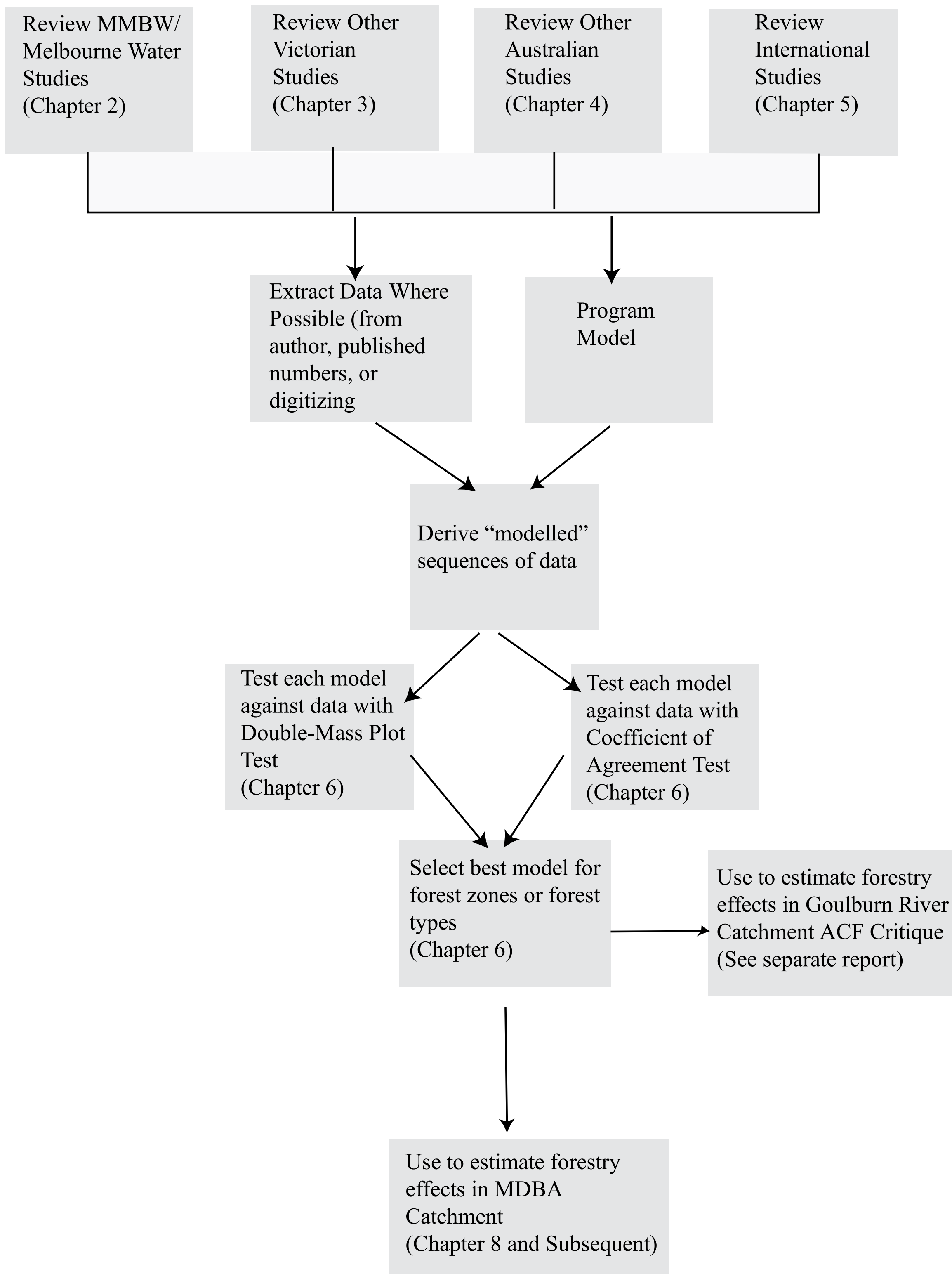

Figure 1.1: Flow chart of this study

The Basis for Comparison with Models

Two criteria were selected for comparisons of the “fit of models” – the Nash-Sutcliffe Efficiency Parameter, and the overall fit as described by the correspondence between a single mass plot of the data and a single mass plot of the model.

The Nash-Sutcliffe Coefficient of Efficiency Parameter

This had its origins in the work of Nash and Sutcliffe (1970). A good description of this is given in Krause, Boyle, and Base (2005). The coefficient is commonly used in hydrology for evaluation of hydrologic models. It is defined as “one minus the sum of the absolute squared difference between the predicted and observed values normalised by the variance of the observed values during the period under investigation. It is calculated as:

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad (1.1)$$

in which O_i is the i^{th} observation and P_i is the corresponding prediction of that observation. The range of the coefficient lies between 1 (perfect agreement) and minus infinity. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model.

Agreement with Single Mass Plots

A “single mass plot” was used to compare the cumulative value of the model output with the cumulative value of the “real data.” The closer the line was to the 1:1 line, the more highly regarded the model was.

1.2 A Simple Water Balance Formulation

A reasonable place to start any consideration of the impact of native forest logging on catchments with the water balance of a catchment. Consider a catchment water balance measured over a year:

$$P = ET + S + \Delta m + \varepsilon \qquad (1.2)$$

where

P	=	annual precipitation, mm,
ET	=	annual evapotranspiration, mm,
S	=	annual stream-flow (catchment yield), mm,
Δm	=	increase in soil moisture (sometimes defined as catchment storage) over the period of measurement, mm, and
ε	=	error in measurement, including deep seepage, mm.

If the period of measurement is taken between times of similar flow and seasonal conditions, then the change in soil moisture can, at the cost of some error, be viewed as negligible and ignored. Similarly scientists optimistically assume that the error term, ε , is small relative to the other measurements. Given this, equation (1.2) reduces to:

$$P = ET + S \qquad (1.3)$$

This can be rearranged as:

$$S = P - ET \qquad (1.4)$$

or

$$ET = P - S \qquad (1.5)$$

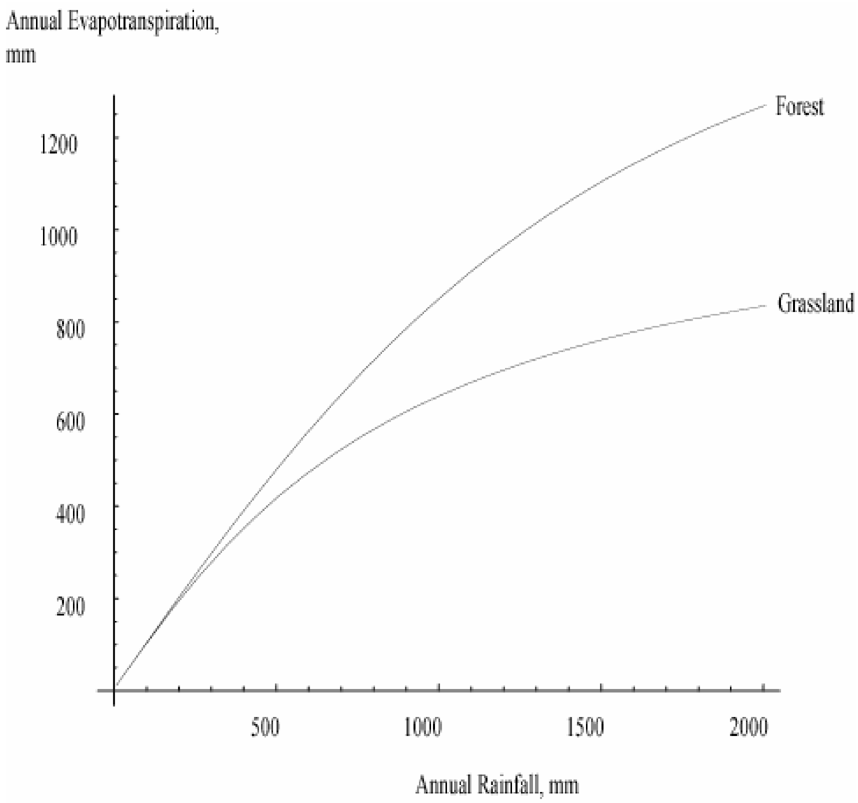

Figure 1.2: Comparative evapo-transpiration curves of Zhang, Dawes, and Walker (2001) for forest and grassland.

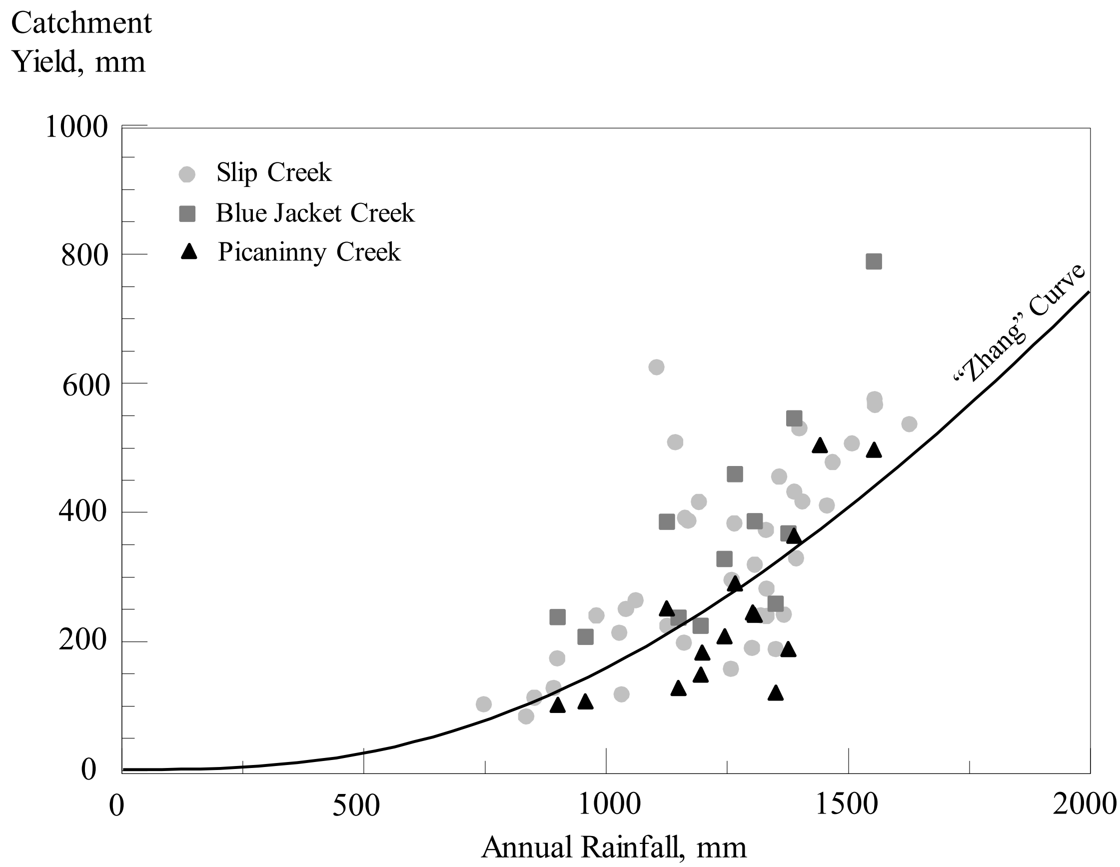

Figure 1.3: Annual runoff from mature forest for the three catchments within the Coranderrk project as a function of annual rainfall and the "Zhang" forest runoff line.

The Zhang Model of Forest and Grassland Annual Evapotranspiration

Zhang, Dawes, and Walker (2001) presented evapotranspiration (ET) of forest and grassland as a function of annual rainfall (P). The curves (referred to as “Zhang Curves”) were derived from a world-wide study of forest and grassland runoff using data from 250 catchments with agricultural and forest land uses. The curves are shown in Figure 1.2 for the range of rainfalls used for radiata pine plantations. Zhang *et al*. (2001) state that “the model is a practical tool that can be readily used to predict the long-term consequences of reforestation, and has potential uses in catchment-scale studies of land use change.” Their discussion includes a comprehensive consideration of the errors induced, and notes that the variation can be substantial, with root-mean-squares of error in the 70-90mm range. The curves can be expressed as:

Forest

$$ET_{forest} = \left(\frac{1 + \frac{2820}{P}}{1 + \frac{2820}{P} + \frac{P}{1410}} \right) P \qquad (1.6)$$

Grassland

$$ET_{grass} = \left(\frac{1 + \frac{550}{P}}{1 + \frac{550}{P} + \frac{P}{1100}} \right) P \qquad (1.7)$$

ET refers to annual evaporation (mm) and the subscript “grass” or “forest” defines the type of community. More generally, for catchments with mixtures of forest and grassland, a weighted average would be used:

$$ET = (1 - p_{frac}) ET_{forest} + p_{frac} ET_{grass} \qquad (1.8)$$

where p_{frac} is the fraction of grassland in the catchment, and the catchment is assumed to comprise only forest and grassland.

An issue in the use of “Zhang Curves” is their behaviour at low rainfalls compared to the observed behaviour of Australian forested catchments at low rainfall (see Bren, Lane, and McGuire (2006) for a discussion of this). In general, the forested catchments have little runoff at below about 700 mm whereas Zhang curves suggest a more gentle decrease in runoff with decreasing rainfall. For most forest hydrology applications this is of little concern because commercial forests are usually found in higher rainfall areas. However it can be an issue in extending the results of analyses over wider areas.

1.3 The Concept of the Age-Water Yield Relationship

Figure 1.3 shows the “forest runoff” line derived from Equation 1.4, together with annual mean data points from the Coranderrk project. It can be seen that the data conforms reasonably well to these curves when the means are used. This line has been used as the basis of a number of relationships for “mature native forest.” Use of actual annual data in such a relationship gives a much higher variability. This variability includes such factors as whether the annual rainfall came in one large storm or many small storms, but also errors in measurement and processing, and imperfections in the streamflow measurement systems (and these alone can be large). However it has usually been assumed that once a forest has achieved “dominance” (or full ground-cover) over a site that the water yield for a given rainfall does not alter.

This appears not to be the case for at least some Australian eucalypts. In these there is an age-water yield or age-rainfall-water yield relationship. Thus, for a given site and rainfall, a different outflow will be given by older trees compared to younger trees. This adds another source of variation to hydrologic studies. It is argued that, because water is so valuable, that our forest management should aim at keeping the forests in stages which, according to the age-water yield relationship, give the highest water yield. Chapter 2 is devoted to examining the evidence for such age-water yield relationships.

“Scientific Hydrology” and Some Practical Issues of Measurement

A practical issue to be faced in subsequent chapters is the evidence for often-quoted age-water yield relationships; these are critical to the view of the interaction between forest management and Australian water resources. In particular, in the following text we have attempted to ask the following questions:

1: What data supports particular forest-water relationships?

2: Can the age-water yield relationship be distinguished above the general hydrologic "noise" associated with storm size, rainfall intensity, and imperfections in our measurement systems?

3: If there is no data base for a particular forest type, are we justified in assuming particular forms of relationships?

What is "Ash" and what is" Mixed Species?"

This report refers heavily to "ash forests" and to "mixed species" forest. This at least partly reflects its Victorian origins, although the term "mixed species" is cosmopolitan. "Ash" refers to an even-aged forest of *Eucalyptus regnans.* Although there are often other tree species present, mountain ash is the dominant species in terms of height, size and numbers. By its nature, mountain ash regenerates in "wheat-field-like" even-aged forest. The species is fire-sensitive and is easily killed by a fire, resulting in the pattern of even-aged, fire induced regeneration.

Mountain ash typically occurs on southern mountain slope areas in the 1200-2000 mm rainfall zone. The term "ash" is sometimes applied also to alpine ash (*Eucalyptus delegatensis*), and shining gum (*Eucalyptus nitens and Eucalyptus denticulata)*. In their native form, these are of far less importance than mountain ash.

"Mixed species" forest refers to forest in which no one species has overall dominance. Typically such a forest may be a mixture of 5 or more eucalypt species – in Victoria one may expect to find messmate (*Eucalyptus obliqua*), manna gum *(E. viminalis*), candlebark gum *(E. rubida*), peppermints (*E. radiata* and *E. dives*) and mountain gum (*E. cypellocarpa*). Typically in any one area two or three tree species will be present. The forests may grade into mountain ash at their upper ends.

Mixed species forest are variable in their response to disturbance. However they do not reproduce as an even-aged forest as mountain ash does. Thus typically it is difficult to assign "age" to such forests, although it is also incorrect to view the forests as uneven aged. Commonly the forests are viewed as "clumps" of even-aged forest and can be managed quite successfully this way.

Chapter 2:

The MMBW Studies:

Quantifying the Age-Water Yield Relationship

Old growth mountain ash in the Coranderrk
Paired Catchment Project Area

2.1 General Comments Concerning the Victorian Work

Melbourne and Metropolitan Board of Works (MMBW) was a major Victorian governmental agency managing Melbourne's water until 1992. After this time its functions were transferred to a collection of new agencies and new businesses. MMBW pioneered much of the work on water use of forests and the changing water needs of mountain ash forest as it ages. Victorian work on tree water use "led the way" from about 1970 to the mid-1990's. The impetus for this was a drive by commercial timber interests for logging on Melbourne's water catchments (see the report of the State Development Committee 1959). Then, as now, there was an inherent and long-standing conflict because the areas of best forest from a commercial point of view were also the areas of best water yield (see Evans 2005 for an account of this conflict.)

A number of debates concerning logging of catchments led to various yield-age-rainfall relationships for ash and mixed species being used. The data sources for Victorian studies can be grouped as:

1: Routine gauging records, as used by Langford (1974, 1976). These are adequate to show gross trends but have many imperfections relating to the quality of the stage-flow relationships, gaps, and adequacy of recording.

2: Paired catchment experiments at Coranderrk and North Maroondah. These were administered by the MMBW. Unfortunately other "paired catchment experiments" were discontinued.

Most of the work ceased in the mid-1990's, although the routine of flow data collection from the various paired catchment studies was maintained. The advent of severe drought in this century has reawakened interest in this data but to date there has been little published from the results of this century.

2.2 Age-Water Yield Relationships: The Work of Langford (1974)

The first quantitative definition of an age-water yield relationship was that of Langford (1974, 1976) who examined the change in yield of water following a bushfire in a forest of mountain ash. This used “routine” hydrographic data for four catchments in the Maroondah (Healesville area). These catchments, ranging from 14 to 105 km^2 in area, all had substantial mountain ash forests and had been burnt in the 1939 fires.

Langford’s work looked at the change in flows relative to old growth ash. In this he developed a rainfall-climatic index model of streamflow in the pre-burnt period, and used this as a surrogate “control catchment” to assess the deviations in flow after the fires. He also examined the streamflow in the O’Shannassy catchment, using “double-mass” plots. It was argued that although this catchment had been burnt (29 per cent of regrowth was from 1939, but only 15 per cent of the area was regrowth mountain ash) there was little change in the water yield.

His work showed a decline in flow that started 3-5 years after the fire and appeared to have reached a maximum decline 15-20 years after the fire. No increase in flow could be found after the fire; this perhaps indicates a certain insensitivity in the gauged records. The work showed a clear age-related impact of the forest burning. Subsequently the analysis was superseded by Kuczera (1985) using “improved” versions of the same data sets. Langford’s work is viewed here as a “stepping stone” to the work of Kuczera (1985).

Using multiple regression of the catchment data, Langford (1974) developed a forest-water relationship expressed as:

$$A = 153 + 1.79a - 2.29\,ms \qquad (2.1)$$

where A is the average reduction in streamflow (mm),

a is the percentage of ash regeneration, and

ms is the percentage of mixed species forest.

The R^2 of the relation is quoted at 0.99, but the degrees of freedom are not given.

This regression should be used with care since it implies that if a is 0 and ms 100 per cent, then streamflow increases. Langford (1974) stresses the point that larger amounts of mixed species "suppresses" the reduction in flow.

The work of Langford (1974, 1976) was substantially superseded by the work of Kuczera (see next section) who used extended versions of the same data set and used these to define algebraic relationships. However, two points stand out from this:

1: There is an age-water yield relationship embedded in "very noisy" data from predominantly mountain ash catchments, and

2: There was no evidence of this relationship extending to "mixed species" forest.

2.3 Age-Water Yield Relationships: The Work of Kuczera (1985)

Kuczera (1985, 1987) used extended versions of the data set of Langford (1974) in an examination of age-related water yield decline after the 1939 fires. The catchment data set was extended to 8 catchments, ranging in area from 416 ha (Sawpit Creek) to 90,700 ha (Thomson River at Coopers Creek). Kuczera (1987) queried the assumption that O'Shannassy catchment was substantially unaffected, arguing that, rather, there was an effect but it was "buried" in the "hydrologic noise."

Kuczera (1987) presents a two parameter model showing the reduction in yield for each of the catchments. This model is:

$$g(t) = L_{max}K(t - 2e^{(1-K(t-2))} \quad (2.2)$$

$$g(t) = 0 \; for \; t < 2$$

where g(t) (in mm) is the change in water yield relative to old growth, L_{max} is the maximum reduction in annual streamflow, and 1/K is the period from the start of the decrease to the point of maximum decrease. L_{max} should be taken as negative for the usual form of the curve. The fit of the curve was designed so that the forest was close to its "long term value" (i.e. zero) at about age 150 years. Figure 2.1 shows the set of curves for his data set (which have become known generically as “Kuczera curves”) derived by Kuczera (1987). The shaded portion shows the area for which there was data. The curves reflect the proportion of mountain ash in the catchment.

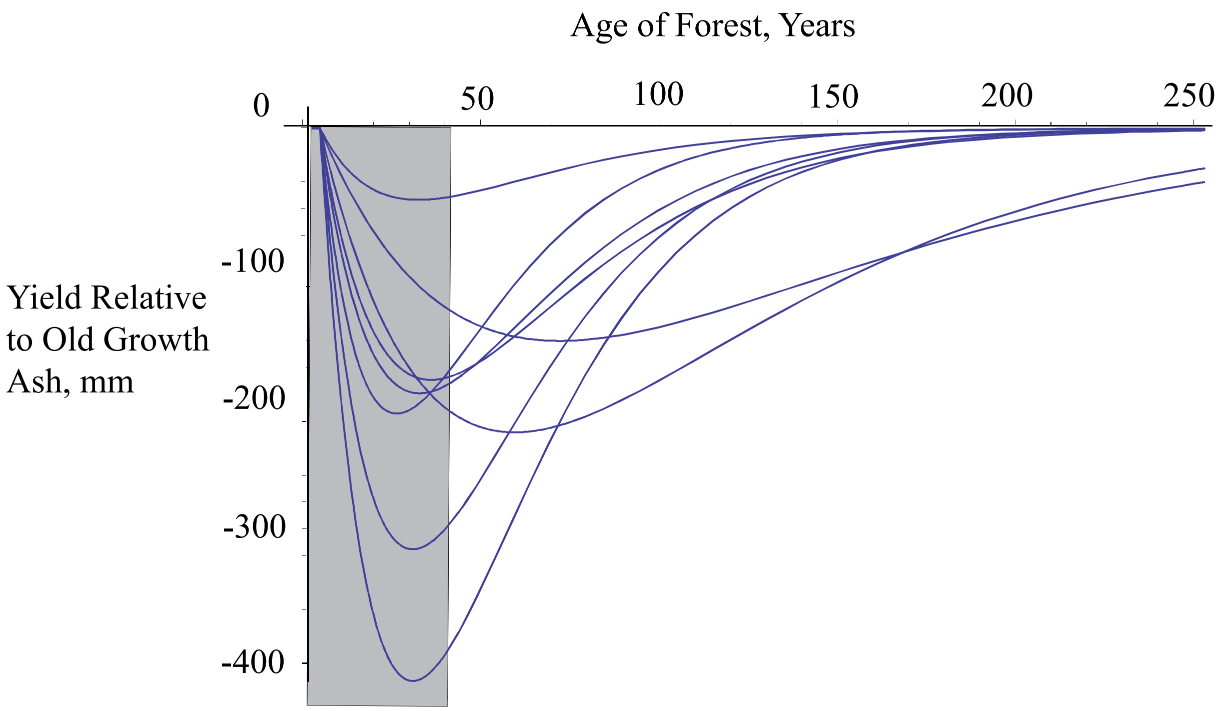

Figure 2.1: Change of water yield as a function of age for the various ash catchments from Kuczera (1987). The smallest decline is for the Thomson River; the largest is for Graceburn Creek. The shaded area is the approximate limit of data. The catchments all had varying amounts of ash species in them.

Kuczera (1985) examined the statistical relationship between the modelled yield decline (L_{max}) and the percentage of ash, mixed species, and the area of the catchment. The model derived was:

$$L_{max} = 6.15\ a \quad (2.3)$$

where a is the percentage of ash in the catchment. If we substitute Equation 2.3 into 2.2, then we arrive at the relationship:

$$g(t) = 6.15\ a\ K(t-2)e^{(1-K(t-2)} \quad (2.4)$$

$$g(t) = 0\ for\ t < 2\ years$$

An examination of the relationship between the percentage of ash and the value of K arrived at the optimal relationship of Log_e K = -3.24, with no gain from knowing how much ash was in the catchment. Substitution of these values into equation 3.4 leads to a relationship illustrated in Figure 2.2 below

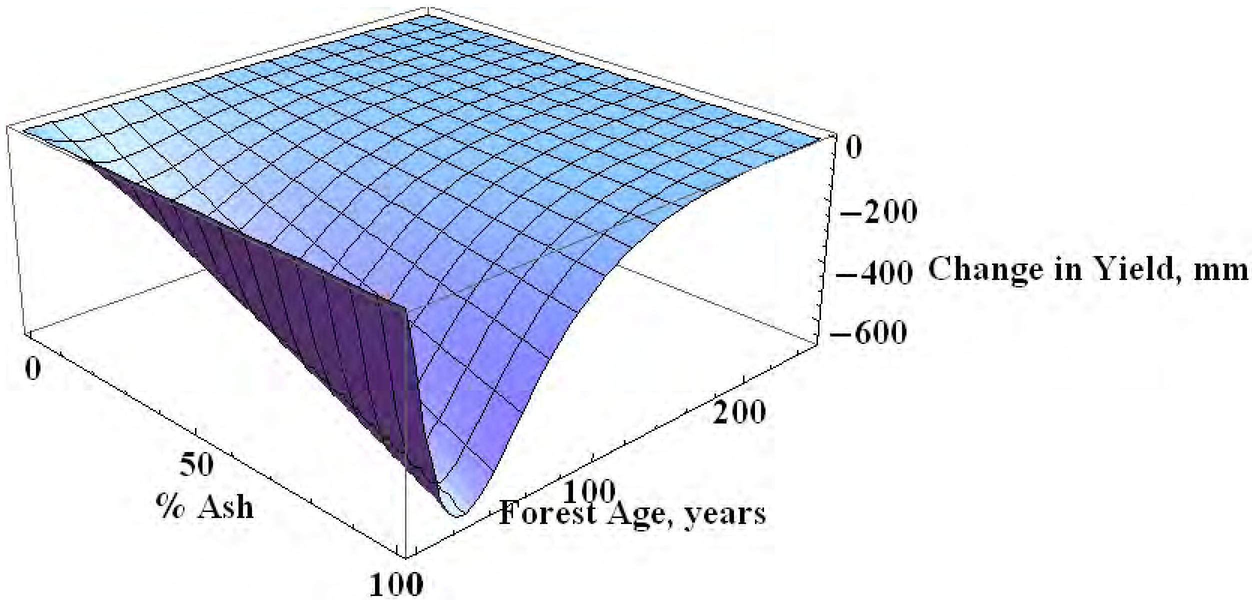

Figure 2.2: Change in yield as a function of the percentage of age in the catchment and the forest age (from relationships derived by Kuczera 1987).

The value of k = $e^{-3.24}$ puts the minimum flow as occurring between ages 25 and 26 years of age. Kuczera (1987) then proposed a modeling scheme based on dividing a complex catchment into small components.

If a is taken as 100 per cent, then equation 2.4 becomes:

$$g(t) = -24.086\ (t-2)e^{(1-0.0392(-2)} \qquad (2.5)$$

$$(t) = \ 0\, t < 2$$

The minus sign indicates a decrease in yield. This is shown in Figure 2.3 below. It is effectively the “edge value” (i.e. at ash = 100 per cent) of Figure 2.2. It should be noted that Kuczera (1985) referred to this (page 120) but never actually “plotted” it.

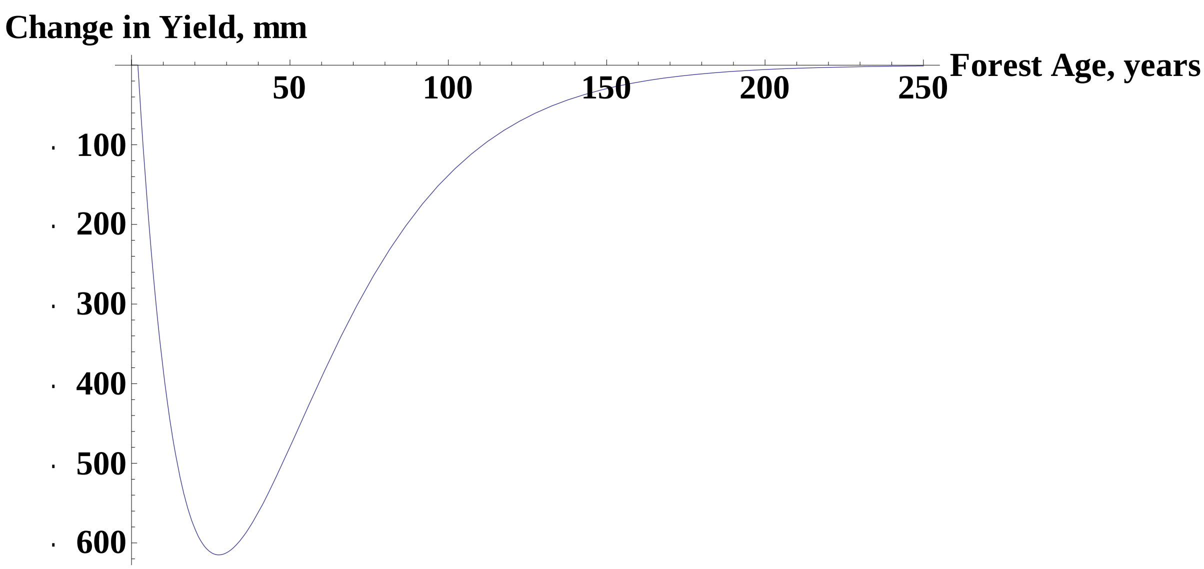

Figure 2.3: Change in yield as a function of forest age for a catchment with 100 per cent mountain ash. The "drop" is 615 mm per year.

Kuczera has derived some degree of fame in "Kuczera curves", although his modeling was more refined than that of many citers. His work is still fresh and relevant today. However, looking at the work from 25 years on, the following comments can be made:

1: The analysis was based on "routine" gauging with a large degree of error in them.

2: The curve selected was based on the author's feelings of how the data should return to zero over time. Thus there was no data beyond the "shaded zone" of Figure 2.2. This point has, to the best of our knowledge, never been criticised so clearly many people share this view.

3: The changes in the catchments were associated with fire; there was no component of logging in them.

4: In transposition of these results from "fire" to "logging" there is an inherent danger of ignoring the differences between the two processes.

5: The work was only concerned with the change in yield in going from old growth to regrowth. There was no consideration of the absolute water yield.

6: There was no incorporation of annual rainfall into the formulation, and

7: The work was based on a “single-catchment” study using a model as a control.

If the “average ash yield” from old growth forest is taken as 1200 mm per year, then:

Yield (mm) = 1200 $-24.086\ (t-2)e^{(1-0.0392(t-2)}$ (2.6)

where t is the age of the forest in years. Figure 2.4 shows this curve below.

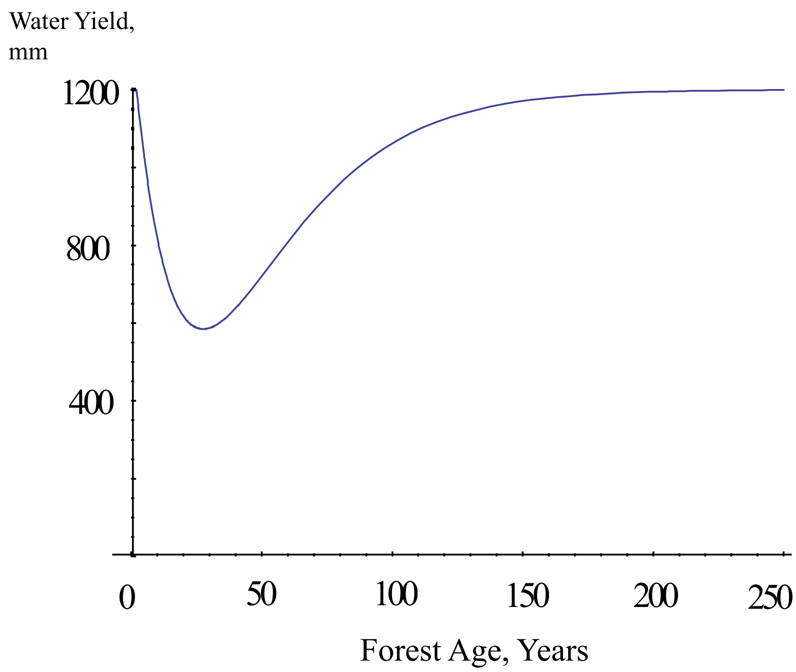

Figure 2.4: A second form of the Kuczera curve predicated on an average old-growth ash yield of 1200 mm per annum.

This form of the curve is cited in Vertessy *et al.* (1998, Page 7), and has been used by many authors since. This reference states that” the mean annual runoff from large catchments covered by pure mountain ash forest in an old growth state is about 1200 mm per year.” We believe that the choice of 1200 mm as a “base runoff” for old growth mountain ash is high. “Zhang curves” - a simple predictor of the amount of rainfall needed to get 1200 mm runoff in a forested environment - suggest a rainfall above 2,500 mm (2,576 mm is the exact value) would be needed. Watson *et al.* (1999) shows that the average daily runoff over long periods for

Myrtle Creek 1 (an old growth catchment) is around 2 mm day^{-1} – thus the annual runoff from these would be around 700-800 mm.

The Continued Life of Kuczera Curves

Over the years a number of "trends" have appeared in the use of these curves for evaluations:

1: The (t>2) qualification has usually been dropped.

2: The curve of Figure 2.4 or Figure 2.5 has been used with no further qualification about the percentage of ash in the catchment or whether the catchment being analysed could sustain such a rate of outflow (e.g. Creedy and Wurzbacher 2001).

3: The criterion that it applies only to 100 per cent mountain ash has faded.

Two major limitations on the utility of Kuczera curves are:

1: The curve does not accommodate the flow increase found for five or more years after harvesting. This flow increase has a profound impact on economic analyses using interest rates because of the proximity of these in time to the point of valuation. It is noted, of course that for whatever reason, the data of Langford (1974, 1976) and Kuczera (1985, 1987) did not show such an increase.

2: The curve make no provision for variation in rainfall. Again, the period of data over which they were collected was, by the standards of this century one of relatively high and constant annual rainfall compared to the drought-stricken first decade of this century.

2.4 The Coranderrk Paired Catchment Experiment

The next project to elucidate the age-yield relationship(s) for Australian commercial species was the Coranderrk Paired Catchment Project. Measurement on this is continuing, although the relatively short "calibration" period will ultimately limit the life of the project.

Coranderrk is a paired catchment project following the pattern of Coweeta (USA) and other "classic" designs (see Elliot and Vose 2010). Although measurement commenced in 1954 the data from then until 1968 is not useful in the design because of the unreliability of the gauging weir on Slip Creek. This was replaced by a new one in 1968. Comprehensive reports on the project establishment and periodic analysis can be found Langford and O'Shaughnessy (1980). Bren, Lane, and Hepworth (2010) summarises the data to April 2007 and should be referred to by those wanting a more comprehensive view. Table 2.1 summarises the Coranderrk project.

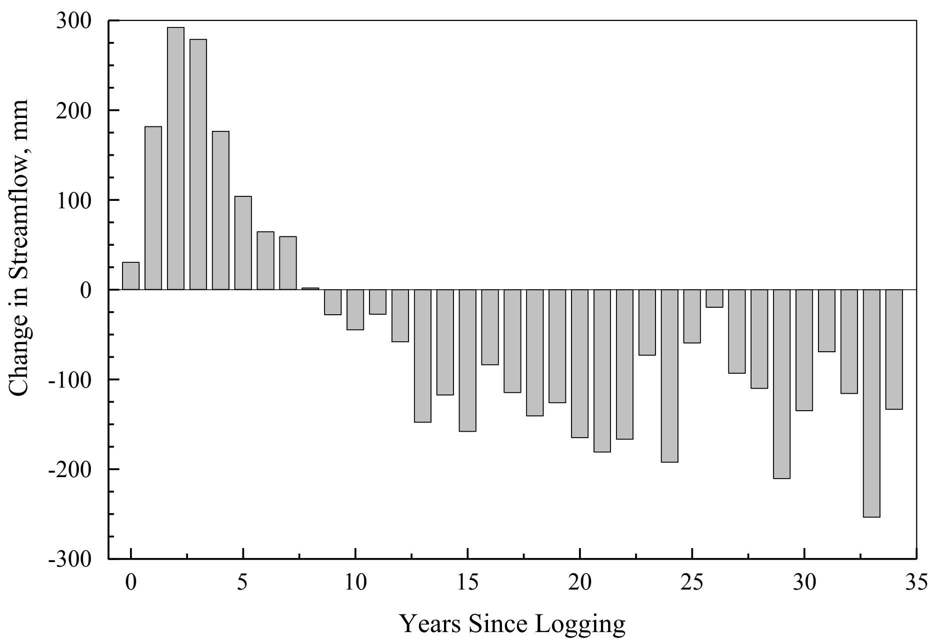

Figure 2.5: Change in flow as a function of years since logging in Picaninny Creek catchment.

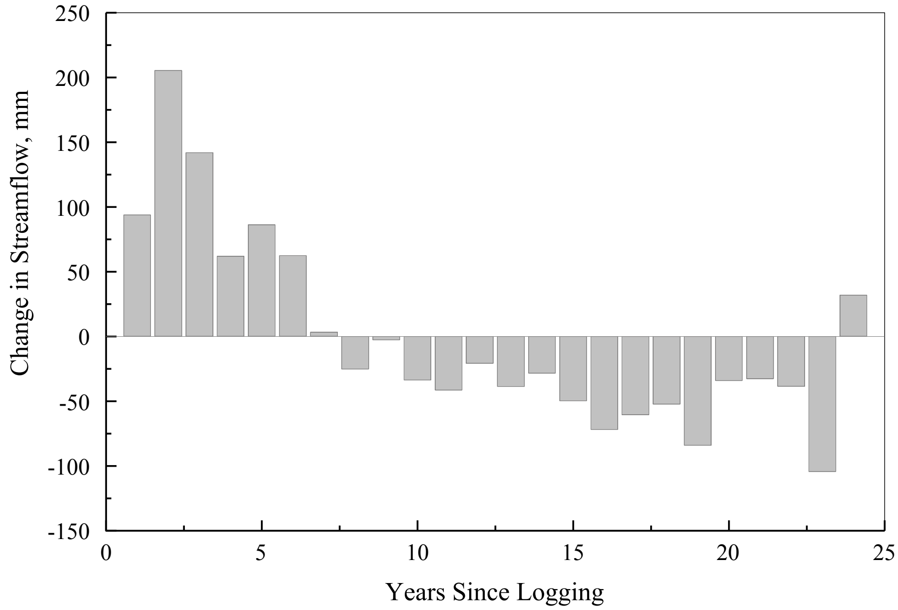

Figure 2.6: Change in flow as a function of years since logging in Blue Jacket catchment.

Table 2.1: Catchment Statistics and Dates for the Coranderrk Paired Catchment Project

Attribute	**Slip Creek**	**Blue Jacket Creek**	**Picaninny Creek**
Area, ha	62.3	64.8	52.8
Mean “lid” slope	40^{o}	37^{o}	38^{o}
Vegetation			
- Dry sclerophyll	1%	6%	33%
- Wet sclerophyll	91%	73%	61%
- Mesophytic shrub	8%	21%	6%
Period of measurement	May 1968 to May 2007	August 1958 to June 1997	March 1956 to May 2007
Treatment	Control	50% Selection	Clearfall and burn
Treatment Date			
- Roading	Control	1971	1970
- Logging commenced	Control	8th Nov 1972	26th Nov, 1971
- Regen. Burn	Control	None	March, 1972

Figure 2.5 shows the annual response of Picaninny Creek to logging of the mixed mountain-ash and mixed species forest and regeneration with substantially pure mountain ash. Figure 2.6 shows the comparable response of Blue Jacket Creek. This had a 50% "sawmiller selection" thinning. Figure 2.7 shows the Coranderrk response against the Kuczera curves generated by equation 3.4 and with Log_e K = -3.24. In this, the value of a is set at 58 per cent, reflecting that the final composition was 31 ha of regenerated ash on a 53 ha catchment. It can be seen that the Kuczera curve overstates the water use and lacks the year to year variability of the real data.

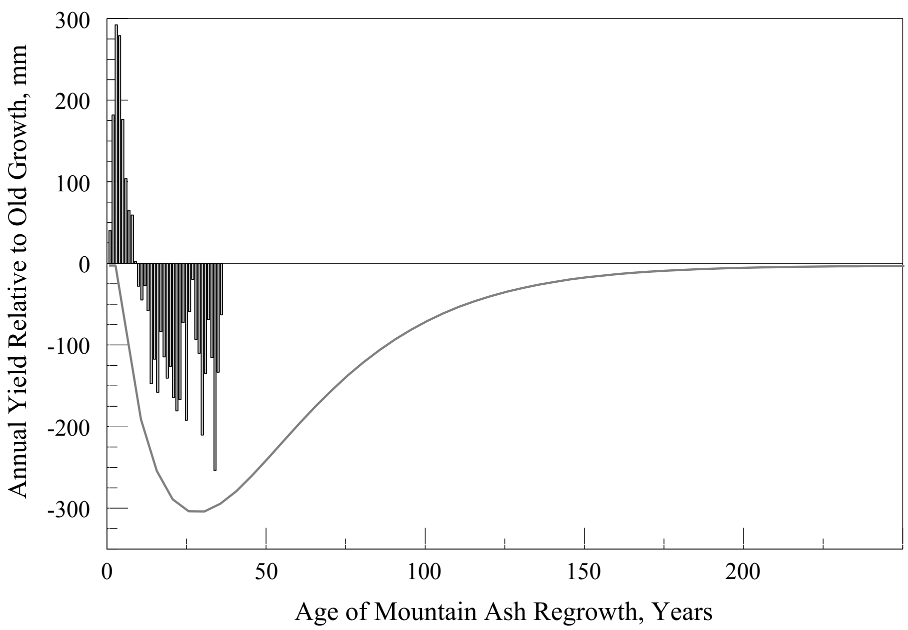

Figure 2.7: The Kuczera curve generated by the application of Equation 2.4, together with the observed response of Picaninny catchment. This assumed 58 per cent ash in the catchment.

A number of issues become obvious:

1: The curve of Kuczera (1987) makes no provision for flow increase because Kuczera did not observe any flow increase. In both the Picaninny and Blue Jacket cases, there was a definite and sustained flow increase which lasted about six to eight years.

2: There is a “Kuczeroid behaviour” of the Coranderrk data in that the flow diminishes but the magnitude of the dip observed is less than expected on the basis of Kuczera (1987).

3: The use of the correct proportion of ash in a given catchment makes the “dip” of the Kuczera curve a quite reasonable fit to the dip observed after the increase in flow associated with logging has dissipated.

4: The lack of any rainfall correction in the Kuczera model makes its application at anything other than a conceptual level doubtful

Many scientists view Coranderrk with some reservation because it is not a “pure” ash site and the rainfall – averaging 1280 mm per annum – is at the lower end of the range for ash (although very typical of many ash sites). Others argue that any relationship derived should “work” across the range of sites. It is the longest-running experiment and, although not without issues, has no replacement.

Bren used the analysis of Bren, Lane, and Hepworth (2010) to generate a model of behaviour. The analysis assumed that the old-growth runoff corresponded to that of “mature completely empirical formula:

$$S[P,A] = \left(17.7462 + 100 \left[1 - \left(\frac{1 + \frac{2820}{P}}{1 + \frac{2820}{P} + \frac{P}{1410}} \right) \right] - 2.478A + 0.0473366A^2 \right) \frac{P}{100} \qquad (2.7)$$

where *S*[*P,A*] is the estimated streamflow from an ash forest given annual rainfall P mm and age A years. This is shown graphically in Figure 2.8. The upper line represents the yield with no trees. The lower line represents the yield with 26 year-old regrowth. The central line represents the yield of old growth forest. The dotted lines represent catchment efficiency (or coefficients of runoff). The results suggest a very low “catchment efficiency” with the combination of 26 year-old regrowth and low rainfalls. The relationship was derived with the age of the trees ranging from 0 to 34 years of age. Assuming that the water use of the forest slowly moves towards the "mature forest" line, this behaviour is referred to as "Kuczeroid."

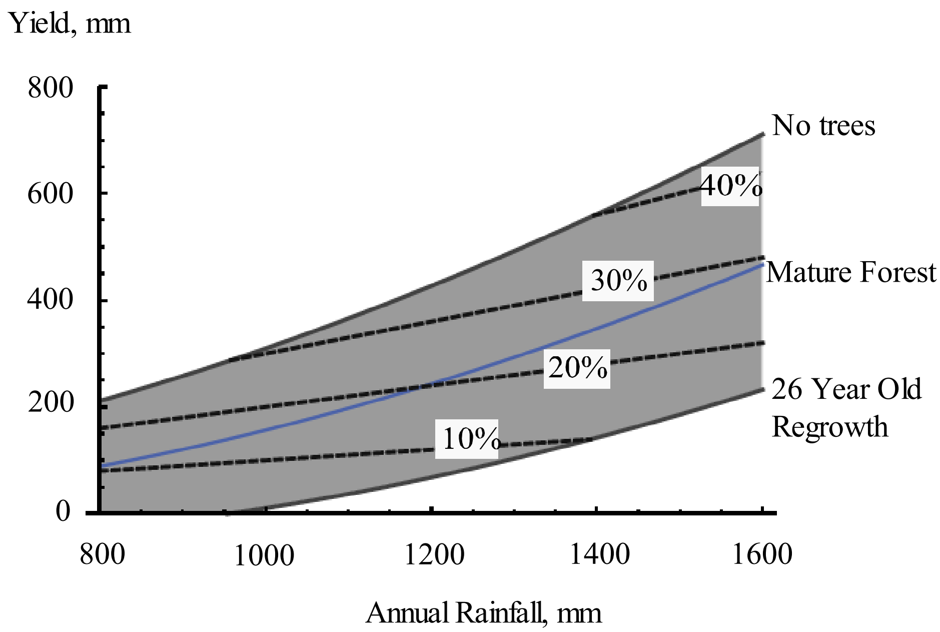

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Figure 2.8: A visual presentation of equation 2.7 for the "no trees", "mature forest" and maximum water-using regrowth case. Lines of equal catchment efficiency are also shown. The shaded area represents the domain accessible by the forest. This has not, as yet been published in a refereed journal and is presented for illustrative purposes.

2.5 North Maroondah Experimental Work

This work used a "deep ash" (i.e. much wetter) environment. Following on from Coranderrk a collection of work was undertaken at the "North Maroondah Experimental Area." This work commenced in 1969. The work was initiated because it was felt that the Coranderrk site was "unrepresentative" of the dense, high-rainfall regrowth mountain ash forests which had resulted after the 1939 fires. The site ultimately consisted of 15 catchments, ranging in size from 4 to 120 hectares. A range of treatments took place including clear-falling, patch-cutting, and thinning. Unfortunately the detailed results from this work are unavailable.

The most comprehensive account of the results to date is in the paper of Watson, Vertessy, McMahon, Rhodes, and Watson (2001). This gives a number of results up to 1997. The focus of the paper is on the methodology of extracting the results. Although results are presented they are limited and there is little consideration of the meanings or implications for forestry. To facilitate discussion we have digitized aspects of the results from the small-scale plots using the program *"Didger"* (Golden Software). In general we have plotted these results against a background of the Picaninny results from Coranderrk to facilitate comparisons. We have only used the "treatment effect" and have accepted that their method does a fine job of extracting this from the long-term data.

Myrtle 2

This was an old growth (>200 years old) forest and was 74 per cent clear-felled during the 1984-85 summer. The nearby Myrtle 1 catchment was used as the control. The pre-treatment period was 151 months. Watson *et al.* (2001) describe the results as "in the post-treatment period, significant positive disturbances are consistently observed for 2-3 years after treatment. These then decline until, at about 6 years after treatment, a 4 year period with a tendency for significant negative disturbances occurs." Watson *et al.* (1998) commented that "the results also show that un-modelled variability in streamflow due to factors such as climate is large relative to the magnitude of treatment-induced change in streamflow.

Figure 2.9 illustrates their data. For clarity we have only shown their 12 month moving average – this suppresses much seasonal and other variation. The "upturn" about 1997 is noted as due to a Psyllid infestation reducing transpiration. However this was also a wet period. Within the limits of variability associated with paired catchment work, the results do show a marked similarity to the Picaninny case. In particular the magnitude of the yield change is similar and the duration of the change is not dissimilar, although the transition from an increase in flow to a decrease in flow is more sudden.

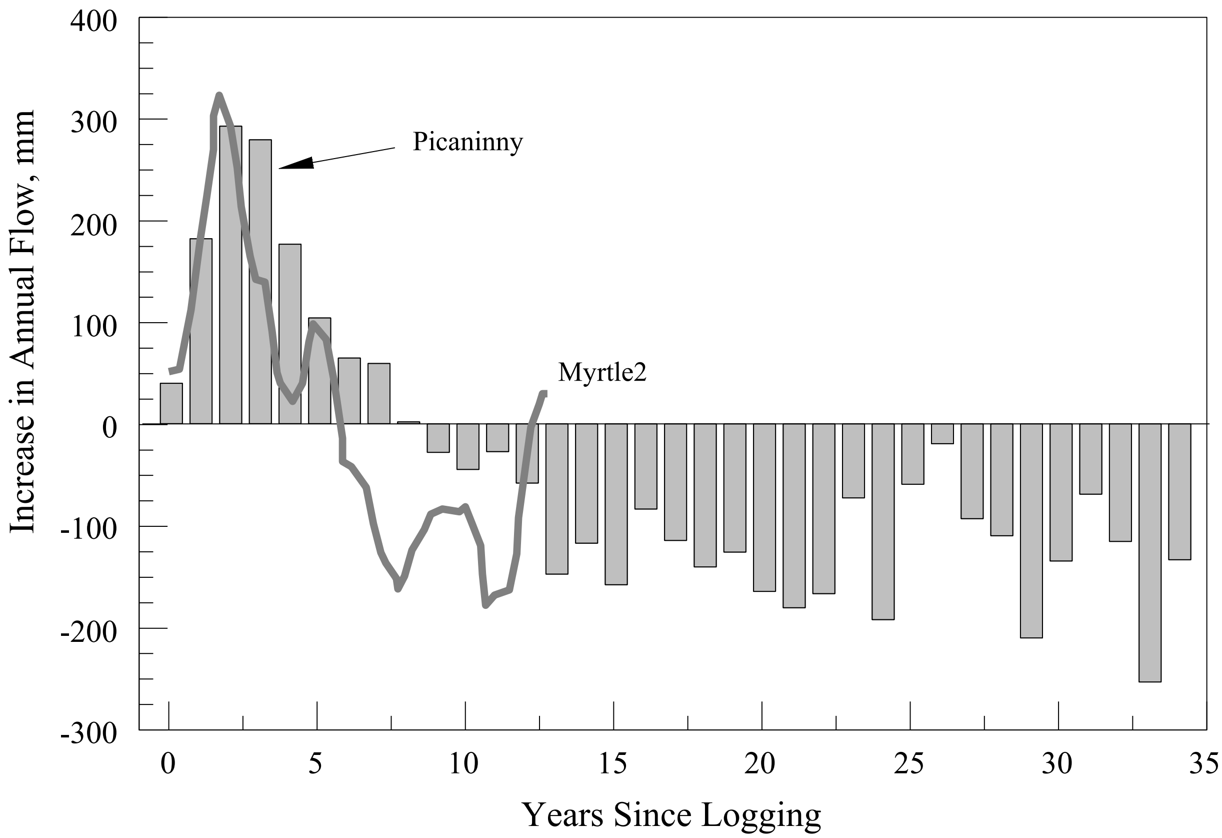


Figure 2.9: Change in yield associated with the logging of the old-growth ash at Myrtle 2 catchment. The hatched bar plot in the background is the Coranderrk response.

The Monda Group

Watson *et al.* (2001) note that the Monda catchments 1, 2, and 3 were 1939 regrowth and were clearfelled and either seeded (Monda 2) or planted (Monda 1 and 3) at nominal densities of 2000, 5000, and 500 seedlings ha^{-1} respectively in the summer of 1977-78. Regeneration at Monda 2 was achieved by scattering seed at 3.2 kg ha^{-1}, which was expected to give a seedling density of 5,000-10,000 per hectares.”

Figure 2.10 illustrates the changes after treatment against a backdrop of Coranderrk results. Watson *et al.* (2001) argue that the high peak and the sustained increase reflects the relatively low runoff “base” associated with assessing runoff change from logging a 1939 regrowth catchment. This is supported by Figure 2.10 in the sense that if the 1939 regrowth had a reduced yield of 100-200 mm per year, then clear-falling would change the absolute level of runoff to that effectively associated with bare ground (and thus might be expected to be 100-200 mm higher increase than Coranderrk results). This is the observed pattern.

A practical consequence of the "Kuczera curve" behaviour is that if a forest at or near the point of minimum yield is logged (or allowed to grow on) the yield will, by definition, increase. Thus, given the nature of the control catchment, the change in flow will not drop much below the zero because the control yield itself was low.

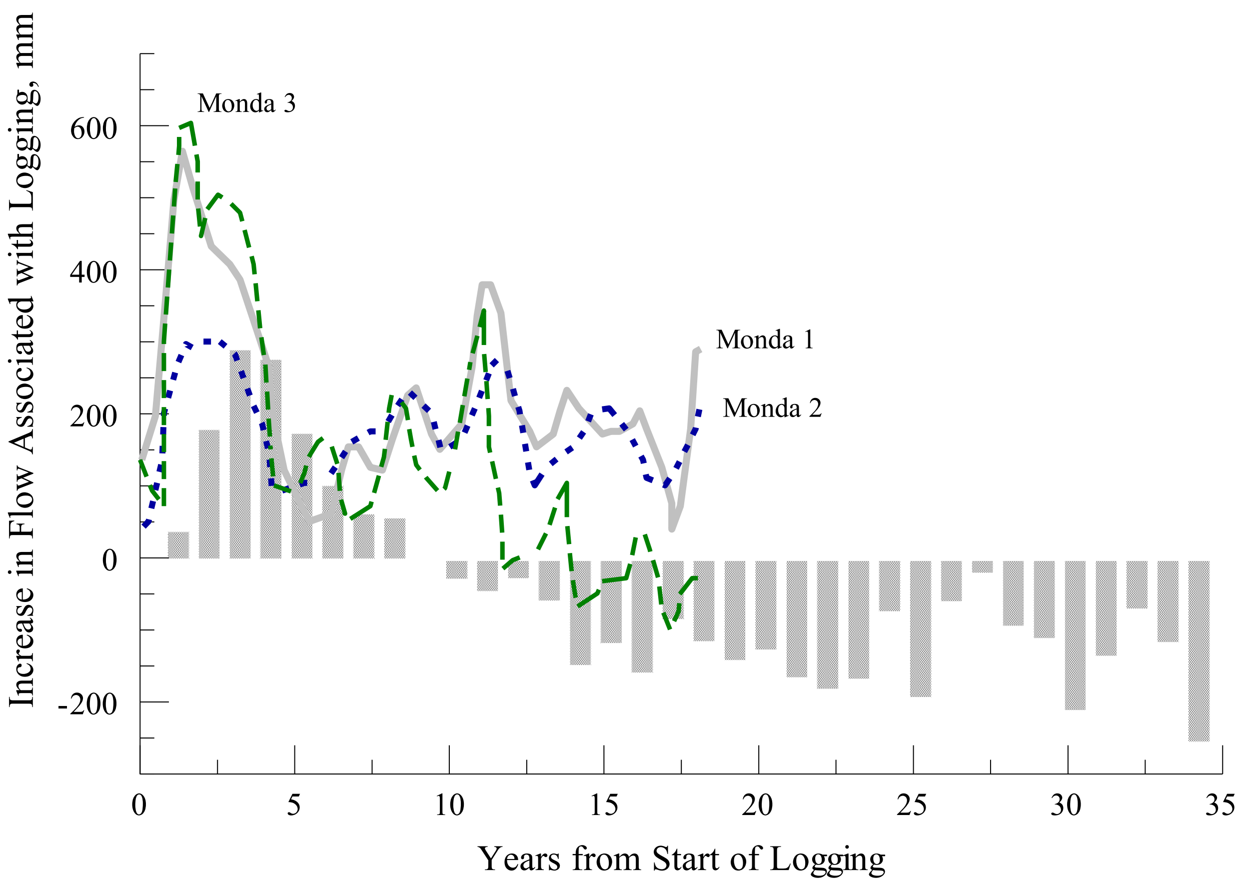


Figure 2.10: Change in yield associated with logging of the 1939 regrowth at Monda catchments 1 to 3. The hatched bar plot in the background is the Coranderrk response. Data were digitized from the illustrations within Watson *et al*. 2001.

2.6 Watson and Others on the MMBW/Melbourne Water Data

Watson *et al. (1998*) led a very interesting synthesis of the data from the various catchments. He noted in passing that although overlaying data (as we have done in the previous two illustrations) had attractions, the difficulty from a scientific point of view was the differing age of the control catchments and that the control catchments were, themselves, non-stationary. He derived a simple model of one-equation form, and by least squares analysis using all the data derived parameters. He noted that because of various statistical issues (such as the same variable being on both sides of the equation) he could not derive valid estimates of the errors of fit of the equations.

Using the data he derived the following equation:

$$\text{aetash} = \left(-1 + e^{-\frac{\text{age}}{\text{p7a}}}\right)\text{p3a} + \left(-1 + \frac{2}{1+e^{-\frac{\text{age}}{\text{p6a}}}}\right)(\text{p2a} + \text{p3a} - \text{p4a}) + \text{p4a} + \frac{\text{age}\, e^{1-\frac{\text{age}}{\text{p5a}}}(\text{p1a}-\text{p2a}-\text{p3a})}{\text{p5a}} \qquad (2.8)$$

in which:

aetash	=	Estimated annual evapotranspiration of ash,
age	=	age of the forest, years,
e	=	Exponential constant
p1a-p7a	=	Constants.

The various constants can be viewed as having physical meanings. The curve can be viewed as a super-positioning of various wave forms. Being a six-parameter model allows many permutations and variations to represent any arbitrarily bumpy line. Some of the constants are interpreted as components of evaporation and can be ascribed units to assist visualisation. However varying values of parameters gives a wide variety of “curve forms.”

Figure 2.11 gives the example quoted by Watson *et al.* (1998), using the parameters from his Table 2. An annual precipitation of 1,995 mm was assumed. This rainfall value was taken as

800 mm plus 1195 mm, where 1195 mm was the regional average old-growth water yield estimated by Kuczera (1985). The water yield is estimated as precipitation minus ET.

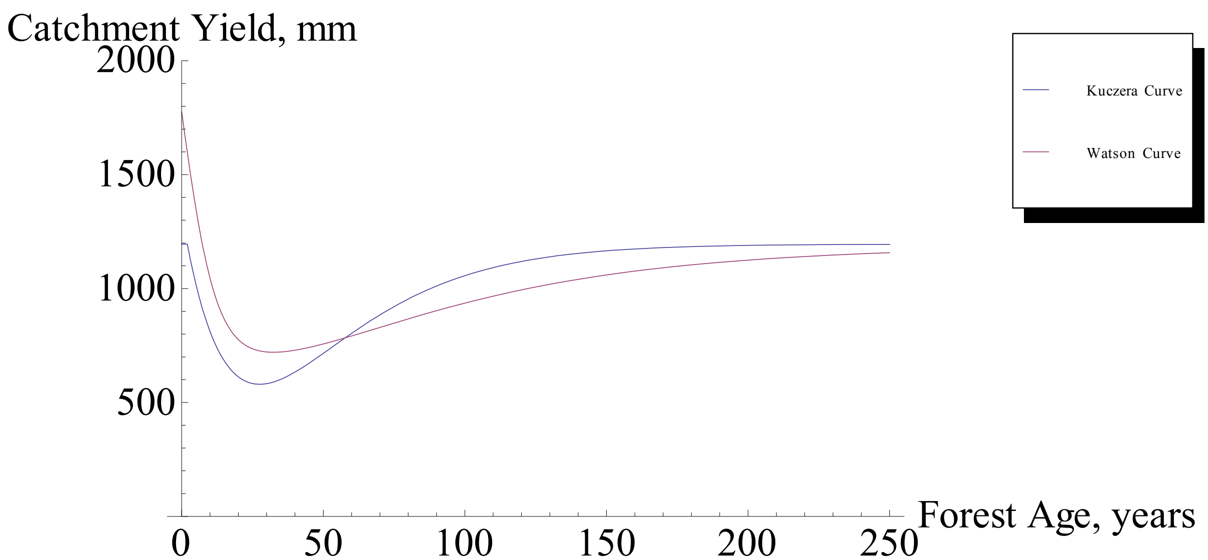


Figure 2.11: Comparison of Watson's (1998) runoff curve with the classic "Kuczera Curve."

Watson *et al*. (1998) note that the curve "inherits the limitations of the ET curve in that no account is taken of the catchments' treated fractions." It also notes that in the "deeper ash" the non-ash fractions are usually rain-forest, of which little is known. Watson *et al.* (1998) stresses that the curve is not intended as a replacement for the Kuczera curve but rather to show that data from experimental catchments can by synthesised in a single equation. On the one hand, we are filled with admiration for this approach. At the same time, a formula with seven parameters used in complex ways does, indeed, give a complex output. In some ways the curve is an "improvement" on Kuczera curves in that it makes allowance for a post-logging increase. However, ultimately any curve is basically fitted on data on the 0 to 60 year period and the vague expectation that it will tend somehow "asymptotically" to some future yield. Hence, without continued comparison with new data it is hard to assess the validity of the curve.

Unfortunately since this block of work, there has been a loss of “intellectual momentum”, and measurements have either been discontinued, not analysed, or the analyses not made public.

CRC for Catchment Hydrology Work

In the period of the mid to late 1990’s, the CRC for Catchment Hydrology, under the leadership of Dr Rob Vertessy, did much excellent work on the hydrology of mountain ash catchments. This was substantially reported in Watson *et. al*. (1998). This particularly included much of the work of Watson, reported above. Much of the work provided insight into the hydrologic processes and the short-term dynamics of the water cycle in mountain ash, and relied on the “framework” of paired catchments of Melbourne Water. The CRC for e-Water which replaced the CRC for Catchment Hydrology did not have a forest hydrology component.

2.7 After 1998

Changes in organisational structures and a possible feeling that “we know enough about water” led to a diminution of the work on the catchments. In recent times there has been an upsurge in work at the Department of Forest and Ecosystem Science at the University of Melbourne. One publication from this has been the previously discussed Bren, Lane, and Hepworth (2010) and there is a collection of other work being readied for publication. However in general this work is not available for inclusion in this report.

Macaque Modeling for Victorian Forests

Subsequent to the modeling on the Thomson River catchment (Peel *et al.,* 2002) the model “Macaque” was used to predict the effect of bushfires on long term yields after the 2003 fires (Lane *et al*., 2008, 2010) and for input into the Victorian government’s Wood and Water Project (Feikema *et al.* 2006). This project, undertaken in response to Action 2.21 from the Victorian Government White Paper “Our Water Our Future”, set out to model the wood and water tradeoffs for various harvesting regimes in the State forests that contribute water to Melbourne. There were also some bushfire and climate change scenarios considered as context to the harvesting results (Feikema *et al.,* 2008; Lane *et al.* 2010).

“Macaque” is a physically-based distributed parameter model that operates at a daily time-step. It was developed specifically to allow calculation of spatially varying ET that is driven by topography-controlled soil moisture stores, and the evapotranspiration, age and species of forest in each hillslope unit. The vegetation dynamics are defined by age-LAI–conductance curves for either individual or groups of species.

Both pieces of work were based on calibrating “Macaque” against historical streamflow which gives an indication of the model’s ability to model the system. For the 2003 bushfire project the pre-fire calibration period vegetation layers were replaced by new age-species distributions based on fire severity classes and known or assumed fire severity-ecological responses. Scenarios were then run under fixed climate conditions to evaluate the effect of the fires. The catchments modelled were the Mitta Mitta River and the Tambo River. For the “Wood and Water” Project the approach of Peel *et al*. (2002) was followed as shown in detail in Section 3.2. The resultant AET curves were then used as spatially varying input to the Woodstock Timber Yield model (Mein, 2008) to give both water and timber yields. The harvesting scenarios included variable rotation length, thinning and “cease to harvest” (see summary by Mein, 2008). The catchments modeled were those of the Thomson, Armstrong Creek Main, Armstrong Creek East, Cement Creek, McMahons Creek, Starvation Creek, Tarago River and Bunyip River.

The calibration parameters varied from good (approaching the Nash-Sutcliffe Coefficient of Efficiency E = 0.8) for some catchments, notably the Thomson River, Armstrong East and Cement Creek, to satisfactory (i.e. E = 0.6-0.7) for most others, with the Tambo River and Bunyip River the worst. The modeling was able to reproduce flow duration curves of the streams reasonably well.

As with all process models, there are a number of assumptions and “best-guess” parameterisations in Macaque. Perhaps the most important assumption lies in the use of single age-LAI-conductance curves for each species or group of species. Although age can be spatially varied, the LAI and associated conductance cannot. Further, these relationships are untested for most mixed species. It is notable that “Macaque” returns the best calibrations when applied to catchments with good spatial representation of rainfall and with significant ash species (*i.e*. Thomson, Armstrong East and other Melbourne Water catchments). “Macaque” has recently been used to explore the impact of the 2009 fires for Melbourne Water (unfinished at this time).

Although models such as “Macaque” have considerable potential for addressing issues such as these, the calibration relies heavily on the availability of paired catchment data. Complex, multi-parameter models such as this do give enhanced prediction capacity, but at the expense of higher levels of catchment experimentation to allow their calibration.

Conclusions from the Coranderrk and North Maroondah Work

The work has led the way in defining a number of concepts:

1: The concept that *Eucalyptus regnans* has a distinctive water use signature – so distinctive in fact that it has given its name to the Kuczera curve that is often cited in popular discussion.

2: Applications of the curve should correct for the amount of ash in the catchments.

3: That no similar response could be found in “mixed species” forests.

4: That for five to eight years after logging there is a period of enhanced flow. This was not observed in earlier work based on “routine” data sets from forests affected by bush fires.

The work, when viewed from a perspective of two decades later was relevant and well-done.

Chapter 3:

Further Victorian Work on Age-Related Water Yields and Water Quality

Regrowth alpine ash forest (1939 fires), Upper Goulburn

3.1 Subsequent Victorian Water Use Work:

Although water-use issues have become prominent in public debate, there has been relatively little measurement work brought to fruition since the MMBW/Melbourne Water studies. Two paired catchment experiments were initiated but not continued. The Reefton Experimental area was reported on in the "Reefton Experimental Area Pretreatment Compilation Report" of 1984 (Wu, Papworth, and Flinn 1984). The catchments were located near Warburton in a tributary of the Upper Yarra River. Treatments were to examine the water use of mixed species. Wu, Papworth, and Flinn (1984) reported the "treatment of three of the catchments is scheduled to commence in the summer of 1983/84" but this never happened. A second paired catchment project with a eucalypt forestry component– Stewarts Creek (near Daylesford, Victoria) had treatments initiated, but very little has been published.

In the mid-nineties, various issues came to the fore, including logging in the Otways Ranges of Victoria, logging in the catchment of the Thomson Dam, and impacts of fire. A number of "modeling studies" were undertaken to quantify the impacts of logging on water yields.

From our point of view, the issues are:

1: What did this work have to say about age-water yield curves of ash and mixed species? and

2: What is the value of such information, or how can its value be assessed?

We present the findings below. An evaluation of the findings is given in Chapter 6.

3.2 Water Yield Curves Developed for Using "Macaque"

Peel *et al.* (2002) looked at "Predicting the water yield impacts of forest disturbance in the Maroondah and Thomson catchments using the "Macaque" model." The report "presents an alternative methodology which can be used to produce separate water yield versus forest age curves, for different locations within an ash forest, defined by variables such as species, climate, topography, and soils." Their modeling used an improved version of the "Macaque" model developed by Watson (1999). Development of the model was, itself, a notable achievement. The model was calibrated against monthly streamflow records at the Thomson River dam wall. This dam is located to the east of the Yarra catchment. The catchment has an alpine south-western edge with an annual rainfall of up to 2100 mm. However most of the catchment is in the 1200 to 1800 mm per annum zone, and the eastern side of the catchment is in a distinct rain-shadow, with rainfalls in the 700 mm zone and below. The catchment carries a complex suite of vegetation ranging from rainforest to dry sclerophyll mixed species.

The report presents the “Kuczera curve” with the usual 615 mm drop between old growth and regrowth (see Chapter 2). Peel *et al.* (2002) note that “it is unlikely that information on the impact of disturbances on water yield could be easily extracted from further analysis of the region’s rainfall and runoff records.” To some extent the application of modeling on the Thomson catchment can be viewed as “heroic” given the complexity of soils, vegetation, fire, and land use history and the paucity of information before this study.

Parameterisation of the model was difficult. For instance their Table 3.2 lists 28 parameters charactering the leaf area indices of 14 different species or mixtures of species. Similarly there are perhaps one hundred physical parameters included in the model (their Table 3.3). Considerable work was put into estimating the spatial distribution of precipitation. Ultimately, after the input of considerable modeling skill, satisfactory “calibration” was achieved between predicted model flow and observed outflow at the Thomson Dam wall.

Figures 3.1 and 3.2 below presents an example of the age-yield curve used in their report. These have been widely used in other venues since (e.g. ACF/Practical Ecology, 2009). Peel *et al.* (2002) in their Section 7.5 discusses the rationale behind such curves; this rests mainly on the leaf-area index relationships assumed by Watson (1999). The curves predict “a range of 662 mm.” Similar results are applied to alpine ash (*E. delegatensis*) and shining gum (*E. nitens*). Their report notes that “physiological data...is sparse.” Watson (1999) suggests that the LAI of this species was about “0.3 lower” than mountain ash and this was adopted. Their presented curves for mixed species show a decline of about 200 mm with a minimum yield reached about ten years after logging and a return period of about two hundred years.

The ash–type yield curves are distinguished by their “pointiness” – thus the ash type forests are predicted to reach a minimum yield at around 7 or 8 years of age. “The lower ash-type forests vary more, from about 5 years of age on north-facing slopes to a slower 15 years of age on some shaded slopes." The authors summarise their results in their Figures 8.1 and 8.2; these will be used in the basis of further analysis below.

The effectiveness of such a curve in reproducing the Melbourne Water data will be examined in Chapter 6. It is stressed that this work was developed to resolve issues in the Thomson catchment and was never viewed as being general in application.

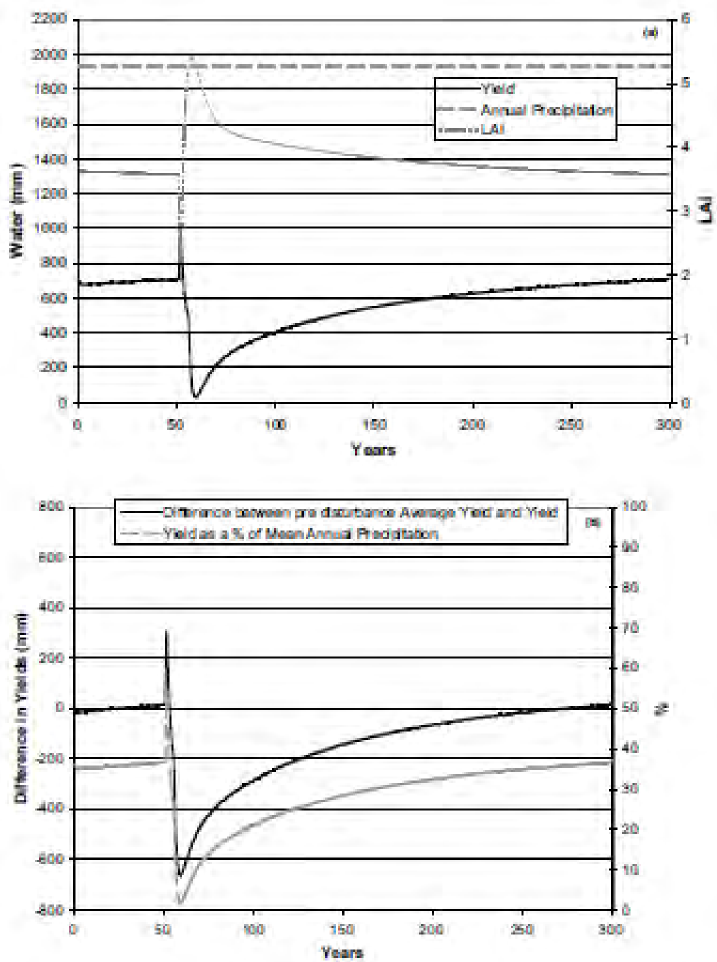


Figure 7.6 Results for a Mountain Ash ESU using a synthetic climate. (a) Time series of annual water yield, annual precipitation (1933mm) and LAI. (b) Time series of annual differences between pre-disturbance average water yield and annual water yield and the annual water yield as a percentage of mean annual precipitation.

Figure 3.1**:** Example of curves generated in the Peel *et al*. (2002) study for mountain ash. Similar curves are generated for other "ash types." The upper one is a time series of annual water yield, annual precipitation (1933 mm) and leaf area index. The lower is the annual differences between pre-disturbance average water

yield and annual water yield and the annual water yield as a percentage of mean annual precipitation.

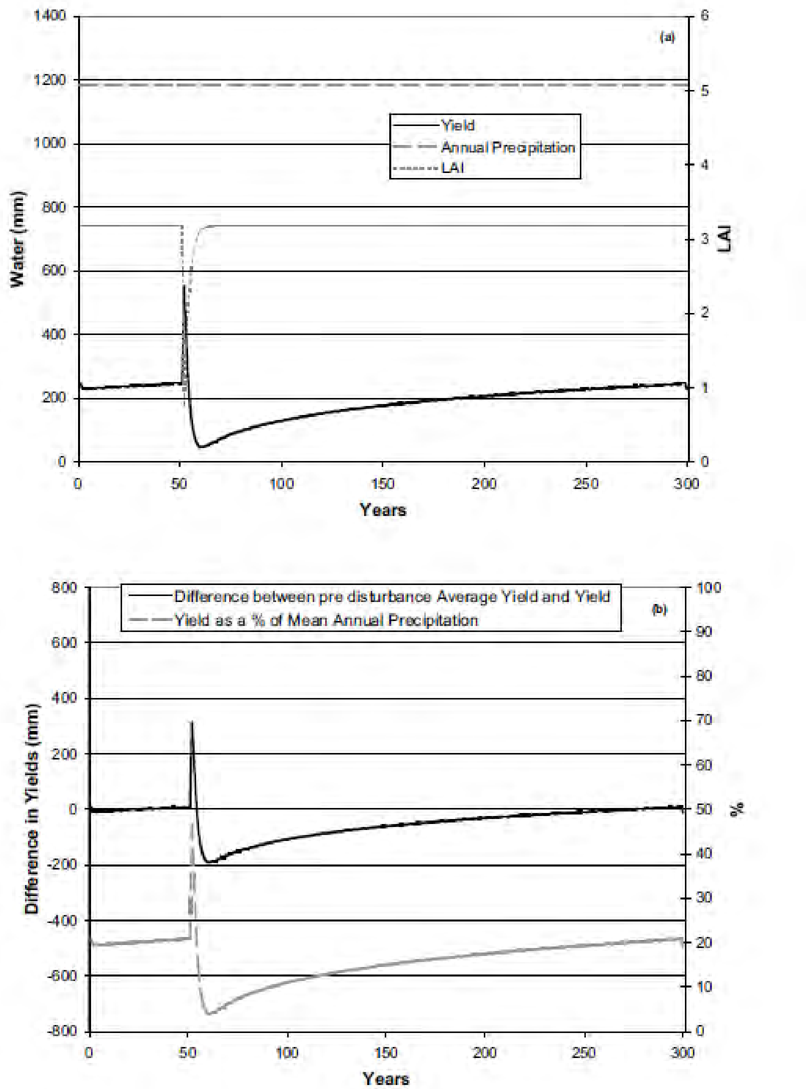


Figure 7.10 Results for a mixed species ESU using a synthetic climate. (a) Time series of annual water yield, annual precipitation (1184mm) and LAI. (b) Time series of annual differences between pre-disturbance average water yield and annual water yield and the annual water yield as a percentage of mean annual precipitation.

Figure 3.2: Example of curves generated in the Peel *et al*. (2000) study for mixed species. The upper one is a time series of annual water yield, annual precipitation (1933 mm) and leaf area index. The lower is the annual differences between pre-disturbance average water yield and annual water yield and the annual water yield as a percentage of mean annual precipitation.

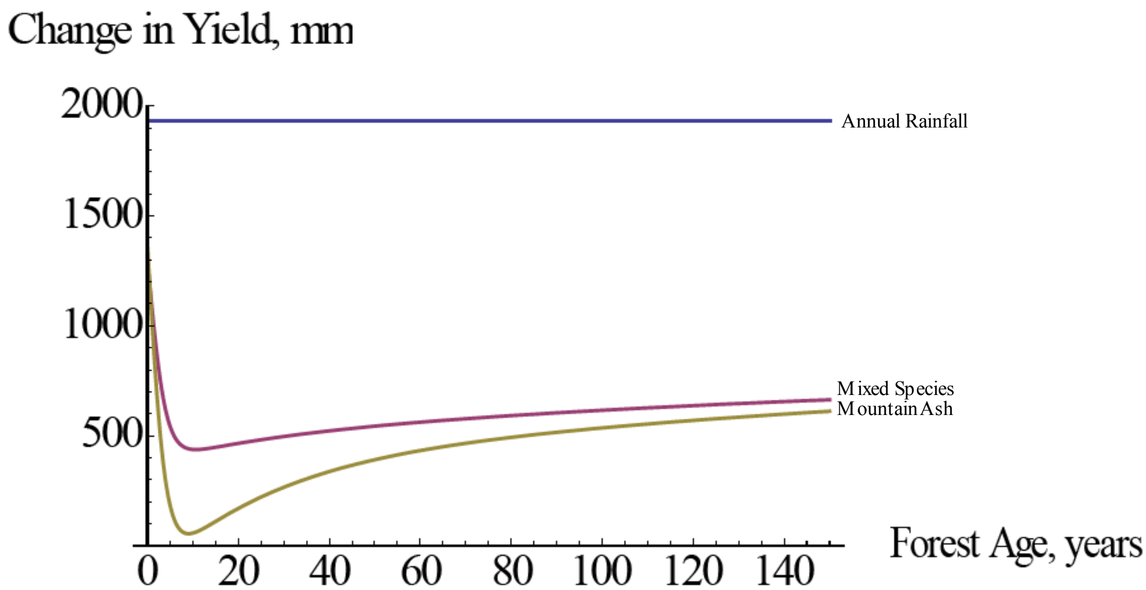


Figure 3.3: Re-plotted runoff curves from Peel *et al*. (2002) for mountain ash and mixed species runoff as a function of forest age.

3.3 Otway Ranges Studies

The Otway Ranges are to the west of Melbourne and contains a few larger areas and many small pockets of mountain ash embedded in mixed species forest of varying quality (from the point of view of harvesting). The question of the effects of timber harvesting operations on streamflows was raised because of concerns by the residents of Apollo Bay that their water supply was being compromised due to logging. Subsequently logging was withdrawn and the area is now in a National Park. Various studies attempted to apply the results from the Melbourne Water areas to the Otways. A number of modeling studies looked at water yield associated with ash. In general the studies quoted Kuczera curves, curves generated by Watson *et al* (1999), and occasionally other sources. There was no original data and little justification given for applying these curves to mixed species work.

Daamon *et al*. (2000 looked at the impact of logging in mountain ash in the Otways. They state that "the streamflow response function for mountain ash forest in the Otway Ranges was fitted by eye to functions presented by Kuzczera (1985) and Watson *et al.* (1999). This study used a streamflow response function for mixed species forest which was, essentially, a scaled Kuczera curve with a reduction in streamflow of 240 mm (relative to old growth) and flow reaching a minimum about 25 years after logging, and slowly returning to zero (relative to old growth) at about 120 years. They concluded that the impacts of logging on mean streamflow were minimal.

SKM (2000) developed a quite sophisticated series of "Kuczera curves" scaled by rainfall. These were applied to both mountain ash and mixed species. The methods followed the original unpublished work of Moran (Department of Sustainability and Environment, Victoria) in extrapolating the mountain ash work to a different environment.

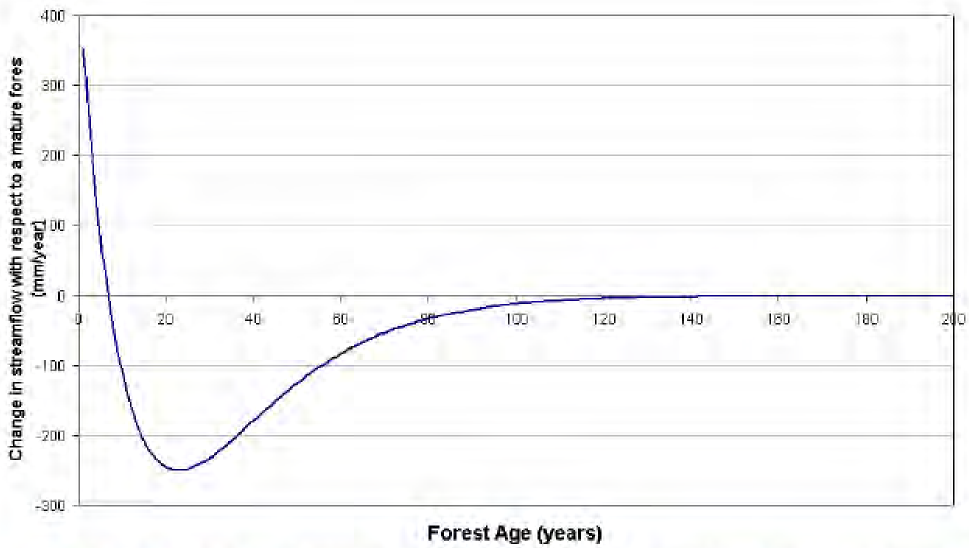
Whatever the virtues of the Otway modeling, it was "derivative" in the sense that it used forest-water relationships derived from outside of the Otway forest. There were no empirical observations of such relationships in the Otways.

3.4 "Bush Fire Impact on Streamflow" Modeling

The "BISY" study ("Bush fire impact on stream yield") was undertaken by MDBC (2007) after the 2003 Victorian fires to assess the impact of these on streamflow yields. As a part of this a scaling technique was used to "correct" age-yield curves for different rainfalls. The work comments "Note that the effects of fire on tree species other than Ash are not yet fully understood. Thus, the approach adopted here is somewhat pragmatic and based upon a consensus between technical experts. This has been deemed acceptable for this broadscale assessment, where the methods suggested are proposed as an upper and lower limiting response."

For ash the modelers chose the work of Watson (1999) over Kuczera (1987) because they felt that the seven parameters gave greater flexibility. They did, however, note the difficulties and inconsistencies inherent in this.

For mixed species the modelers chose curves developed for NSW by the same group for studies on agreed forestry levels. This, in turn was "developed using results from the Karuah catchments (Cornish and Vertessy 1998) and the Yambulla/Wallagaraugh catchments.” Their composite curve, extracted from MDBC (2007), is shown in Figure 3.4. The species of Karuah catchment would not be classified by most Australian foresters as “mixed species.”



- **Figure 4-3 Streamflow response curve for Mixed Species eucalypt forest developed for Southern NSW (SKM, 1999).**

Figure 3.4: Streamflow response curve for Mixed Species eucalypt forest developed by MDBC (2007) following work done by Sinclair Knight Merz in 1999 for southern NSW.

The methodology devised allowed scaling or transposing the functions using the difference between the generalised “Zhang Curves” for forest and grassland; the method is laid out in principle in MDBC (2007). The result is a “family” of curves for different rainfalls for both ash and mixed species. The methodology is laid out in some detail but is not very explicit; we programmed this methodology in *“Mathematica*” and the curves match those in the above publication. Figure 3.5 shows the resulting curves derived for mountain ash and for mixed species forest for both absolute yield and yield relative to mountain ash.

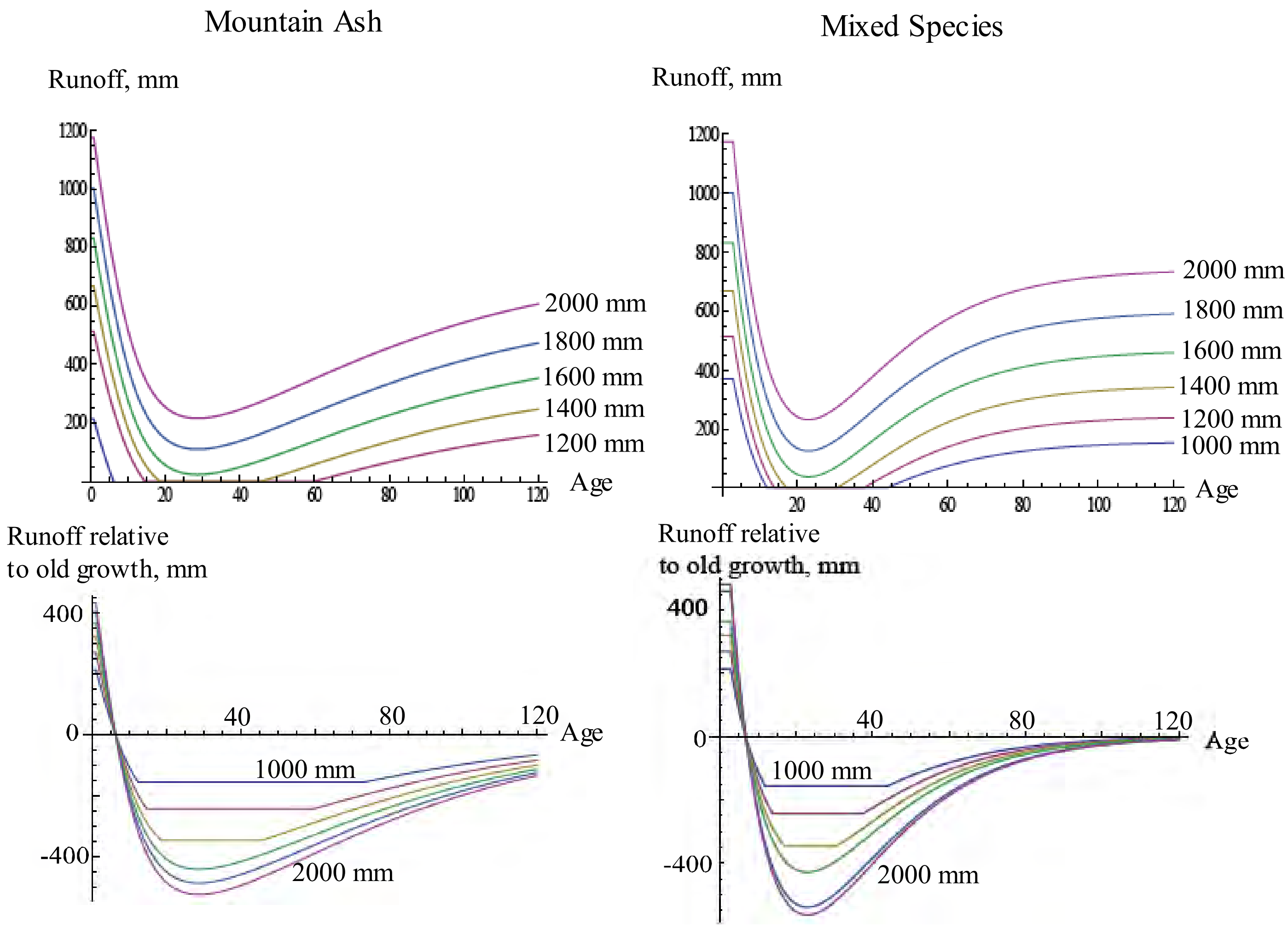


Figure 3.5: Scaled age-yield curves for mountain ash and mixed species, as derived by SKM for the BISY study of MDBC (2007). The curves in the illustration have been derived from programming from the instructions for using their method and appear to conform to the lines presented in that publication.

3.5 Conclusions on Victorian Studies on Age-Related Water Yield

1: There is clearly an age-water yield curve for mountain ash. There is no evidence in the Victorian data presented of any such relationship for species other than ash.

2: The "Kuczera curve" usually presented as Kuczera (1985) was never actually presented by Kuczera and represents an extreme case with 100 per cent ash harvested in a high rainfall catchment. To that extent the common representation of it overstates the water use of ash.

3: The full model of age-related water yield presented by Kuczera (1985) does a reasonable job of representing the Coranderrk data after the initial streamflow increase, but does not include flow variability and over-estimates water use.

4: The classically presented "Kuczera curve" does not include the period of increased flow that occurs after forest harvesting. This may perhaps represent a difference between the effects of fire and the effects of logging. Certainly there was no such effect evident in the data of Langford (1976) or Kuczera (1985).

5: Many authors have assumed a similar age-relationship must exist for mixed species and have used such relationships, derived by various computational strategies in reports. Hence application of these have biased the results towards computations of greater water use by the forests than we actually believe to be the case. However this is hypothesis that requires testing.

6: Victorian catchment management would benefit from "solid" information on the water use and the age-related variation of major native forest types that may be subject to burning and/or logging. Logging issues are likely to be of limited impact compared to fires because of the relatively small scale of logging compared to large areas of regrowth generated by wild-fires.

3.6 Possible Water Quality Risks

The "Terms of Reference" of this report refer to the impacts of water quality. This has been well-studied in similar environments, and hence we have not included this explicitly in this document. The reader is referred to a major study on the impacts of timber harvesting on water quality in State Forests supplying water to Melbourne (SKM 2006). This made the following conclusions:

1: Unsealed forest roads are the major sources of sediment in managed forests, particularly where channelised flow pathways form at drainage outlets.

2: Road usage is a critical factor in explaining the rate of sediment production on these roads.

3: Sediment and nutrient yields from forested (managed and un-managed) catchments are considerably lower than those from other land uses, particularly agriculture.

4: Sediment production rates on roads and tracks decline within the time frame of 2 to 5 years after logging ceases to levels comparable to lightly disturbed General Harvesting Areas

5: In-stream impacts as a result of increased sediment and nutrient input may occur but observed impacts are short-lived and transient with no long-term effect.

6: Best management practices such as vegetated buffer strips, dispersed sediment flow paths, appropriate road surface treatment and maintenance and retention of vegetation on GHA's that provide roughness and slow overland flow are effective at minimising sediment and nutrient inputs to waterways.

Thus, although timber harvesting is not without its water quality implications, it is unlikely to pose a major risk in this regard.

Chapter 4:

Work on Age–Related Water Yield from Other Australian States

Mixed species, non-commercial forest in the upper Avoca River

4.1 Harvesting -Tree Water Use Studies from Other States

Discussions about the relationship between water yield and harvesting never achieved the controversial and adversarial level that distinguished Victoria. However it was considered important enough to lead to paired catchment projects that had treatments implemented in Queensland, NSW (two projects), and Western Australia. Another project commenced in Tasmania but, as yet, no treatment has been implemented.

We have not considered the results of the Babinda Project in Queensland (Gilmour 1975) because the rain-forest type does not occur in the Murray Darling Basin. The NSW work covered two forest types – wet eucalypt forest north of Newcastle (the “Karuah” project) and dry sclerophyll forest in the forests around Eden in southern NSW (the “Yambulla” Project). We have also briefly mentioned a body of work done in Western Australia because it throws some light on “generalities” concerning the reactions of eucalypts to logging.

4.2 Moist Eucalypt Forest in NSW – the Karuah Experiment

Good accounts of the Karuah Project undertaken by the (then) Forestry Commission of New South Wales are found in Cornish (1993) and Cornish and Vertessy (2001).The project consists of eight small (13 to 97 ha) catchments located in the headwaters of the Telegherry River, 200 km north of Sydney. The climate is warm-temperate and annual rainfall averages between 1,450 and 1,750 mm depending on elevation. The forest type was undisturbed, old-growth forest. The research area forms part of the escarpment of the Great Dividing Range between 350 and 940 m elevation. Slopes exceed 30^{o} in some parts but generally fall within the range of 5-25^{o}. Soils are porous with a high infiltration capacity (1-50 mm) but rainfall intensities can be high in this environment.

Before treatment the catchments were occupied by a tall (>35 m) wet sclerophyll forest of between 100 and 500 years of age. Major species were Sydney blue gum *(Eucalyptus saligna*, silver-top stringybark (*E. laevopinea*), and New England blackbutt (*E. campanulata*). Other than some minor logging associated with road construction, the forest was in an undisturbed state.

The results from this are covered by Cornish (1993) and Cornish and Vertessy (2001). The abstract of Cornish and Vertessy (2001) provides an overview:

> “Water yields in a regrowth eucalypt forest were found to increase initially and then to decline below pre-treatment levels during the 16 year period which followed the logging of a moist old-growth eucalypt forest in Eastern Australia. Both regrowth and old-growth stands were dominated by Sydney Blue Gum (*Eucalyptus saligna* Smith) and Silvertop Stringybark (*Eucalyptus laevopinea* R. Baker). Using a paired-catchment approach we observed significant reductions in five of six gauged catchments and were able to associate their magnitude with forest growth rate, canopy cover, and soil depth. Regular yield declines were interrupted for a period in some catchments, possibly due to foliar insect attack. Yield reductions of up to a maximum 600 mm per year in logged and regenerated areas were in accord with water yield reductions observed in mountain ash (*Eucalyptus regnans* F.J. Muell.) regeneration in Victoria. This study therefore represents the first confirmation of these Maroondah Mountain Ash results in another forest type that has also undergone eucalypt-to-eucalypt succession. Base-flow analysis indicated that base-flow and stormflow both increased after logging, with stormflow increases dominant in catchments with shallower soils. The lower runoff observed when the regenerating forest was aged 13-16 years was principally a consequence of lower base-flow.”

Figure 7 of Cornish and Vertessy (2001) is presented as Figure 4.1 below. This is a generalised summary of the logging response in the various years. We will use some of this data in our analysis of Chapter 6.

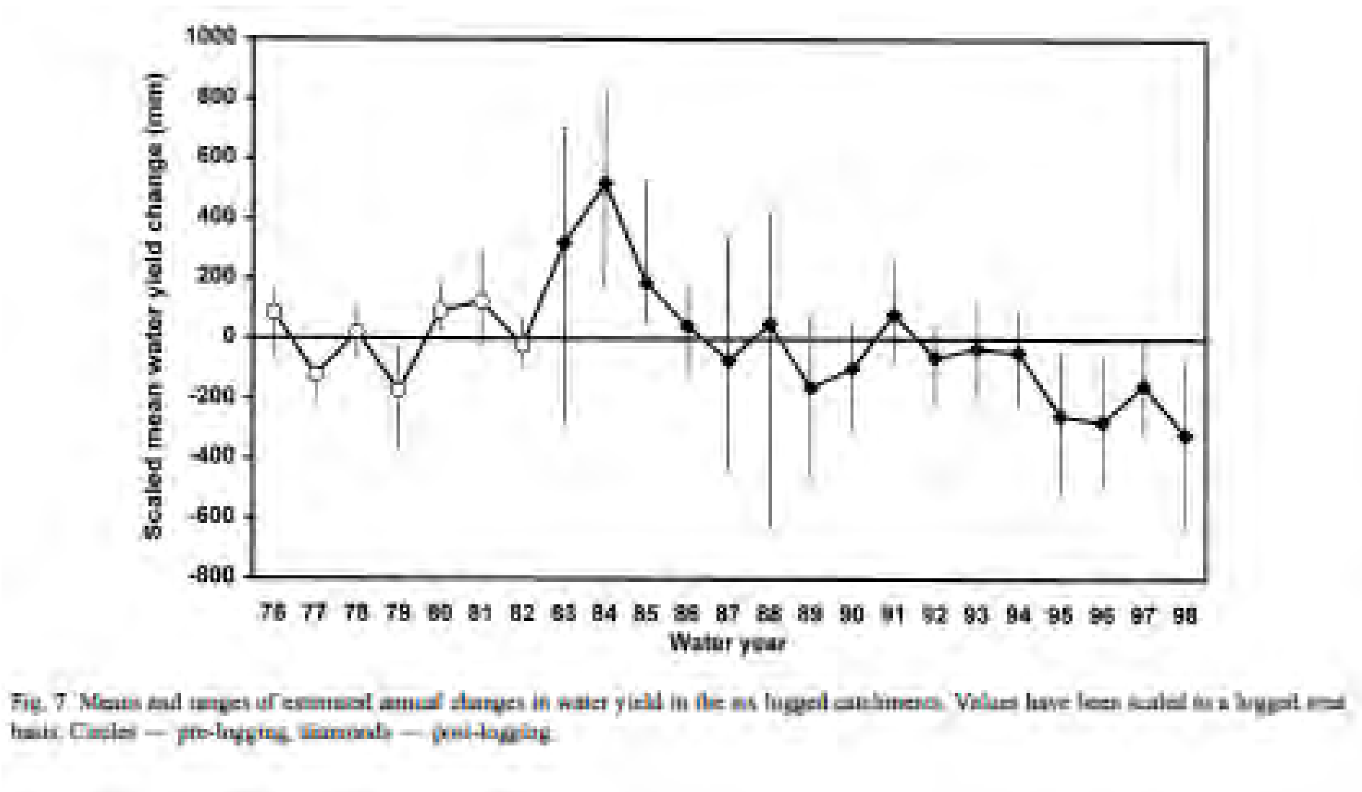


Figure 4.1: Means and ranges of estimated annual changes in water yield in the six logged catchments, as presented by Cornish and Vertessy (2001). Values have been scaled to a logged area basis. Circles represent pre-logging and diamonds represent post-logging.

It is disappointing that no further results have, to date, been published from this well-founded study.

4.3 Silvertop Ash and Yambulla Paired Catchment Study

In principle there should be a solid basis of information concerning the hydrology of silvertop ash (*Eucalyptus sieberii*) due to the installation of the Yambulla multiple catchment study at Eden (NSW) in 1977. The area receives about 1,100 mm of rainfall per annum. However the project was compromised when two catchments were burnt fairly soon after installation, disturbing aspects of data collection. There has been little published in the thirty three years that the project has been running.

One analysis has been published – that of Roberts *et al.* (2002). This work arose from her PhD thesis and considered only annual water yield. Two “treated” catchments and one control catchment were considered. The “treatments” were:

- Catchment 5: Harvesting commenced in May 1978. In January 1979, when 36 per cent of the catchment had been harvested, the catchment was burnt by the January 1979 wildfire.

- Catchment 6: Burnt by the January 1979 wildfire. Logging to recover burnt stems was conducted over 86 per cent of catchment.

The work concluded:

1: Prior to harvesting, actual and predicted flows did not differ in the treated catchments.

2: In the six years immediately following treatment, actual runoff exceeded the 95 per cent prediction internal for 9 out of 84 months in catchment 5, and for 7 out of 84 months in catchment 6.

3: During the period 1986 to 1998, flows were significantly less than predicted for 7 out of 156 months in catchment 5, and 9 out of 156 months in catchment 6 respectively.

In any given year the magnitude of the difference between actual and predicted runoff did not exceed the 95 per cent prediction intervals. There are some grounds for inferring the existence of a small “Coranderrk type” response, although the response appears very “faint” compared to the hydrologic “noise” of this environment.

The maximum increases in flow occurred in 1979 when runoff was 131 and 101 mm greater than predicted in catchments 5 and 6. The greatest reductions occurred in 1992 when flows were 67 mm and 93 mm less than predicted for catchments 5 and 6 respectively. If this was scaled to 100 per cent of catchment 6 being treated, then the maximum yield reduction was 104 mm.

The analysis was restricted by the short period over which the calibration relationships were derived. Roberts *et al. (*2002) argued that the responses (or at least the water yield decline) seen were consistent with those of Kuczera (1987) but that the magnitude was substantially less.

Overall, the report by Roberts *et al.* (2002) is brief. Given the thirty years of data collection and the value of the data it is disappointing that much of it remains unpublished.

Roberts, Vertessy, and Grayson (2001) also published an analysis of transpiration from silvertop ash forests of different ages found in Yambulla. They computed transpiration from estimates of sap velocity gauged by the heat-pulse method. Sapwood and leaf areas were determined by destructive sampling. They found that transpiration declined with age from 2.2 mm day^{-1} in a fourteen year old forest to 1.4 mm day^{-1} in a 45 year old forest to 0.8 mm day^{-1} in a 160 year old forest.

4.4 East Coast Foothill Forests – the Tantawangalo Study

This was a small paired catchment study carried out at Tantawangalo Creek in south-eastern Australia between 1987 and 1998. The area is on the foothills of the Great Diving Range, in a rainfall zone of around 1100 mm. The study consisted of three catchments – Wicksend (68 ha), Willbob (86 ha), and CEB (21.7 ha). The most comprehensive report is that of Lane and Mackay (2001). The forest is probably best classed as a "mixed species", consisting of Cut-tail (*Eucalyptus fastigata,* 50 per cent), messmate (*E. obliqua,* 20 per cent), and mountain grey gum (*E. cypellocarpa,* 20 per cent,). The two principal stand types were both complex mixtures of regrowth and old-growth.

CEB catchment was retained as the control catchment. Wicksend and Willbob were logged in November-December 1989 following a four-year calibration period. Wicksend was patch cut and Willbob was selectively thinned. The logged area in Willbob was burnt very patchily. The net result was that Wicksend catchment had 25.7 ha of logging (38 per cent of the catchment) whilst Willbob had 25.3 ha of logging (30 per cent of the catchment).

The results obtained are not entirely clear. In general, two phases of response in monthly streamflow to the treatments at both catchments were apparent; an initial increase in flows followed by a diminution towards or below pre-logging values. The latter effect was more marked for Wicksend. Figure 4.2 reproduces data from Figure 3 of Lane and Mackay (2001).

Lane and Mackay (2001) concluded the logging has affected streamflow in the treated catchments, and that the streamflow changes have been largely driven by the alteration of "base-flow" (although the separation of streamflow into stormflow and base-flow is something of an arcane art). Scaling of the initial yield increases from Tantawangalo on a logged area basis gives increases of around 250 mm per year from Wicksend (patch cut) and 500 mm per year from Willbob (selectively thinned). Wicksend then showed a yield decline of 190 mm per year (scaled)

Lane and Mackay (2001) note that "the comparatively short post-disturbance period from Tantawangalo, combined with three low rainfall years, prevents definitive comparison with other studies." The paper discusses water yield decline and argues that wet-climate, deep soils with high water storage and larger and more vigorously transpiring mountain ash trees probably represents the maximum potential for yield declines after disturbance.

In view of this somewhat messy situation, the conclusions of authors Lane and Mackay (2001) are of interest. They wrote that:

> "Both total streamflow and base-flow were affected by the treatment. Increases in monthly streamflow and base-flow were detected at both experimental catchments in the first 4 years after treatment. Subsequently Wicksend exhibited a significant decrease below pre-treatment levels in both total streamflow and base-flow. Total streamflow at Willbob returned to pre-treatment levels, while there was a decrease in base-flow relative to pre-disturbance values. Regeneration data and anecdotal evidence suggests that the greater and more rapid decrease in flow relative to pre-logging flow at Wicksend was due to a greater density of regrowth than that observed at Willbob, and that there was a high stocking rate of understorey vegetation in the first 3-4 years after logging at Wicksend which may have confined significant flow increases to 1990 and 1991. Improved regeneration at Willbob post-1993 coincided with decreasing flows. The percentage of basal area removed was not an indicator of the magnitude of flow increases."

From the point of view of this study, it is hard to know what to make of the results from the Tantawangalo experiment. The results have some inherent "contradictions" relative to other studies. The increases in flow achieved statistical significance but the decreases did not – although the consistency of the sequence indicates the possibility of a decrease in flow. The complexity and lack of homogeneity of the forest type before treatment make it difficult to “pin the results” to any particular theory or model. Lane and Mackay (2001) identified problems in the data collection method resulting in some loss of records.

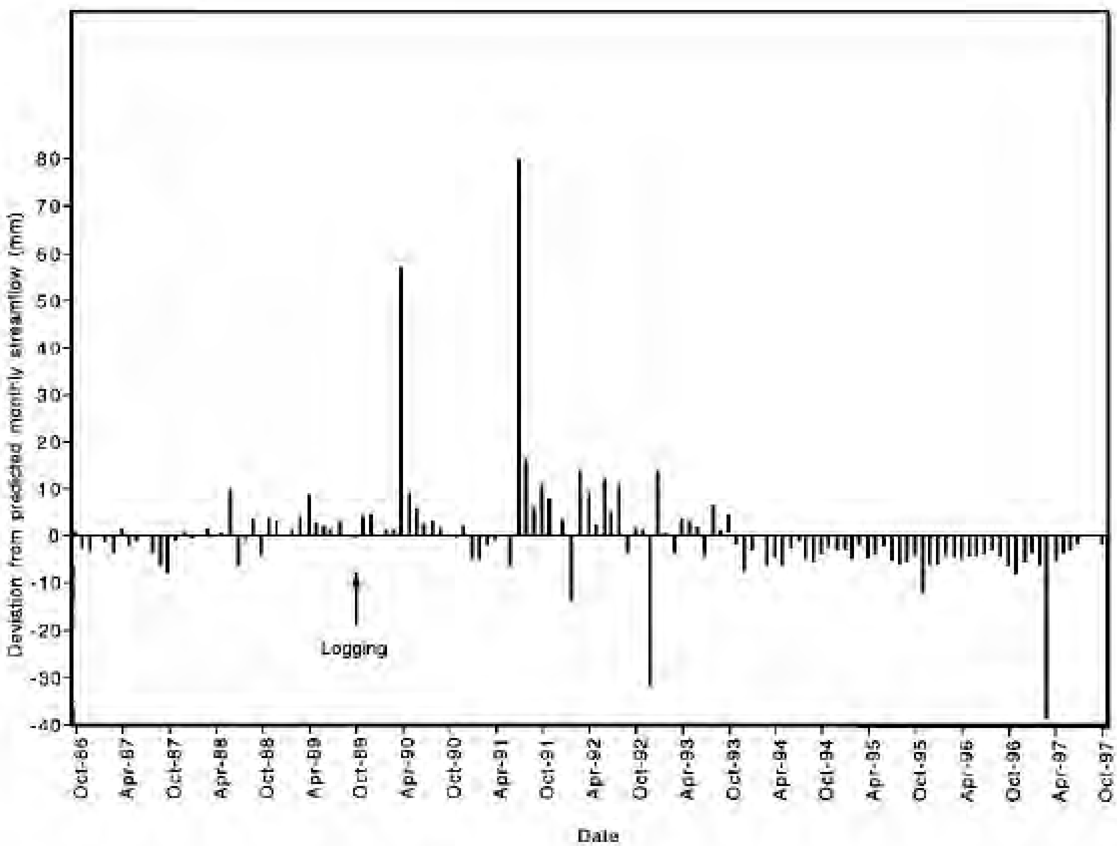


Fig 9. Monthly deviations from predicted streamflow, Wicksend catchment, Tantawangalo Creek. After Lane & Mackey (2001)

Figure 4.2: Monthly deviations from predicted streamflows, Wicksend catchment. This plot is taken from the report of Hughes (2006) and has been abstracted from the paper of Lane and Mackay (2001).

4.5 Western Australian Forests and Water Production

Although jarrah does not occur in the Murray-Darling Basin, it is a eucalypt which has been the subject of intensive study regarding hydrological aspects. Ruprecht and Stoneman (1993) note that the forests produce little streamflow from moderate rainfall (typically 900-1100 mm per annum). This low water yield is attributed to the large soil-water storage available for continuous use by the forest vegetation. Forest harvesting and regeneration generally led to an initial water yield increases followed by a gradual return to pre-disturbance values. Ruprecht and Stoneman (1993) cite the case of the Lewin South catchment in which the water yield initially increased by 15 per cent of annual rainfall 3 years after harvesting, whilst ten years after harvesting the water yield increase was 4 per cent of the annual rainfall. For a logged lower rainfall catchment the initial increase in water yield was similar, at 14 per cent of annual rainfall, and had diminished to 5 per cent of annual rainfall 10 years after harvesting.

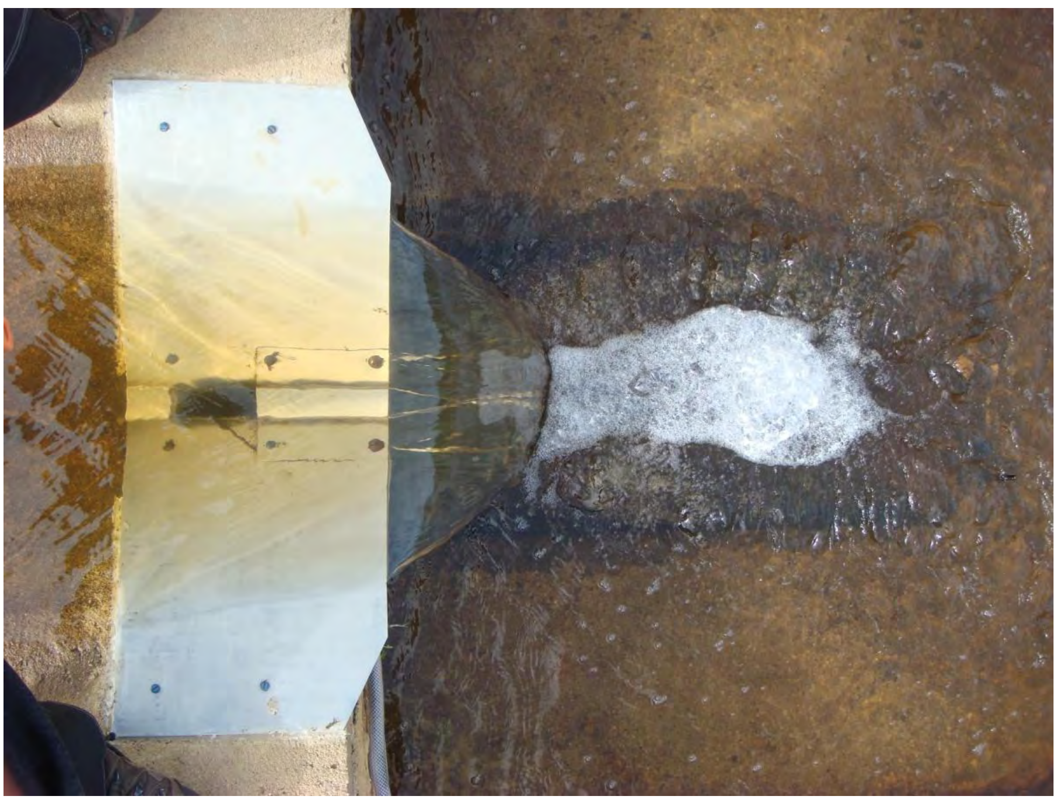
4.6 General Comments

Best *et al.* (2003) published a critical review of paired catchment studies with a focus on Australian results. The conclusion reached was their review "highlights the lack of information available in the literature for examining the impacts of vegetation changes on seasonal yields and flow regime." In this respect there does not seem to have been large strides forward since this review was published. There are relatively few Australian paired catchment studies, and those that are available do not seem to be utilized for forest hydrology research. There is some "anecdotal" evidence but this usually must be interpreted with care; more usually the inherent variability of the hydrologic system over-rides a relatively "weak" signal imposed by a land use effect.

Best *et al.* (2003) warn that "the previous reviews of paired catchment studies have focused mainly on regrowth catchments where changes in water yields are only observed in the first couple of years following treatments before returning to pre-treatment levels. Given the transient nature of the water yield changes in regrowth catchments, the applications of these results to permanent land use changes are questionable." Forest management in production and reserve systems needs to elucidate trends in forest hydrology through long-term field measurement, analysis, and reporting.

Chapter 5:

International Studies on Age-Water Yield Relationships Associated with Native Forest Management



The nappe of a flume in a Weyerhaeuser Research Project looking at differences in water use between native vegetation, pastures, and eucalypts in Uruguay.

5.1 An Overview of International Findings

There have been many excellent international reviews of the impacts of forest harvesting on water yields; these include Best *et al.* (2003) and the often-quoted Bosh and Hewlett (1982) study. In general the results show an increase in streamflow immediately after logging. This reflects the reduction in cover density. After that the streamflow generally recovers to a similar level of that prior to the disturbance – *i.e.* if there is any generality there is no age-water yield function apparent.

There is a vast literature on this subject, and given the excellent reviews already available there is little point summarising this. However we shall look at some specific examples. It is a source of some controversy in hydrologic circles as to whether Australia is, somehow, "different" in the way forest outflow responds to regeneration. We do not have an opinion on this, but it is of some relevance to note international studies.

Bosch and Hewlett's 1982 Study

Bosch and Hewlett (1982) reviewed 94 catchment experiments and studies to examine their impact on water yield and evapotranspiration. They concluded that

> "the direction of change in water yield following forest operations can be predicted with fair accuracy since no experiments, with the exception of perhaps one, have resulted in reductions in water yield with reductions in cover, or increases in yield with increases in cover. Pine and eucalypt forest types cause, on average 40 mm change in yield per 10 per cent change in cover."

It is worthy of note that the "exception of one" was the finding of Langford (1976) on the impacts of the 1939 fires on streamflow from mountain ash catchments.

The authors concluded with the following interesting observations:

> "While we hesitate to offer derived functions relating water yield changes to forestry practices...we do feel that the accumulated evidence presented in Figure 1 (a plot of annual streamflow increase as a function of percentage reduction in cover) can be used for some practical purposes",

and

> "At least it may be reasonably argued that results from repeated experiments are more convincing than conclusions based on computation from evapotranspiration theory or on correlations between uncontrolled variables."

Their paper remains the most widely cited review of forest hydrology catchment studies.

A More Australian-Centric Update of this Review

Best *et al.* (2003) made a critical review of paired catchment studies to look at impacts of land uses on annual water yield. This included consideration of the Bosch and Hewlett (1982) review, and examination of further reviews by Stednick (1996) and Sahin and Hall (1996). Best *et al.* (2003) noted that the overseas reviews did not always explicitly take into account vegetation age, and may have used regrowth in the control catchment. It was argued that the maximum change in water yield may not occur in the first five years but may occur 20 or more years after logging; certainly this has been the case in the Coranderrk case.

Following the findings of Bosch and Hewlett (1982) and Best *et al.* (2003) it seems reasonable to conclude that at least some of the Australian eucalypts behave "differently" from other species around the world, and that generalisations based on world enumerations of results are invalid. Given this, the performance of Australian agencies in collecting consistent paired catchment data to elucidate these differences has been disappointing.

Hydrologic Effects of Logging in Western Washington, United States

Bowling *et al.* (2000) examined possible changes in streamflow associated with logging in 23 western Washington catchments, with drainage areas from 14 to 1600 km^2. Their paper argues that the mountainous areas of the north-western United States can be viewed as having been subjected to a large "experiment" in which much of the old growth, primarily coniferous forest, has been removed and replaced with younger stands of more uniform age and lesser diversity. They reported that the public perception of this change has been increased flows, leading to increased frequency and severity of flooding. The most consistently detected response has been an increase in summer and annual water yield due to a decrease in summer-time evaporation; this in turn reflects the reduced transpiring biomass of the regrowth forest.

The paper provides a voluminous reference list for the topic. It concludes that long-term decreases in low flows noted in catchments are associated with the "regional climate signal associated with the Pacific Decadal Oscillation" rather than land cover change. "Using paired catchment analysis, the number of statistically significant trends detected for the peak flow series is largely within the range of statistical noise." From the reader's point of view there is no clear message other than the detection of a land-use signal in a "noisy" hydrologic environment is classically difficult.

The Swank and Helvey (1970) Paper

A paper of some relevance to this study because of a similarly to Australian conditions is that of Swank and Helvey (1970). This United States study examined the annual water yield from the only forest cutting experiment repeated in time in the United States. The mature hardwood forest on a 16 ha catchment in the Coweeta Hydrologic Laboratory in North Carolina was initially clear-cut in 1939. In the first year following cutting, streamflow increased 360 mm. As the even-aged coppice stand regrew, annual streamflow approached pre-treatment levels as a linear function of the logarithm of time. After 32 years, streamflow was still slightly above pre-treatment levels. The watershed was clear-cut again in 1962 and the streamflow response for the year following cutting was 380 mm. In striking contrast to the first cutting, streamflow increases have diminished at a much a faster rate and it appears that annual water yield will return to pretreatment levels after just 16 years of forest regrowth. They concluded that the revegetation occurred much faster the second time around.

An Overview of the Coweeta Response

Webster *et al*. (1992) analysed a number of studies at the Coweeta Hydrologic Laboratory in North Carolina, USA. They concluded that, after logging, streamflows may remain elevated for 20-30 years following logging, returning to pre-disturbance levels at a rate proportional to forest revegetation. This response has been relatively invariable in the Coweeta experience.

A Californian Paired Catchment Experiment on Effects of Logging on Water Yields

Keppeler and Ziemer (1990) looked at impacts of logging on streamflow from the Caspar Creek watershed in northern California. The catchment carried second-growth Douglas fir and redwood forest. They found the flow response to logging was highly variable. Some of this variability was correlated with antecedent precipitation conditions. Statistically significant increases in streamflow were detected for both the annual period and the low-flow season. Relative increases in water yield were greater for the summer low-flow period than for annual flows, but these summer flow increases generally disappeared within 5 years.

5.2 Conclusions

There is a clear difference between the behaviour of at least some Australian species and other species reported mainly from the US. In the U.S case forest harvesting generally leads to a direct increase in streamflow. This increase "fades away" until the water use becomes the same as the pre-existing forest.

Australian eucalypt forests have a different pattern. Although the initial increase in flow is shown, the water use of the regrowth forest may increase so that yields decline below the pre-existing forest. This pattern is strongly shown by ash-type eucalypts and, to a lesser extent, appears in some other eucalypt forests. However detailed studies in Western Australia have not shown this. Nor was this behaviour exhibited by "mixed species" forest in Victoria. The limited observational data suggests something of a continuum with ash type forests at one end of the spectrum and mixed species and jarrah forests at the other end of the spectrum. Hydrological behaviour in eucalypt forests may not conform to other forest types in other countries

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Chapter 6:

Comparing Models with Experimental Data

Mixed species eucalypt forest in smoke during the 2006 fires

6.1 Introduction

The foregoing chapters have looked at the relatively scant experimental base dealing with annual water yields, and various models promulgated as characterising water yields of even-aged forests after burning or logging. We have also been unable to find much “testing” of models against paired catchment data. Hence, for the purposes of this review, we shall “test” a range of models against the data we have. Criteria of testing, as explained in Section 1.1 are the Nash-Sutcliffe Coefficient of Agreement (Equation 1.1) and performance in a single-mass plot.

6.2 Model Selection Strategy

Chapters 1 to 4 highlighted Australian work on the water use of the trees. A number of models were introduced, the models having varying degrees of data backing from paired catchment experiments or single-catchment analysis. In completing the task of this report and evaluating water use in the Goulburn catchment (Volume 2), our task is to select the “best model” available. Figure 1.1 lays out the strategy that we have used here.

Aim

To select the best possible model of change in water use as a function of forest harvesting or other forest management for major regions within the Murray Darling Basin using as objective a method as possible.

Method

1: Data sets as described previously were assembled (see below).

2: The models were applied to the data sets and the performance assessed by computing both the Nash-Sutcliffe Coefficient of Agreement and a single-mass plot of cumulative observed data against time. Each model was programmed as a function of the relevant variables in *Mathematica*, and appropriate model output was computed using the input model variables.

3: The most appropriate or “best fit” model was selected.

4: The results of the test were tabulated. From these, the “best” models were selected for the following categories:

- Pure ash stands
- Mixed ash/mixed species stands
- Northern NSW mixed species stands

6.3 Test Data

Test data sequences are:

1: The Coranderrk Picaninny/Slip Creek Paired catchment data

This is annual rainfall (May to April basis, and change in flow in Picaninny Creek (logged) relative to Slip Creek as a function of years since logging. Source of the data is Bren, Lane, and Hepworth (2010). The data is listed in Table 6.1.

2: North Maroondah Myrtle Data Set

This is annual rainfall and change in flow in Myrtle Creek as a function of years since logging. Source of the data is digitizing from the Figure 7(b) in Watson *et al*. (2001). This provides a "12 month moving average" of the monthly results and we have effectively sampled this at the same point each year. Figure 6.1 andTable 6.2 shows this data set.

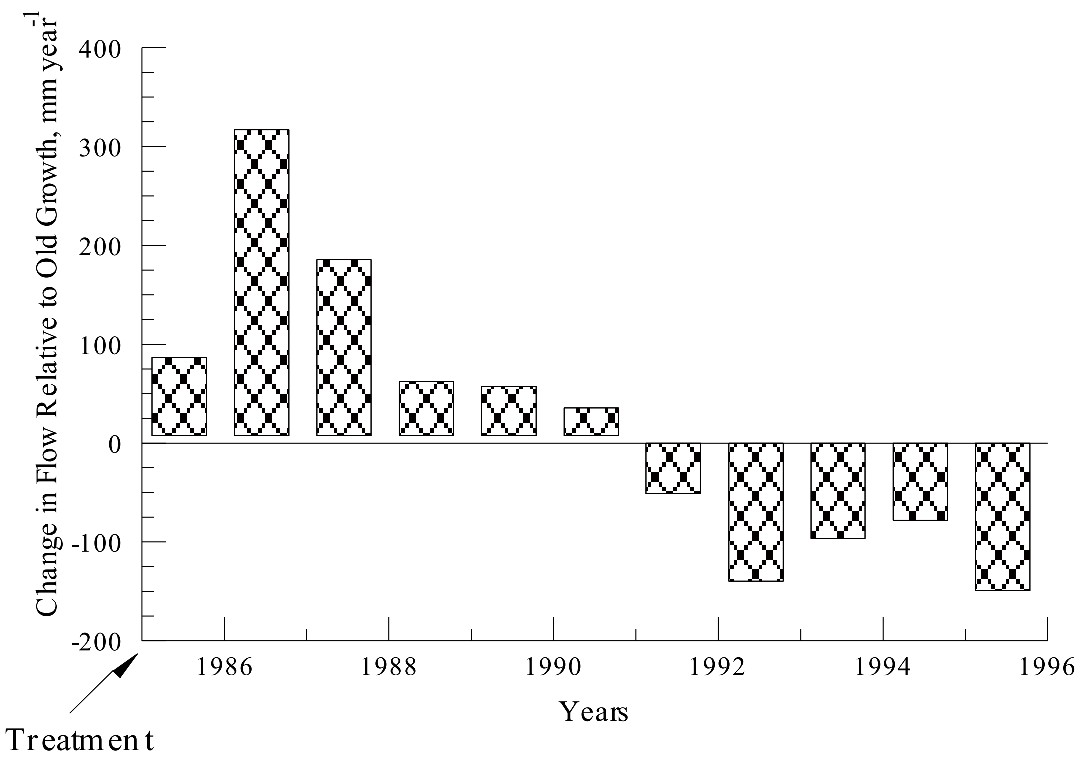


Figure 6.1: Bar chart of response at Myrtle 2 after treatment.

3: North Maroondah Monda Data Set

This is annual rainfall and change in flow in the Monda Creek catchments as a function of years since logging. Source of the data is digitizing from the Figure 9 in Watson *et al*. (2001). This provides a "12 month moving average" of the monthly result. This is defined as:

$$\bar{v}_{t,12\,months} = \frac{1}{12}\left(\frac{1}{2}v_{t-6} + \sum_{i=-5}^{5} v_{t+i} + \frac{1}{2}v_{t+6}\right) \quad (6.1)$$

where $\bar{v}_{t,12\,months}$ is the "disturbance" averaged over 12 months and v_t is the disturbance for the month t.

The traces of the lines for Figure 9 of Watson *et al*. (2001) were digitized and interpolated at the mid-year point using a spline interpolation routine. Figure 6.2 shows the "yearly data" extracted compared to the actual digitized data. It can be seen that the "spline interpolation itself, by attempting to fit a smooth piecewise curve, induces some data variation. For the purpose of the analysis the annual results from all three Monda catchments were averaged (Figure 6.3).

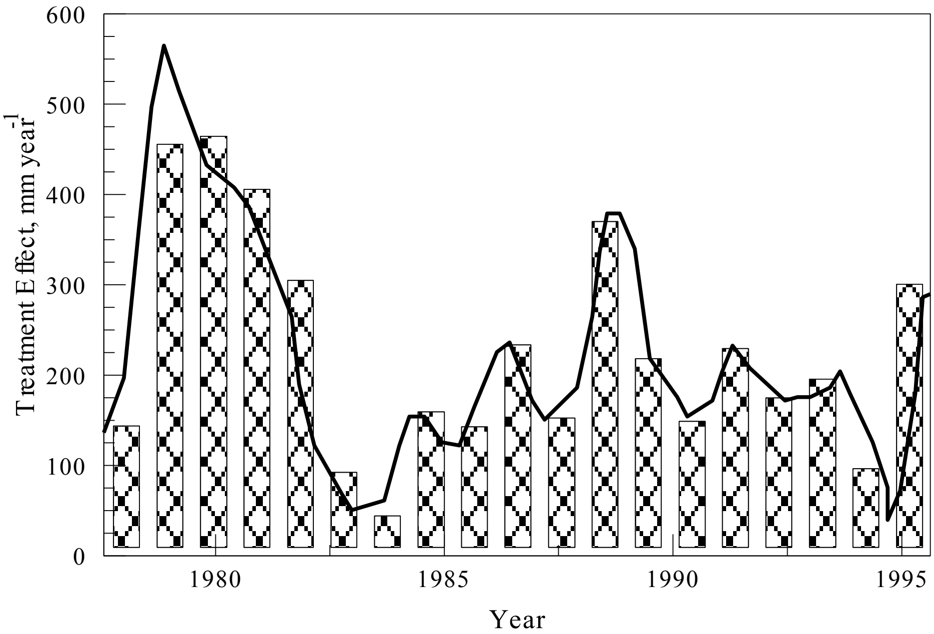


Figure 6.2: Comparison of interpolated annual data (bars) compared to that extracted by the sampled line from Figure 9 of Watson *et al*. (2001) for Monda 1.

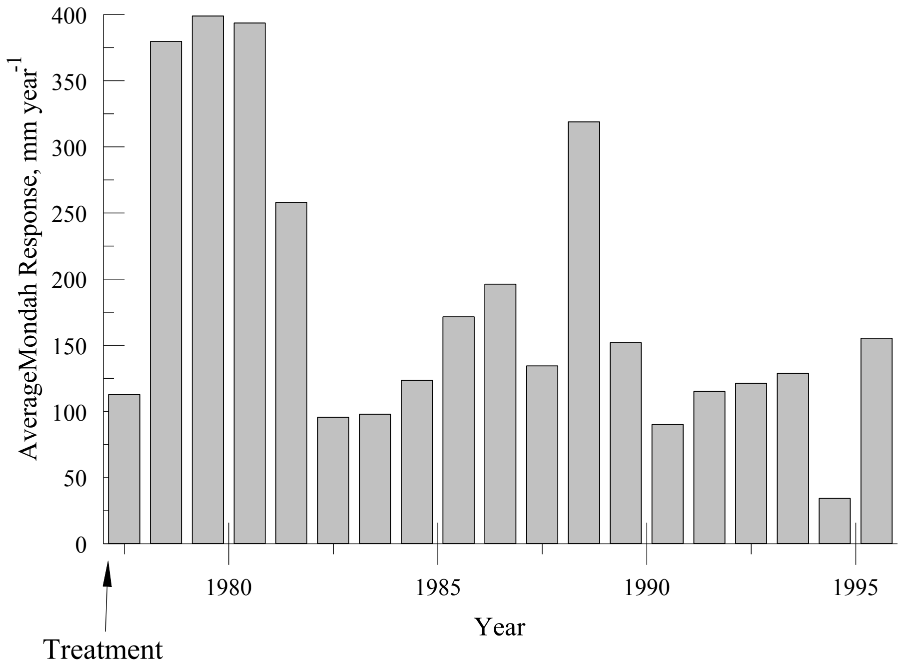


Figure 6.3: Average annual response of Monda catchments to logging, relative to 1939 regrowth ash.

4: Karuah Data Set

Data were obtained from Figure 7 of Cornish and Vertessy (2001). Rainfall data were taken from Table 4 of this publication by averaging all values at the different catchments. Table 6.4 shows this data set.

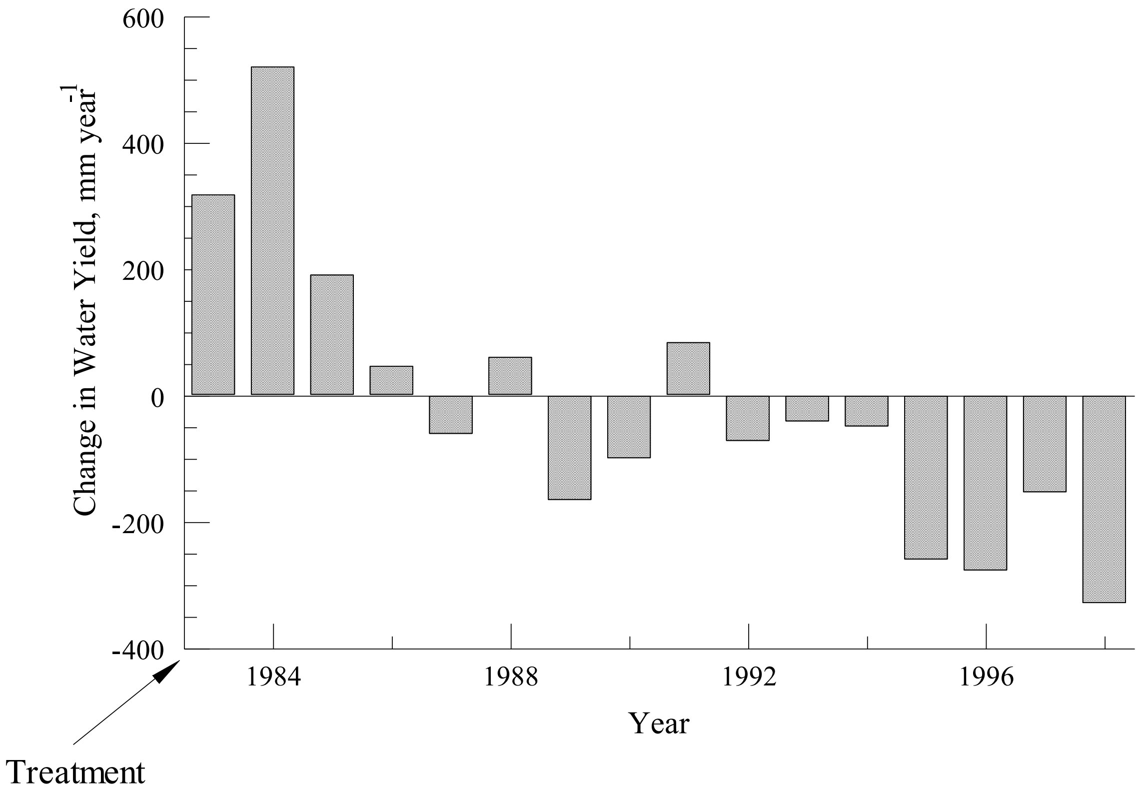


Figure 6.4: Bar chart showing response at Karuah (from Cornish and Vertessy 2001).

Table 6.1: The Coranderrk data set. Tabulation of annual rainfall, annual streamflow, and annual (change in flow + error) for Picaninny Creek. Years go from 1st May to 30th April the following year. This is Table 4 from Bren, Lane, and Hepworth (2010).

Year	Years since logging	Annual Rainfall mm	Annual Slip Ck Streamflow mm	Logging Effect + + Error) mm
1972/73	1	1034	117	182
1973/74	2	1333	280	292
1974/75	3	1401	529	279
1975/76	3	1267	381	176
1976/77	5	1322	239	104
1977/78	6	1172	385	64
1978/79	7	1458	409	59
1979/80	8	902	172	2
1980/81	9	1333	238	-28
1981/82	10	1261	294	-45
1982/83	11	854	112	-27
1983/84	12	1303	188	-58
1984/85	13	1193	415	-147
1985/86	14	1394	328	-117
1986/87	15	1145	507	-158
1987/88	16	1064	262	-84
1988/89	17	1369	240	-115
1989/90	18	1470	476	-141
1990/91	19	1165	390	-126
1991/92	20	1407	415	-165
1992/93	21	1556	574	-181
1993/94	22	1557	565	-167
1994/95	23	982	238	-73
1995/96	24	1628	535	-193
1996/97	25	1107	623	-60
1997/98	26	837	83	-20
1998/99	27	1260	156	-93
1999/2000	28	1029	212	-110
2000/01	29	1332	371	-211
2001/02	30	1043	249	-135
2002/03	31	894	126	-69
2003/04	32	1163	196	-116
2004/05	33	1359	454	-254
2005/06	34	1128	223	-134
2006/07	35	750	101	-63

Table 6.2: Response to logging at Myrtle 2 catchment. Annual rainfall is from the North Maroondah data records.

Calender Year	Annual Rainfall, mm	Average Myrtle 2 Response, mm
1985	1596	86.4
1986	1755	316.7
1987	1380	185.7
1988	1555	62.3
1989	1900	57.2
1990	1501	35.9
1991	1614	-58.8
1992	1805	-147.0
1993	1879	-104.0
1994	1180	-85.4
1995	1832	-156.4

Table 6.3: Average response to logging of Monda catchments, as derived from *Watson et al.* (2001). Rainfall is from the North Maroondah data records.

Calender Year	Annual Rainfall	Average Monda Response, mm
1977	1470	112.8
1978	1736	379.8
1979	1318	398.9
1980	1586	393.6
1981	1616	258.1
1982	1111	95.5
1983	1620	97.9
1984	1863	123.4
1985	1596	171.5
1986`	1755	196.3
1987	1381	134.4
1988	1555	318.8
1989	1900	151.9
1990	1501	90.1
1991	1614	115.2
1992	1805	121.3
1993	1879	128.7
1994	1180	34.3
1995	1832	155.4

Table 6.4: Response to logging at Karuah, taken from Figure 7 of Cornish and Vertessy (2001). Values have been scaled to a logged area.

Year	Years Since Logging	Rainfall mm	Response mm
1983/84	1	1768	318.3
1984/85	2	1915	520.7
1985/86	3	1445	191.8
1986/87	4	1204	47.4
1987/88	5	2371	-61.9
1988/89	6	1856	61.4
1989/90	7	2140	-166.5
1990/91	8	753	-100.2
1991/92	9	1540	84.6
1992/93	10	1466	-73.0
1993/94	11	1031	-41.8
1994/95	12	1568	-50.2
1995/96	13	1548	-260.5
1996/97	14	1548	-277.7
1997/98	15	1682	-154.3
1998/99	16	1551	-329.4

6.4 Models Tested for Experiments with Old Growth Controls

The models tested were:

Model 1: Kuczera Model Corrected for the Percentage Ash

This model is:

$L_{max} = 6.15\ a,$ (6.2)

and hence

$$g(t) = 6.15\ a\, K(t-2)e^{(1-K(t-2)},$$ (6.3)

$$g(t) = 0\ for\ t < 2$$

in which a is the percentage of ash in the catchment, and Log_e K = -3.24. The original equations are discussed in section 2.3 and 2.4.

Model 2: Watson Curve for Ash

$$\text{aetash} = (-1 + e^{-\frac{\text{age}}{\text{p7a}}})\text{p3a} + (-1 + \frac{2}{1+e^{-\frac{\text{age}}{\text{p6a}}}})(\text{p2a} + \text{p3a} - \text{p4a}) + \text{p4a} + \frac{\text{age}\ e^{1-\frac{\text{age}}{\text{p5a}}}(\text{p1a}-\text{p2a}-\text{p3a})}{\text{p5a}}$$ (6.4)

as described in Equation 2.8, where

aetash = Estimated annual evapotranspiration of ash,

and constants p1a to p7a are as follows:

p1a	=	1390
p2a	=	800
p3a	=	370
p4a	=	220
p5a	=	40
p6a	=	6
p7a	=	100

Since this gives the estimated transpiration, the transpiration difference between regrowth and old growth of 250 years for the same rainfall was computed.

Model 3: Peel Curve for Ash, Mixed Species, and Silvertop in the Thomson Valley

These use Equation 6.4 with the parameters as shown in Table 6.5 below:

Table 6.5: Parameter values for applications of the Peel Model.

Parameter	Ash	Mixed Species	Silvertop Ash
p1a	1900	1520	1450
p2a	1160	1150	1060
p3a	920	410	440
p4a	550	620.	610
p5a	40	40	40
p6a	2	2	2
p7a	100	130	130

Model 4: MDBC/SKM (BISY) Models for Ash and Mixed Species

BISY means "Bushfire Impact on Streamflow Yields. The work was developed by MDBC (2007). These cannot be encapsulated in a single equation. The *Mathematica* code for each function is in Appendix 1 and models are shown in Figure 3.5.

Models Tested for Where the "Control" is Regrowth

Consider a model, S[P, A], where S is the change in annual streamflow as a function of annual rainfall, P, and age of the regrowth, A years, with S being assessed relative to old-growth "control." However suppose the "control" itself is of age A_c years. Then the observed response would be:

$$S'[P,A] = S[P, A] – S[P, A_c] \qquad (6.5)$$

where $S'[P,A]$ is the observed result. Thus, for instance, suppose logging decreased flow by 100 mm relative to an old-growth catchment. Thus S[P,A] for this case would be -100 mm, with the minus sign indicating a decrease in flow. However suppose in an experiment, the control was actually a regrowth catchment which, itself, had a yield of 200 mm below old growth forest. Thus $S[P, A_c]$ would be -200 mm. Thus the net observed change from Equation 6.5 above would be -100 -(-200) = 100 mm – i.e. flow in the logged catchment relative to the control would increase by 100 mm. This point is of importance in our evaluation of the impacts of logging in the Goulburn catchment (Volume 2).

This methodology is used to evaluate model performance at Monda Creek since the control catchment is 1939 regrowth.

6.5 Testing of Models

Tests

Not all models were applicable to all data sets. The general procedure was:

1: Each model was programmed as a function of the relevant variables in *Mathematica*, and

2: For each year the appropriate model output was computed using the input model variables.

3: The assembled data were compared with the real data using the Nash-Sutcliffe Coefficient of Efficiency, described by Equation 1.1.

4: A “single-mass plot” was used to compare the cumulative value of the model output with the cumulative value of the “real data.” The closer the line was to the 1:1 line, the more highly regarded the model was.

The results of the test were tabulated. From these, the “best” models were selected for the following categories:

- Pure ash stands
- Mixed ash/mixed species stands
- Southern NSW mixed species stands
- Northern NSW mixed species stands

Testing the Kuczera Model

Picaninny Creek Data

Figure 6.5 shows the comparison of the observed data and the fit of the Kuczera model. The percentage of ash in the Picaninny catchment was taken as 58 per cent. The Nash-Sutcliffe Coefficient of Agreement was computed at -1.864, meaning that the mean of the data gives a better fit. The results suggest that the Kuczera curve gives a substantial overestimate of the water use associated with regrowth.

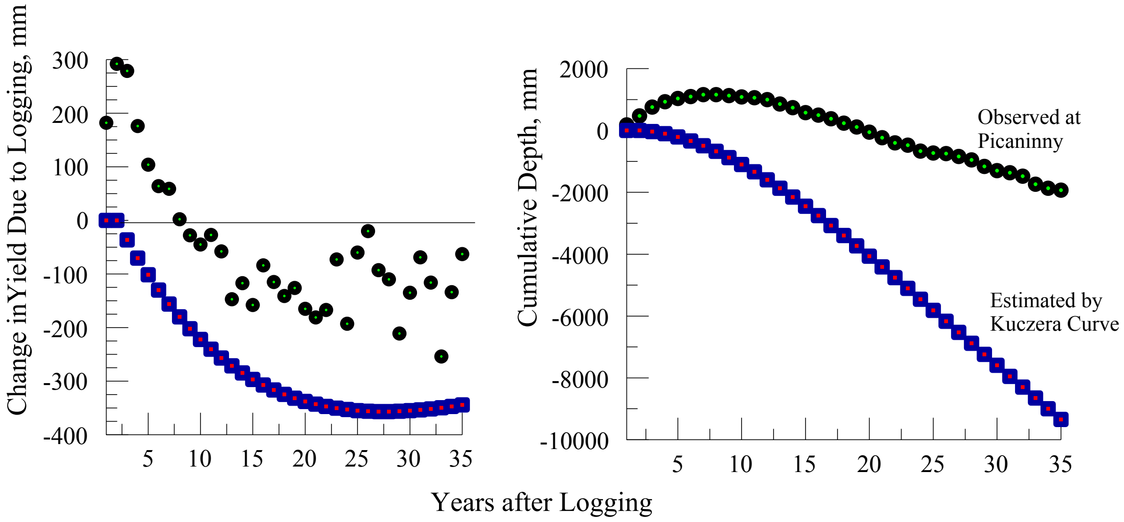


Figure 6.5 Comparison of observed data and the computed Kuczera curve (left hand) and cumulative single mass plots (right hand side).

Myrtle Creek Data

Figure 6.6 shows the comparison of the observed data and the fit of the Kuczera model. The percentage of ash logged in Myrtle 2 was taken as 90 per cent in fitting the Kuczera model, reflecting that probably not all ash was logged. The Nash-Sutcliffe coefficient was computed at -1.38, meaning that the model was not a good fit.

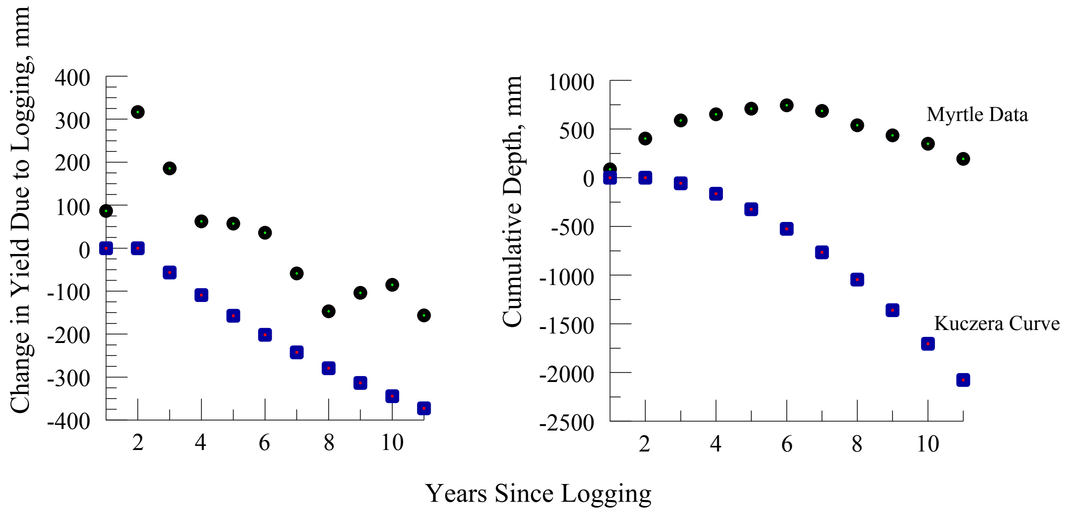


Figure 6.6: Comparison of observed data and the computed Kuczera curve (left hand) and cumulative single mass plots (right hand side) for Myrtle 2 catchment.

Monda Catchments

For this the Nashe-Sutcliffe Coefficient was -1.60, again reflecting that the Kuczera curve did not perform adequately as a model in this situation. In terms of predicting the depth of runoff over the course of the experiment it performed quite well but the absolute errors in individual readings were large.

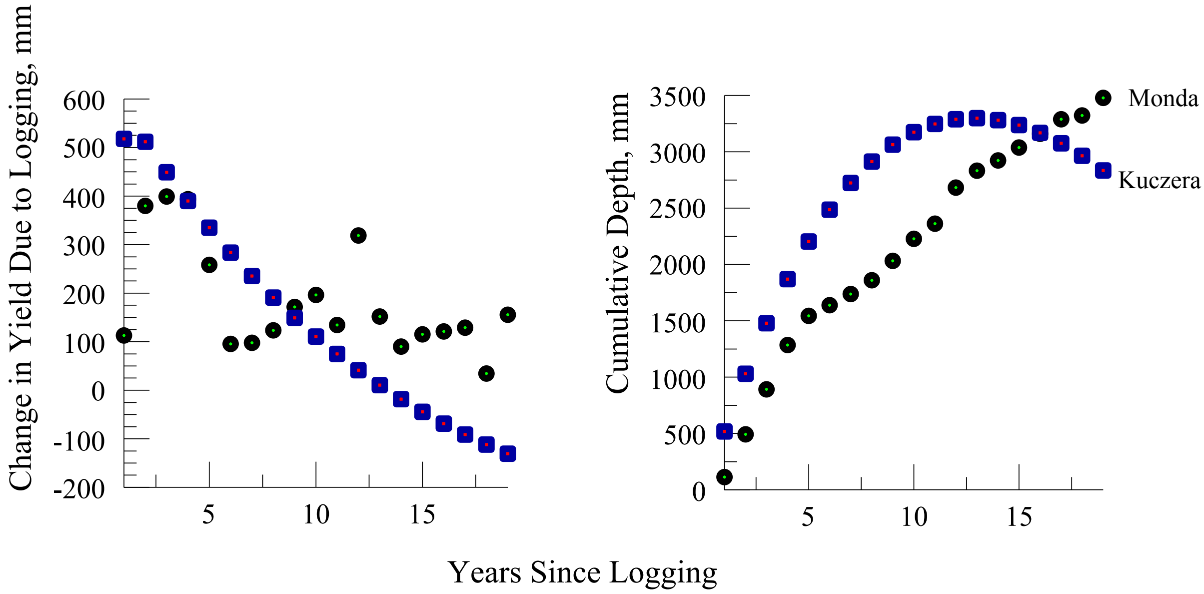


Figure 6.7: Comparison of observed data and the computed Kuczera curve (left hand) and cumulative single mass plots (right hand side) for Monda catchment.

The Watson Model

Picaninny Data

An initial application of the Watson Model to the Picaninny data gave a poor result. However a second application applied it to only the 58 per cent of the catchment that was ash. Effectively this assumed that the mixed species component exhibited no long-term logging response. Figure 6.9 shows the result. This had a Nash-Sutcliffe coefficient of 0.82, indicating good prediction. The results show that as the trees age the deviations from the model and the data become more consistent.

Application of the Watson Model to such a catchment does involve some subtle questions of methodology. If the assumption that mixed species is to be treated the same as ash then the performance of the model at Picaninny, as given by the Nash-Sutcliffe coefficient becomes -0.57

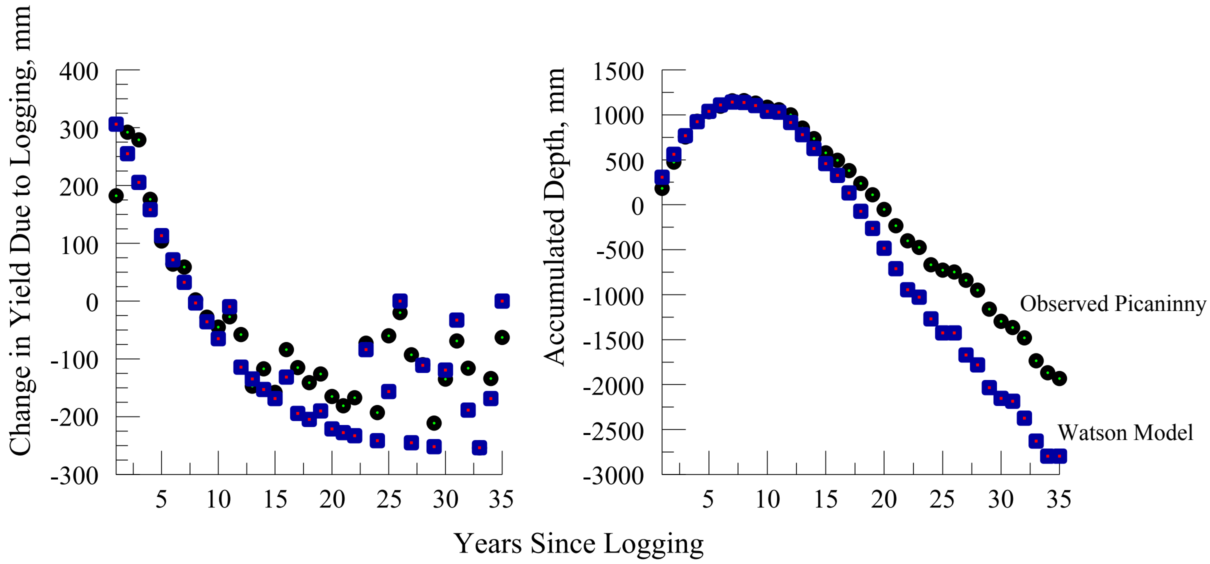


Figure 6.8: Comparison of observed data and the computed Watson model (left hand) and cumulative single mass plots (right hand side) for Picaninny catchment. This result depends on the assumption that there is no contribution from the mixed species forest.

Myrtle Data

Figure 6.9 shows the result of this. The Nash-Sutcliffe coefficient was -0.22. It can be seen that the model is unexceptional and that there is a consistent over-estimate of the yield in this high rainfall environment.

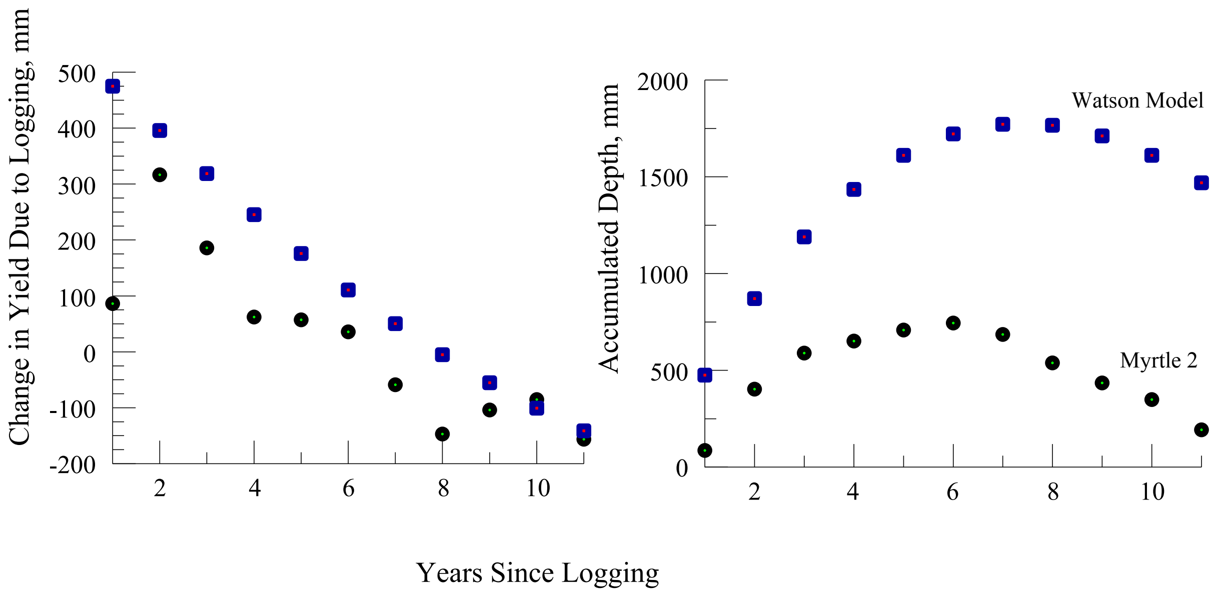


Figure 6.9: Comparison of observed data and the computed Watson model (left hand) and cumulative single mass plots (right hand side) for Myrtle 2 catchment.

Monda Data

Figure 6.10 shows the results of this. The Nash-Sutcliffe coefficient was -6.79. The model fit was unimpressive, with a substantial over-estimate of the volume of water released by the logging.

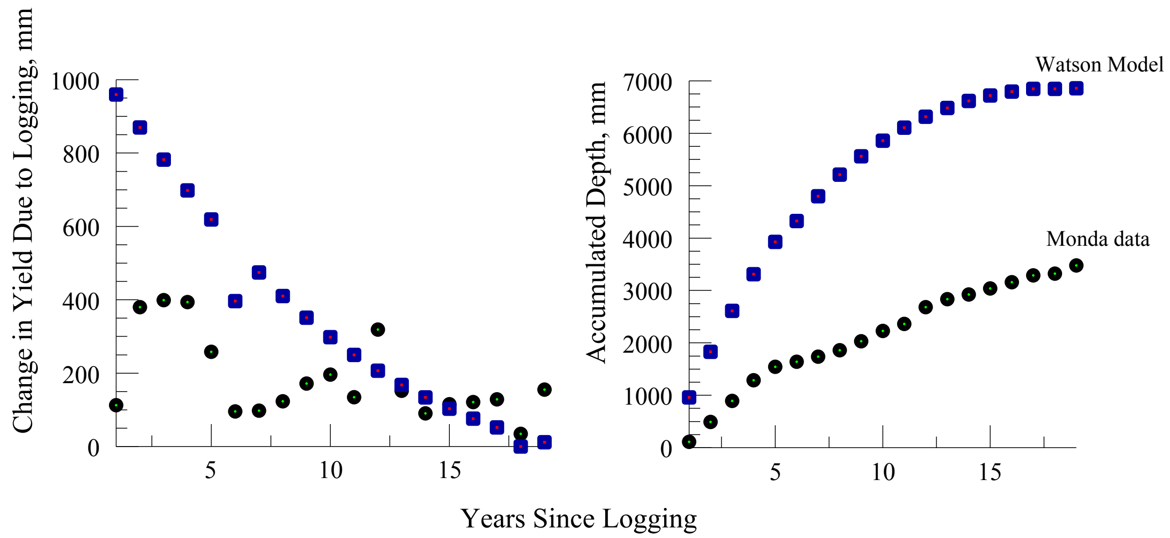


Figure 6.10: Comparison of observed data and the computed Watson model (left hand) and cumulative single mass plots (right hand side) for the Monda catchment data.

MDBC/SKM (BISY) Models for Ash and Mixed Species

Picaninny Data

The model was applied as 0.58 ash + 0.42 mixed species. Figure 6.11 shows that this model achieved a reasonable Nash-Sutcliffe coefficient of efficiency (0.61). However it showed a tendency to overestimate the water loss due to logging.

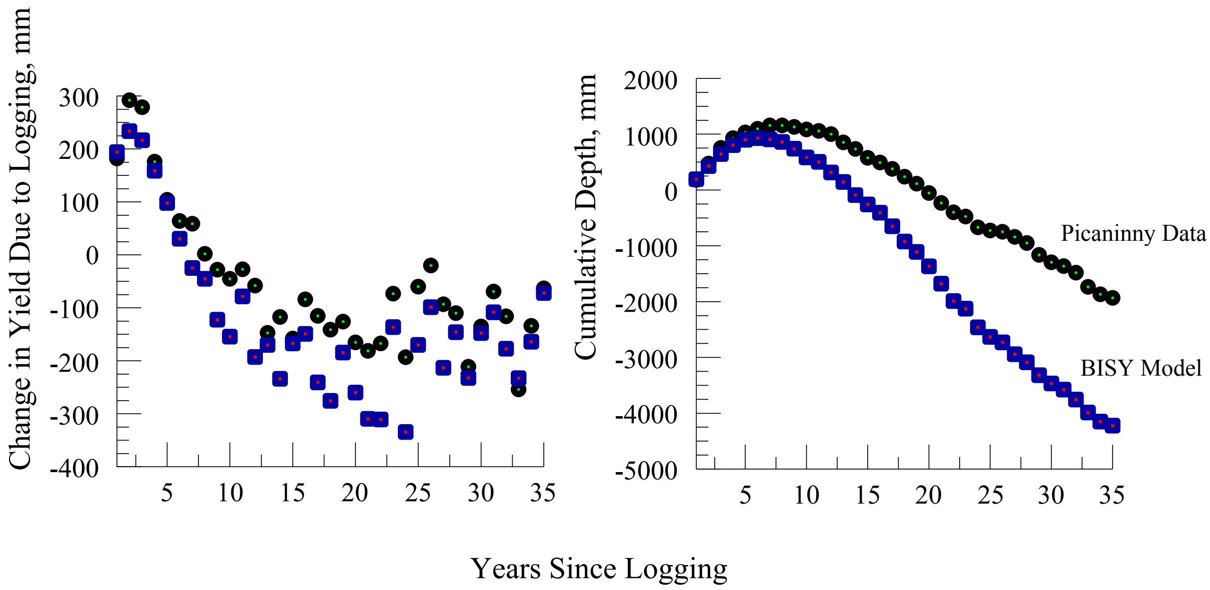


Figure 6.11: Comparison of observed data and the computed BISY model (left hand) and cumulative single mass plots (right hand side) for the Picaninny catchment data.

Myrtle 2 Data

The model performed credibly on this data set with a Nash-Sutcliffe coefficient of 0.65. Figure 6.12 shows the fit.

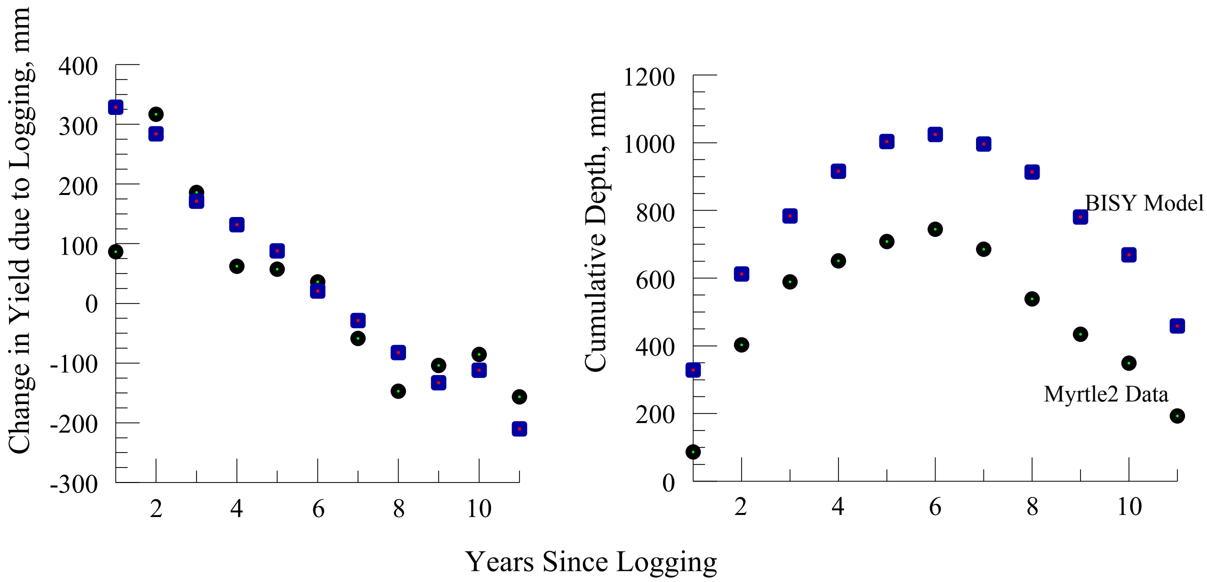


Figure 6.12: Comparison of observed data and the computed BISY model (left hand) and cumulative single mass plots (right hand side) for the Myrtle 2 catchment data.

Monda Catchment

The model did not perform well, with a Nash-Sutcliffe coefficient of -2.72. Figure 6.13 shows the fit.

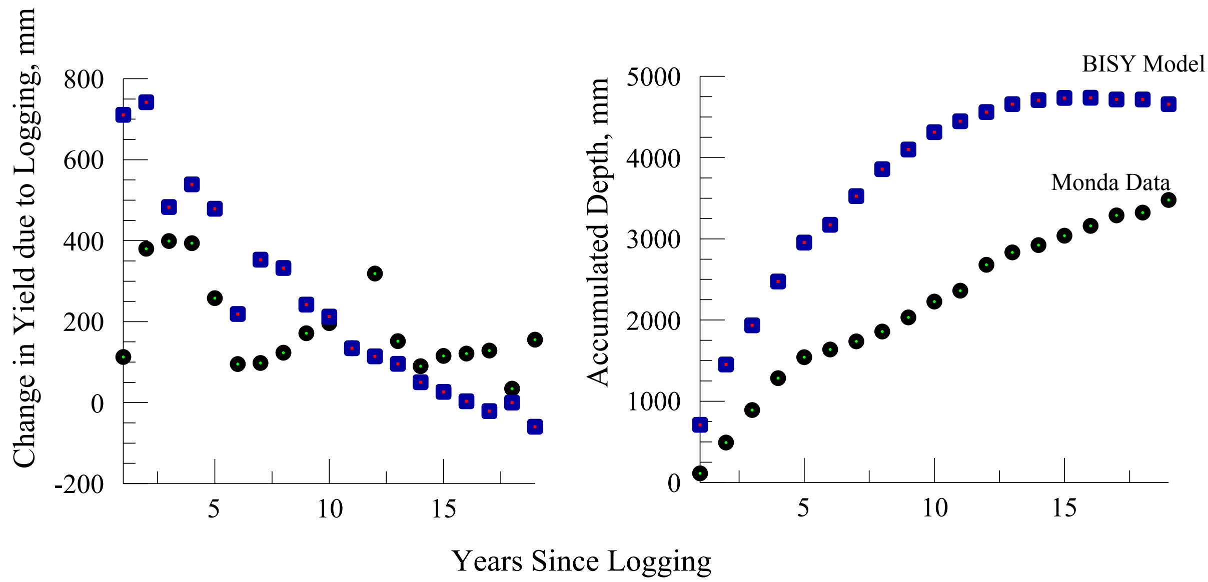


Figure 6.13: Comparison of observed data and the computed BISY model (left hand) and cumulative single mass plots (right hand side) for the Monda catchment data.

Peel Model

The Peel model was derived for the Thomson catchment, and suited to a generally higher rainfall area. Because it is often cited, we have included it in our analysis; however it is noted that at the time of production no claim was made as to its generality.

Coranderrk (Picaninny Creek) Data

The application was weighted by use of 58 per cent of the ash model and 42 per cent of the mixed species model. The large number of zero values is associated with the model giving zero runoff at low rainfalls. The Nash-Sutcliffe coefficient was -0.06, indicating a relatively low performance. Figure 6.14 shows the fit.

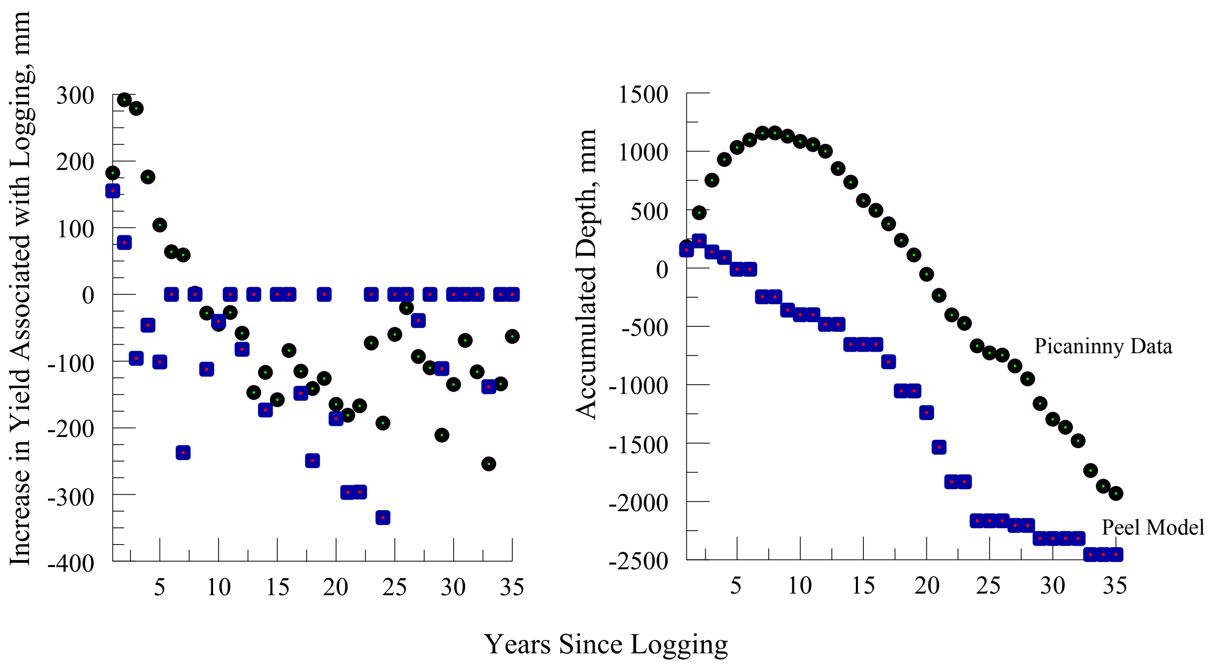


Figure 6.14: Comparison of observed data and the computed Peel model (left hand) and cumulative single mass plots (right hand side) for the Picaninny catchment data.

Myrtle 2 Catchment

The model again seemed to have problems. The Nash-Sutcliffe coefficient was -5.49, and the model tends to over-estimate water use. Figure 6.15 shows the agreement.

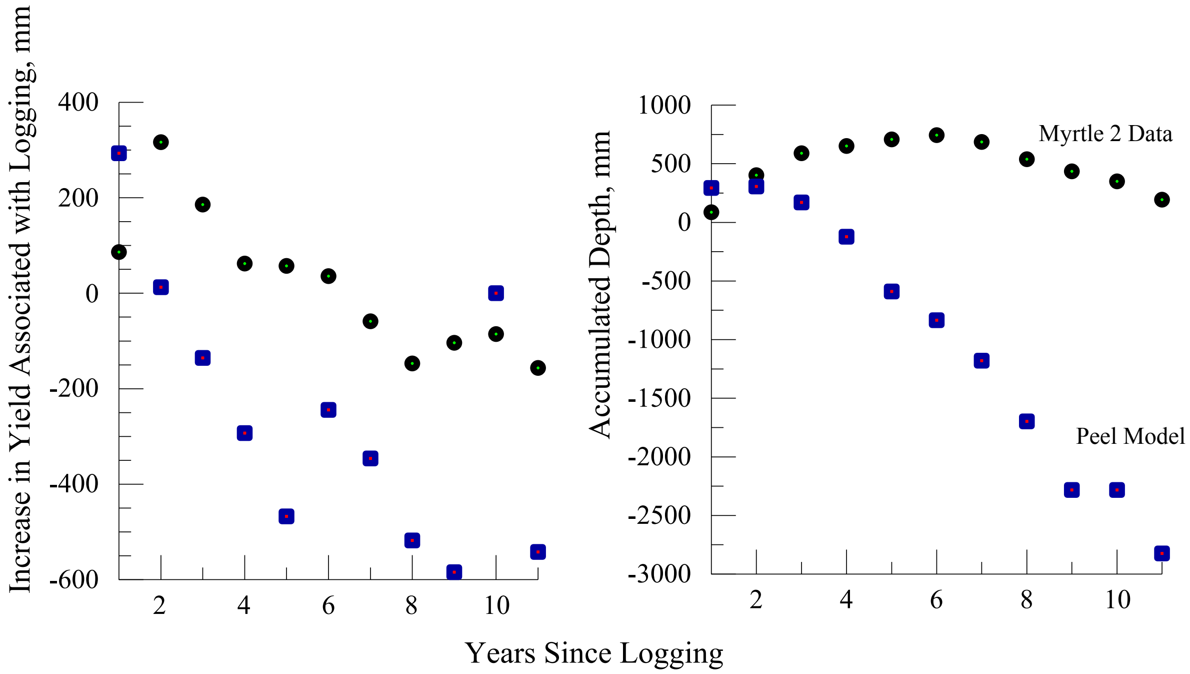


Figure 6.15: Comparison of observed data and the computed Peel model (left hand) and cumulative single mass plots (right hand side) for the Myrtle2 catchment data.

Monda Catchments

Again the Peel model did not reproduce the Monda data well. The Nash-Sutcliffe coefficient was -7.41. Figure 6.16 shows the fit.

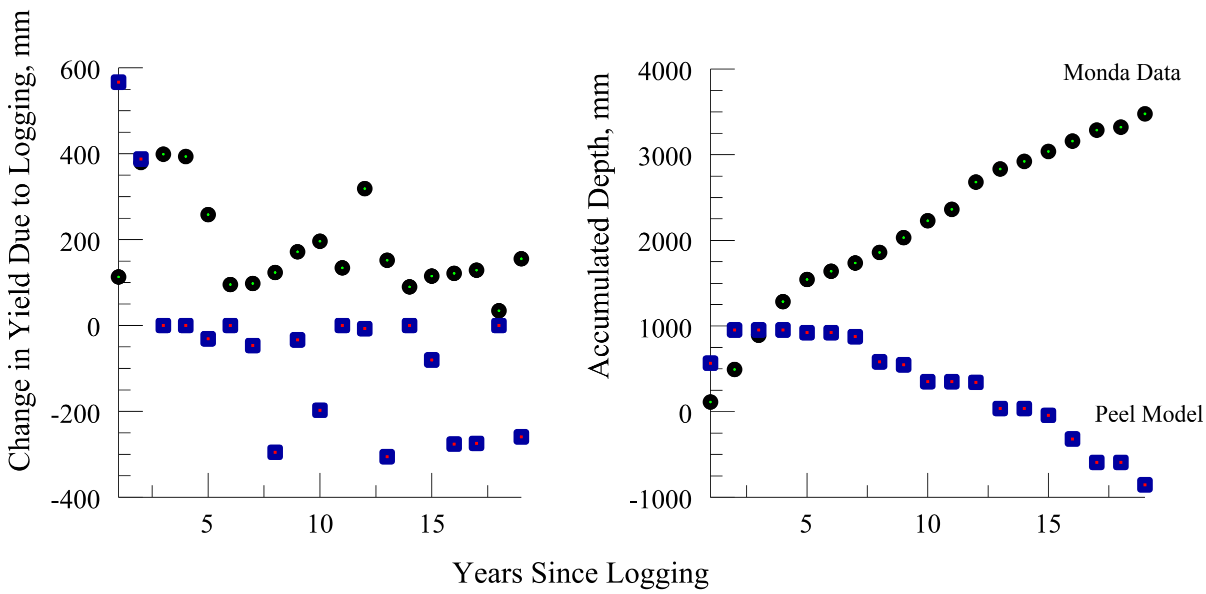


Figure 6.16: Comparison of observed data and the computed Peel model (left hand) and cumulative single mass plots (right hand side) for the Monda catchment data.

Application of Models to Karuah (NSW) Data

The above models and data sets were generated in Victoria. However this study embraces catchments in other states. A reasonable data set is available from the Karuah work of Cornish and Vertessy (2001). Consideration of the results of the modeling above suggested possible models were:

1: BISY Ash (relative to old growth) and BISY mixed species (relative to old growth)

2: Watson (relative to old growth), and

3: Peel (relative to old growth).

Table 6.6 shows the Sutcliffe-Mash coefficient of efficiency gained by applying these models to the data:

Table 6.6 Nash-Sutcliffe coefficients for various models applied to the Karuah (NSW) data.

Model	Nash-Sutcliffe Coefficient
BISY Mixed Species	0.585
BISY Ash	0.710
Peel Ash	-1.99
Peel Mixed Species	0.292
Watson	0.551

Figure 6.17 shows the fit of the BISY Ash model to the Karuah data.

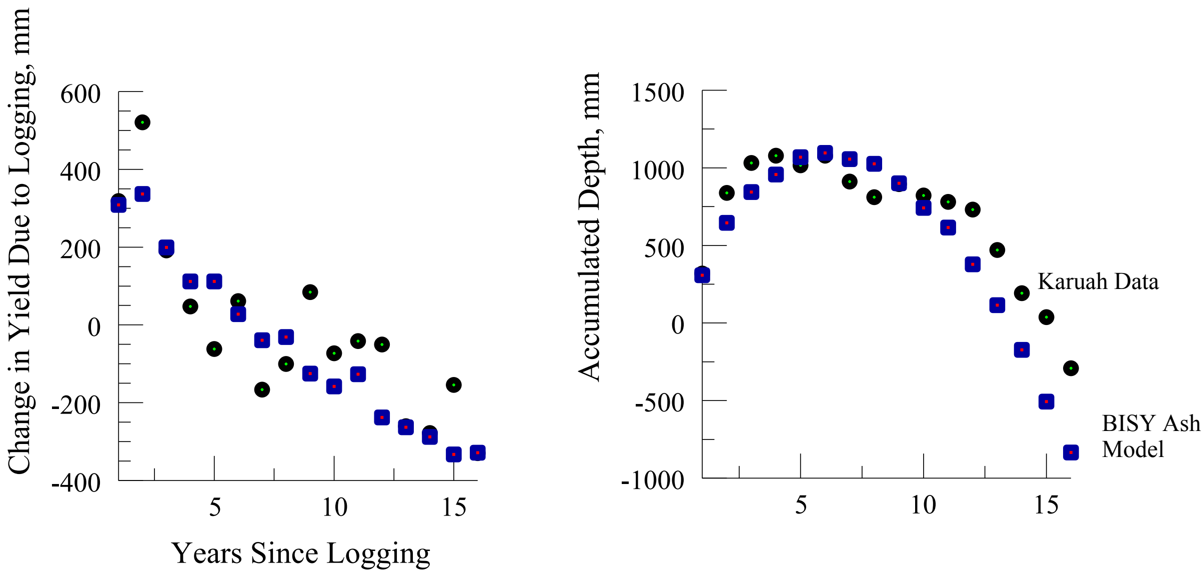


Figure 6.17: Comparison of observed data and the computed BISY Ash model (left hand) and cumulative single mass plots (right hand side) for the Karuah (NSW) catchment data.

6.6 Summary of Model Results and Conclusions

Table 6.7 below summarises the results of applying the various models to the data sets.

Table 6.7: Nash-Sutcliffe coefficients achieved by various models on the available data sets.

Data Set Model	Coranderrk	Myrtle 2	Monda	Karuah
Kuczera	-1.86	-1.38	-1.60	n/a
Watson	0.82	-0.22	-6.79	0.551
Peel	-0.06	-5.49	-7.41	-1.99
BISY	0.61	0.65	-2.72	0.710 (ash) 0.585 (ms)

Overall the SKM/MDBC (BISY) model of MCBC (2007) gave the best performance at predicting yield change as a function of time for various species. In general the performance of the various models across the range of data was not good. In saying this we are somewhat apologetic in that we were applying models to situations for which they were not necessarily designed, and in some cases giving either limited acknowledgement or ignoring qualifications and caveats made by the model authors. All models have subtleties and an application such as this cannot pay particular attention to these. We are also conscious that the data, although the best we could do for this study, could be improved; some pathways to this are suggested in the conclusions to this report.

Of substantial disappointment was that in general, good data sets from these long-term experiments are either not available or not publicly available. There is an excellent opportunity for future work to collate the data, analyse it in a consistent way, and then apply such models with the cooperation of the authors.

The Kuczera curve was derived as an early attempt to model bushfire-related change. The results suggest that it cannot accommodate changes associated with logging and that it should not be used in forest harvesting evaluations.

Chapter 7:

Analysis of Forest Management Water Savings Computed Using the BISY Model(s)

Thinning eucalypt regrowth forest for fibre

7.1 Introduction

The requirements of the consultancy are complex in that the task is to estimate how much water is "lost" to the Murray-Darling Basin as a result of native forest management. Taken to an extreme, this would include effectively huge set of "accounts" since large areas of forests have been managed for a long time over wide areas and have a wide variety of forest management styles applied. Clearly this is not possible but we can, with some judicious assumptions and a realistic consideration of error, make some estimates of how much water is lost as a result of past actions, how much might be "saved", and economic aspects of this. Caveats will also be put on the computations concerning the impacts of actions which are "overlain" on forest management – particularly bushfires and wind-throw, since these will have similar effects and may be of a magnitude that, sometimes, dwarfs forest management. However this consultancy is not concerned with such "wider picture" issues.

This Chapter will look at the implications of the selected BISY model (MDBC 2007) for a hypothetical 1 km^2 area of forest. This will look at the ultimate amount of water which could be "saved" from transpiration by regrowth, and the rate at which this ideal could be approached by stopping logging. Chapter 8 will look at the areas of managed native forest within the Murray-Darling Basin catchment. Chapter 9 will combine the information in this Chapter and Chapter 8 to produced catchment-wide estimates of water that can be saved. This is by scaling up the estimates of this Chapter using appropriate functions.

7.2 The Model(s) Selected

The model selected is briefly discussed in Chapter 3 and is known as the BISY model of MDBC (2007). This has two variants – one for mixed species and one for ash species. The code of the model is intellectual property of SKM Pty Ltd; however from the description the model was coded independently in "*Mathematica*." This code is given as a set of functions in Appendix 1. In the computations only the functions of water yield relative to old-growth were used. Plots of the output from this overlaid on the plots of the MDBC (2007) report agreed perfectly. The work of Chapter 6 showed that it gave the best prediction of change (relative to old growth), as judged by its fidelity of reproduction of research results.

The two variants of the model are designated as functions:

ashrel[age, P] and

mixedspprel[age, P]

where [age, P] is the input variables of forest age and annual rainfall (mm) respectively. The function "ashrel" gives the annual water yield relative to old-growth mountain ash (mm). The function "mixedspprel" gives the annual water yield relative to old-growth mixed species (mm). The full listing of the functions is given in Appendix 1.

The functions have, as their starting point, stream runoff computed using "Zhang Curves" as given in Equations 1.5 and 1.6 and Figures 1.2 and 1.3. The model was originally developed for use in NSW and used data from both Yambulla and Karuah paired catchment projects, although the description of model development in MDBC (2007) is vague. For a fuller description of the algorithm the reader is referred to MDBC (2007). However the following is relevant:

1: The yield of a mature forest is given by subtracting the Zhang curve for forest evapotranspiration (*i.e*. equation 1.5) from the rainfall, as per equation 1.3.

2: The upper limit of yield for a logged forest is given by subtraction of the Zhang curve for pasture evapotranspiration (*i.e.* equation 1.6) from rainfall.

3: The lower limit of streamflow is given by the condition that evapotranspiration + streamflow must be no greater than annual rainfall.

4: The "Watson Model" (see Section 2.6) with parameters appropriate for ash or mixed species is used to compute deviations off the above Zhang curves as a function of age of the trees and annual rainfall. This is scaled by a proportional factor based on the relative difference between Zhang Curves.

5: To obtain the "relative change" the yield given by the model for trees of age 200 years is subtracted from the yield for trees of a given age. A positive value means a streamflow increase. A negative value means a streamflow decrease.

Table 7.1 gives the values of the constants used in the two variants of the model. The reader is also referred to Figure 3.5.

Table 7.1: Parameter values used in the Variants of the BISY Models

Parameter	Mountain Ash	Mixed Species
p1	1500	795
p2	800	843
p3	400	-439.7
p4	300	403.5
p5	34	16.1
p6	6.0	6.8
p7	60	17.1

7.3 Considerations of Modeling of Two Particular Cases

We have considered two cases:

Case 1: Comparing with old-growth forest (*i.e*. the gap in water yield due to the logged forest and the "old growth" forest as a function of mean annual rainfall), and

Case 2: Transitioning a hypothetical managed forest to old growth. Thus the cessation of logging means that when the forest has reached 100 it would not be logged. Rather it would be allowed to grow on to age 101, 102, etc.

The algorithm of computation for these two cases is discussed below.

Case 1: Absolute Difference Between Managed Forest Yield and Old Growth Yield.

Case 1 is viewed as a probably unattainable ideal. To meet the requirements of this consultancy, we have made some judicious assumptions. These presuppose a degree of order in the forest management that usually does not exist. This reflects the changing status of forests and the complex organisational structures that manage forests. The assumptions in Case 1 are:

1: The forest is managed on a "rotation" of 100 years (see Figure 7.1).

2: Management is by clear-falling.

3: The forest is either (i) ash or (ii) mixed species.

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	28	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	77	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Figure 7.1: Our one kilometre^2 forest divided into 100 blocks each of 1 ha. The number indicates the age of the block. An unusually regular arrangement, but useful for our hypothetical argument.

The methodology uses the fictitious but convenient assumption that each square kilometer is managed as a “normal forest” of 100 separate blocks, each of 1 ha. Our square kilometer block will be scaled up as appropriate to the area involved. Management consists of falling one hectare each year. This is then regenerated, and so the forest is in a “dynamic equilibrium.”

Consider the rotational structure of the forest. This will be equal areas of age 1 year, age 2 years, age 3 years, etc. Then at any time the annual average water yield for the forest (mm) can be expressed by:

$$Y = (y_1 + y_2 + y_3 + \cdots y_{99} + y_{100})\frac{1}{100} = \frac{1}{100}\sum_{1}^{100} y_i \qquad (7.1)$$

where Y is the total water yield of our square kilometer (expressed in mm), and y_1, y_2 , etc are the annual water yield in mm. Let us define a new term, R_n, such that:

$$R = Y - Y_{200} = \frac{1}{100}\sum_{age=1}^{age=100}(y_{age} - y_{200}) \qquad (7.2)$$

where

R = Change in yield of our 100 ha forest relative to old growth, mm

$Y - Y_{200}$ = Absolute yield of our 100 ha forest minus the runoff from an equivalent area of 200 year old growth, mm

$y_i - y_{200}$ = Absolute yield of 1 ha of forest of age i minus the absolute yield of a hectare of 200 year old forest, mm.

The term $(y_{age} - y_{200})$ corresponds to the function value ashrel[age, p] or mixedspp[age, p] for mountain ash and mixed species respectively in which the absolute yield is both a function of age and annual rainfall, p. For convenience in Case 2 below let us define:

$$r_i = y_i - y_{200} \qquad (7.3)$$

Then equation 7.3 can be more concisely written as:

$$R = \frac{1}{100}\sum_{i=1}^{i=100} r_i \qquad (7.4)$$

If regrowth forest has a lower water yield than old growth forest then R will be negative. Case 1 is viewed as a probably unattainable ideal since it defines the difference between the water yield of the managed forest compared to a possible maximum catchment water yield if the forest was 200 year old. However it gives no idea of the length of time to achieve this.

Case 2: Transitioning the Managed Forest to Old Growth

Case 2 is a more "practical" case that might, at least be aimed for. It is reiterated that our computations are not concerned with the absolute yield of water – rather the change in yield.

Suppose our forest is, as before, an area of 1 km^2 consisting of 100 blocks, each of 1 ha and age 1 year, 2 years, 3 years, …99 years, 100 years. Suppose, at time 0, a decision is made to cease logging and allow the forest to "transition" such that in 200 years the forest age will range from 201 years to 300 years. All the forest will be old-growth and the increase in yield from the forest will be that given by Case 1 above. Our concern is how fast can we approach this state, given our modeled relative water yield as a function of age and annual rainfall.

The relative change in water yield of our 1 km^2 "normal forest" as a function of the year can be computed as:

$$R_{year} = \frac{1}{100}\sum_{i=1}^{i=100} r_{i+year-1} \qquad (7.5)$$

in which year = 1, 2, 3….100. Effectively this is the same as equation 7.4 except that rather in ranging in age from 1 to 100 the forest ranges in age from the nominated year to (year+100). Thus, for instance, ten years after logging has stopped will mean that the youngest trees are ten years of age and the oldest are 110 years of age. The value of -1 in the subscript is to meet the adopted convention that the youngest age of the forest is 1 (not 0) years. Thus the forest ages such that areas that were 1 year old in (say) 2010 are 100 years old in 2110. We have adopted the arbitrary limit of 100 years for such computations.

Absolute or Relative Versions of Change.

By dividing the value of R or R_{year} by the runoff computed using our "Zhang forest runoff" (equation 1.3 and 1.5 combined), we can obtain the relative fraction of "maximum deviation" that can be captured. Thus, from the assumptions underpinning the BISY model

$$y_{max} = P - \left(\frac{1+\frac{2820}{P}}{1+\frac{2820}{P}+\frac{P}{1410}} \right) P \qquad (7.6)$$

where y_{max} = runoff from mature forest, as computed using the Zhang (2001) evapotranspiration curve. Then the result, in relative terms, can be expressed as:

$$R_{relative\,\%} = \frac{R\ 100}{y_{max}} \text{ or } \frac{R_{year}\ 100}{y_{max}} \qquad (7.7)$$

in which $R_{relative\,\%}$ (per cent) is the degree of relative change compared to old-growth (mature forest) runoff. The value of 100 converts the fraction to a percentage value. A value of -100 per cent would mean that the stream was dry. A value of 0 per cent would mean that the runoff was equivalent to 200 year old growth. A minus sign indicates a decrease in flow.

Setting Error Limits

The BISY model was selected on the grounds of giving the highest Nash-Sutcliffe coefficients of efficiency. Comparison with the results given in the analysis of the Coranderrk paired catchment project by Bren, Lane, and Hepworth (2010) suggests that it may well substantially over-estimate water use (see Figure 6.10). However we have no better model. Reasonable assumptions based on this are that the model chosen is unlikely to under-estimate regrowth water yield effects. The paucity of good data for comparative purposes means that the only thing we can say with any confidence is that the error bars in any such analysis will be large and that the modeled effects will probably be larger than the true effects. This will be an important component in subsequent discussions.

7.4 Method

Equations 7.4 and 7.5 above were programmed in "*Mathematica*", and illustrations and tabulated output produced to illustrate the behavior of our normalized forest. The appropriate code is given in Appendix 1 of this report. These outputs will be scaled up appropriately in Chapter 9. The outputs were used to draw conclusions on how severe the impact of forest management is on water yields and the likely times to recovery if this started immediately.

7.5 Results

Figure 7.2 shows the computed difference in yield between all old-growth and our managed forests for both mountain ash and "mixed species" forest as a function of annual rainfall, P. The results are shown both in absolute and relative terms. This corresponds to "Case 1." It can be seen that, notwithstanding the errors, the amount of water taken up by the regrowth forest can be substantial in both absolute and relative terms. As annual rainfall increases the absolute effect increases but the relative proportion decreases.

Figure 7.3 shows the results for "Case 2" in absolute terms, and Figure 7.4 shows the same result as a proportion of the maximum flow. This corresponds to the yield of managed forest after the cessation of logging. It can be seen that:

1: The forest will, effectively, take one life cycle of the trees to recover. This is assumed to be about 200 years.

2: Cessation of logging will lead to a small diminution of flow, with a period of around 20 years needing to elapse before there is any significant gain in water yield.

3: The qualitative behavior of the mixed species forests and the ash forests of similar rainfall are, according to the model, quite similar.

Of some importance to the ultimate conclusion of this report is the relatively slow initial recovery shown if logging were to immediately cease. Thus the water flow situation diminishes rather than increases for the first few years. It is argued in the conclusions to this report that it follows that, if the water volumes are viewed as worthy of attention by MDBA managers, that the relatively slow initial response should be used to “buy time” to improve the estimates of water use by reworking paired catchment project data, initiating new paired catchment projects, and investigating other techniques such as heavy thinning.

7.6 Further Use of These Results

These results assume a “normal forest” of 1 km^2 in area. Chapter 8 presents the areas of managed forests in various rainfall zones. Chapter 9 will use the absolute results presented in Figures 7.1 and 7.3 to scale the results up to the areas of managed forests. It should be noted that the results presented in this chapter do not make any allowance for areas such as buffer strips, etc. These will be incorporated in the scaling up of used in Chapter 8.

7.7 Conclusions

The Chapter uses the selected “BISY” model to define the maximum difference between a “managed forest” and runoff from a regrowth forest with a “normal” distribution of age classes. The results show that, for the areas of forest, the results can be substantial. However, we believe that although the “BISY” model selected is the best choice, the results are better viewed as an upper limit estimate of water use.

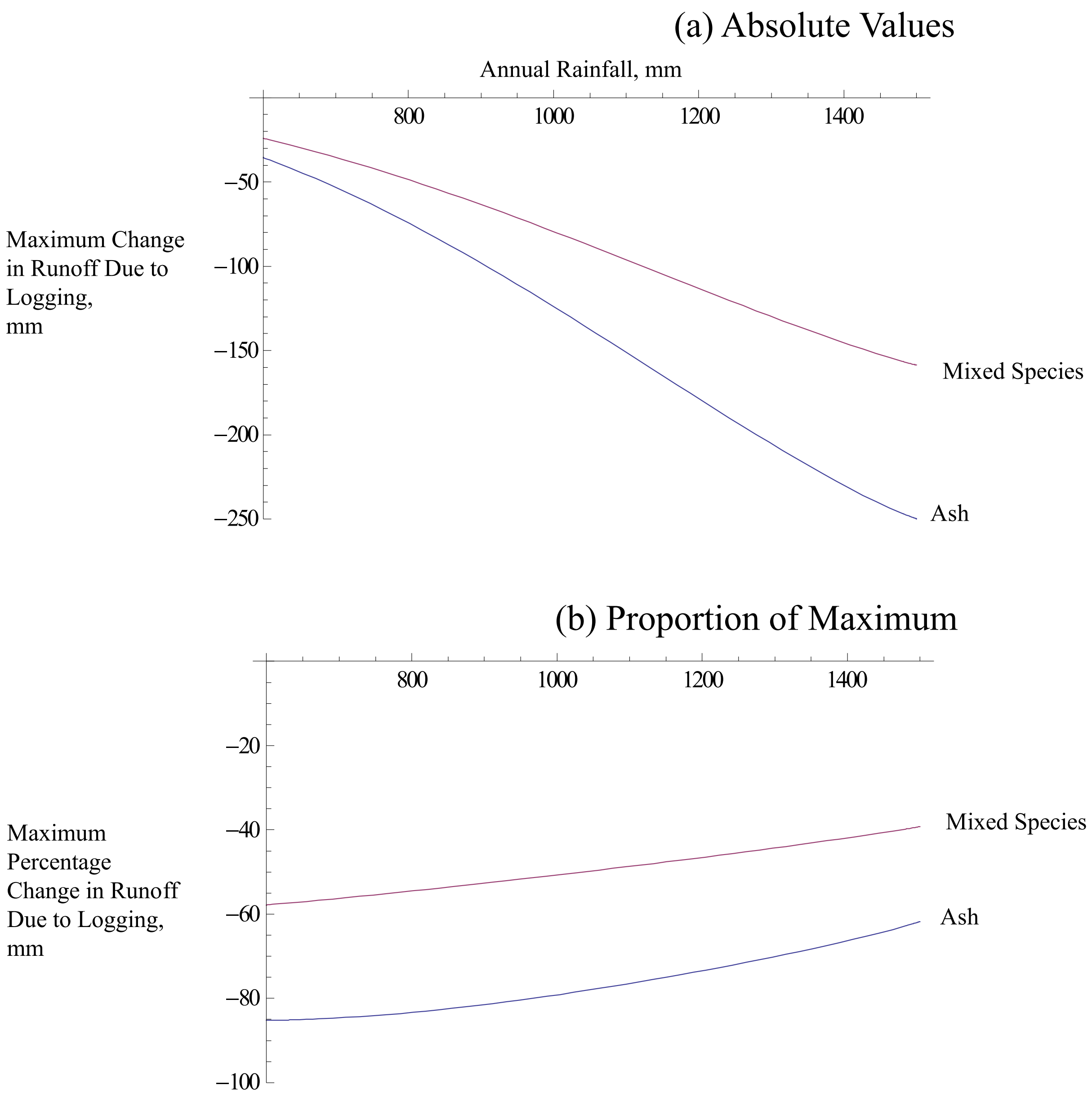


Figure 7.2: Maximum change in runoff due to logging as a function of mean annual rainfall for mountain ash and mixed species forest. Plot (a) shows this in mm decrement from the runoff of old-growth. Plot (b) shows this as a proportion of the maximum annual runoff.

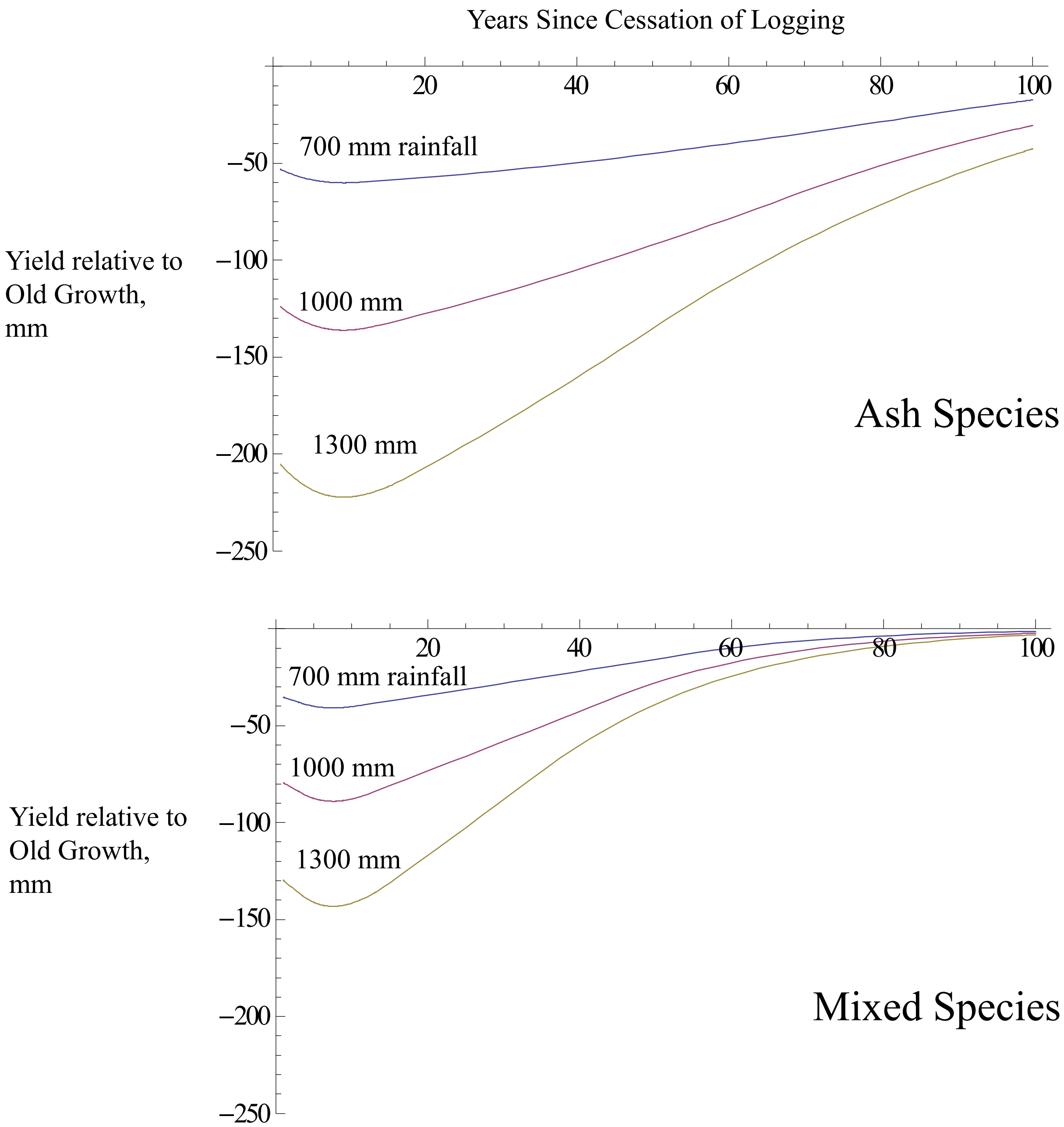


Figure 7.3: Yield relative to old growth as a function of years since the cessation of logging for ash and for mixed species forests of different rainfall.

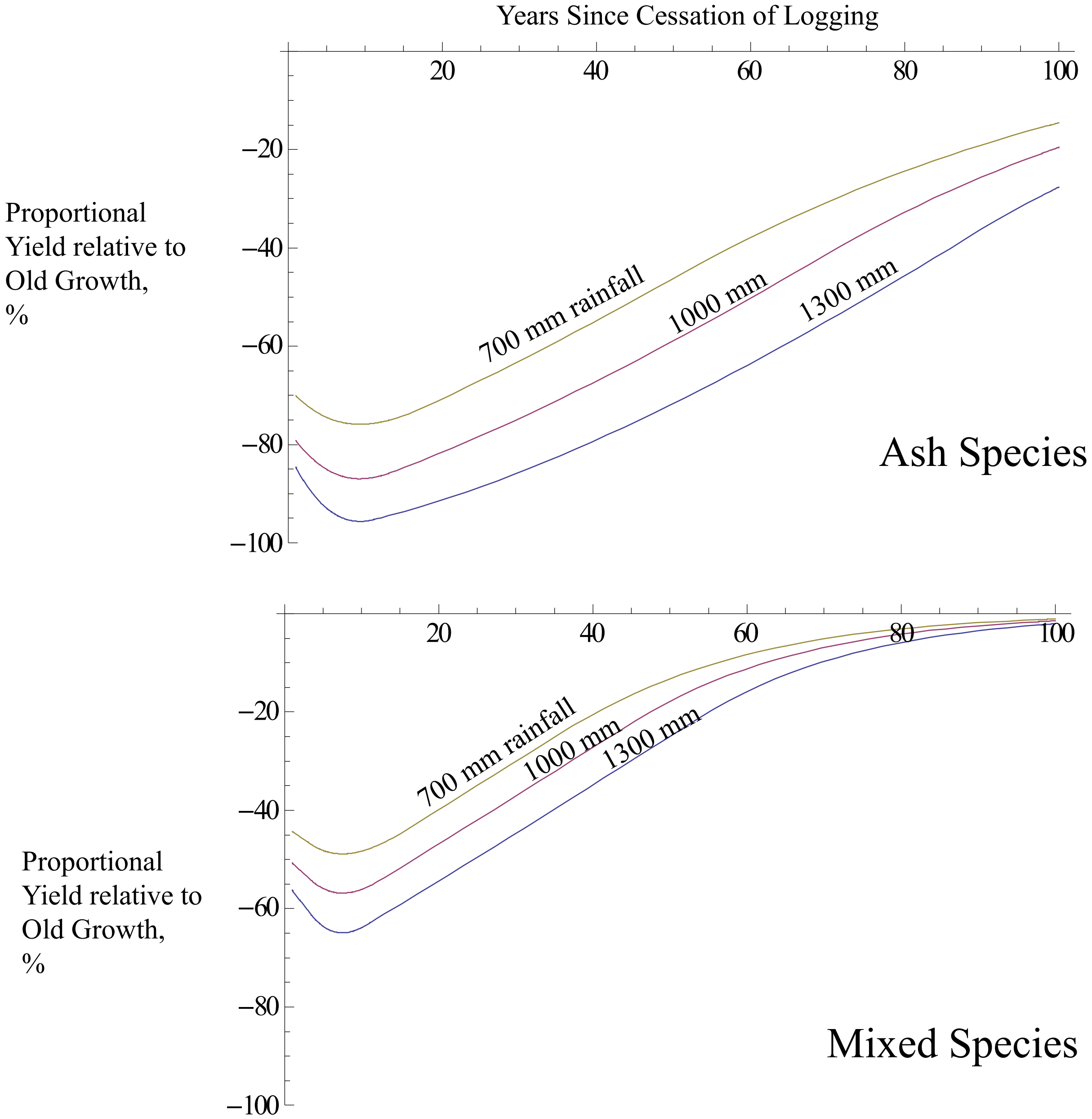


Figure 7.4: Yield relative to old growth as a function of years since the cessation of logging for ash and for mixed species forests of different rainfall. Results are shown as a proportion of maximum yield from old-growth forests.

Chapter 8:

Forests in the Murray-Darling Basin

The River Murray at Gunbower

8.1 Forest Data

In addition to estimating water yield, the MDBA required an analysis and account of types of native forest and forest management practices including harvesting and logging regimes within the MDB, to assess the impact on catchment processes, water quality and quantity. The Australian Bureau of Agricultural and Resource Economics–Bureau of Rural Sciences (ABARE–BRS) undertook this work, particularly to address the following:

- Type and spatial distribution of native forests in silvicultural production systems in the MDB.
- Rate of increase or decline of native forest cover and areas where this may be most prevalent and areas where plantation forest is replacing native forest.
- The main management regimes for native forest across the MDB and, if relevant, the associated forest type or spatial distribution.

The primary function of ABARE-BRS is to provide professionally independent research, analysis and advice to decision-makers within both the Government and private sector on issues affecting Australia's primary industries. ABARE–BRS, through collaborations with other government agencies with data management capacity including CSIRO, Bureau of Meteorology and Geoscience Australia, and a number of state governments and regional agencies, manages a number of forest and forest related national inventories and datasets.

As custodians of these datasets, ABARE-BRS collects, collates and undertakes quality control, documentation, curation, dissemination and maintenance to ensure that data are up to date, accurate and readily accessible by stakeholders and, where appropriate, the public.

For example, the draft Potential Productivity of Australia's Native Forests dataset used in this project has been compiled by the National Forest Inventory using a range of information obtained from State, Territory and Australian Government agencies during a number of projects and studies. A list of these datasets is provided below:

- National Vegetation Information System 3.1
- Comprehensive Regional Assessment datasets covering:
    - South East Queensland
    - South West Western Australia
    - North East New South Wales
    - Southern New South Wales
    - Eden New South Wales

  - West Victoria
  - Central Highlands Victoria
  - North East Victoria
  - Gippsland Victoria
  - East Gippsland Victoria
- Resource Assessment Commission „Forest and Timber Inquiry' datasets, 1992
- Collaborative Australian Protected Areas Database, 2006
- National Forest Inventory - 1997, 2002, 2007 datasets
- Other historical datasets (e.g. Forwood 1975)

These datasets have been collated into a single national dataset that describes forest related information including forest extent, forest type, forest productivity, forest commerciality and forest tenure (including conservation reserves). This information, along with rainfall isohyets and catchment information (Anuclim V.5 mean annual rainfall, 1999 and Australian River Basins, 1997) was used to characterise forests in the MDB (Figure 8.1). Details of datasets and metadata used in this project by ABARE–BRS are available at http://www.abare-brs.gov.au/data.

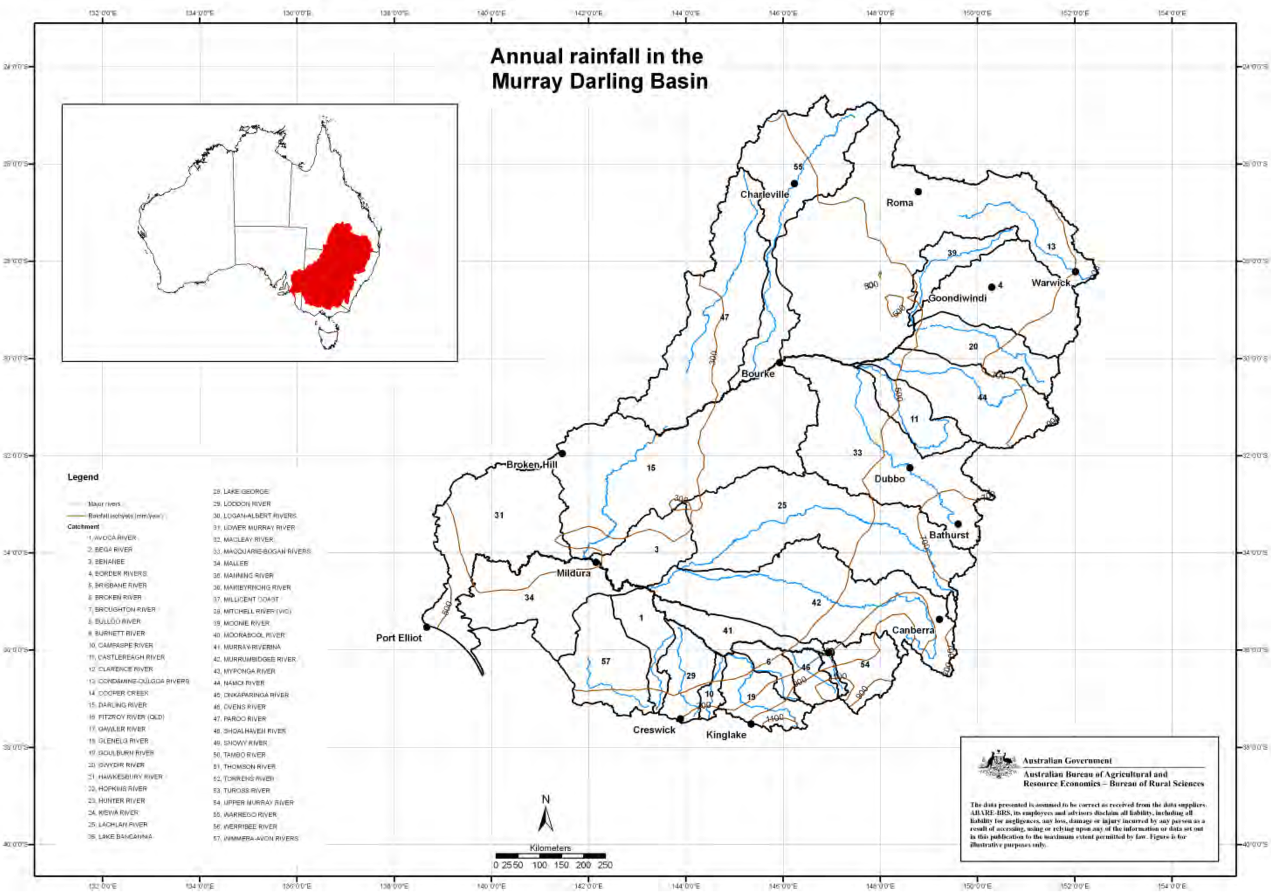


Figure 8.1: Annual rainfall in Murray Darling Basin with catchments presented (Source: Anuclim V.5 mean annual rainfall, 1999 and Australian River Basins, 1997).

8.2 Forest Tenure within the Murray-Darling Basin

The Murray-Darling Basin (MDB) covers approximately 106 million hectares. Forests cover 26 per cent of the catchment (27.2 million ha) is covered by forest (Figure 8.2).

Of this 27.2 million hectares of forest 46 per cent (12.4 million hectares) are on Leasehold lands, 27 per cent (7.36 million hectares) are on Private Freehold lands and approximately 15 per cent (4.19 million hectares) are on Nature Conservation Reserves. Just over 9 per cent (2.56 million hectares) are on publicly owned Multiple Use Forests that are managed by State and Territory agencies for a range of purposes including timber harvesting, water harvesting and storage, biodiversity conservation and public recreation. A small proportion, 2.5 per cent (0.68 million hectares) are on Other Crown Lands that are reserved for a range of uses including scientific research, stock travel, and use by the defence forces.

About 138,000 hectares of forests in the MDB are on Indigenous owned and managed lands (Figure 8.3) which fall across all of the tenure types described above.

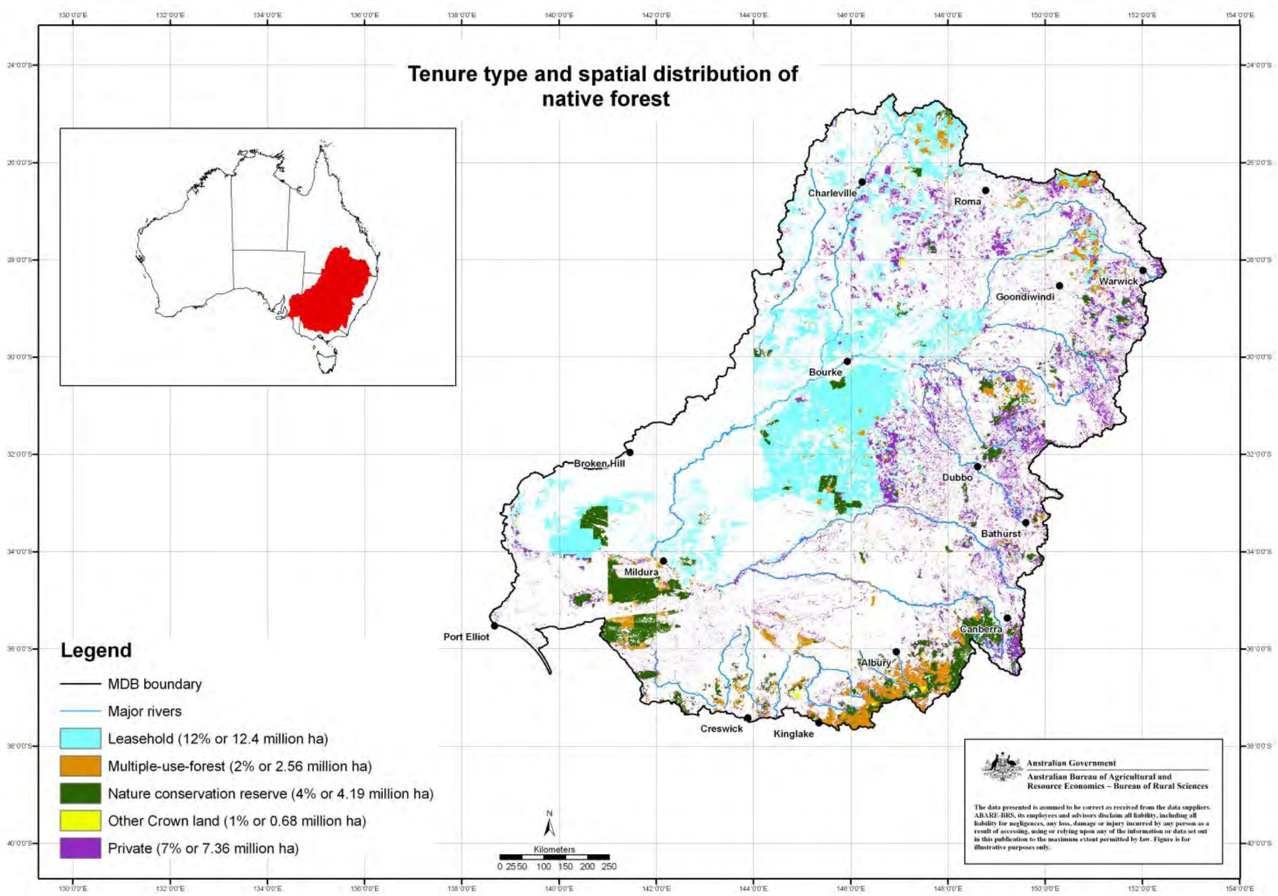


Figure 8.2: Tenure type and spatial distribution of native forest in MDB (source NFI 2008).

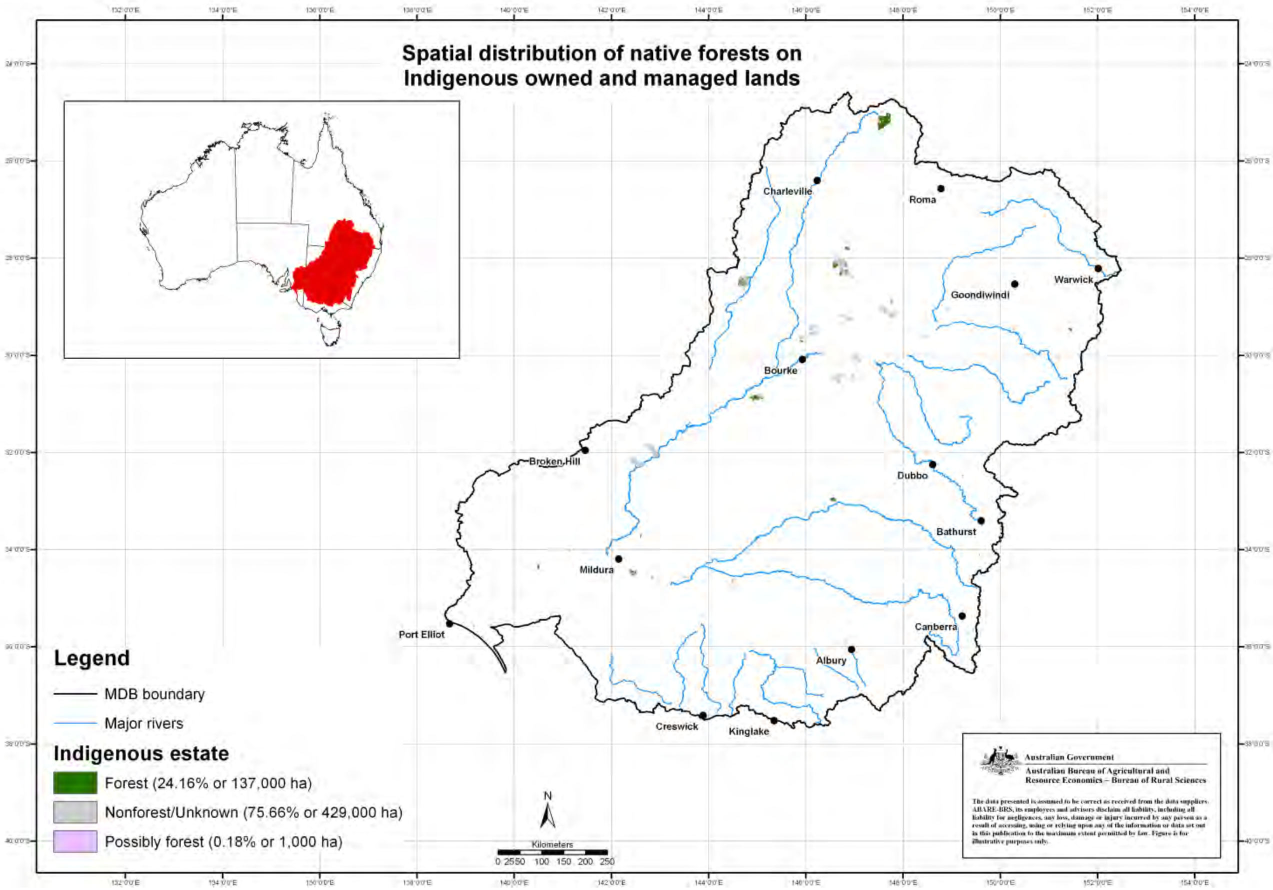


Figure 8.3: Spatial distribution of native forests on Indigenous owned and managed lands (source: Indigenous Land Corporation, 2008).

The Collaborative Australian Protected Area Database (CAPAD) contains information on all protected areas in Australia. This is compiled from information supplied by the Australian, State and Territory Governments and other protected area managers. Approximately 2 per cent (5.4 million hectares) of the basin is declared as protected (Figure 8.4). Of this 5.4 million hectares 63 per cent is identified as forest, while the remaining 37 per cent is either non forest or data are unavailable. The majority of protected areas in the MDB occur in the Lower Murray and Mallee catchments.

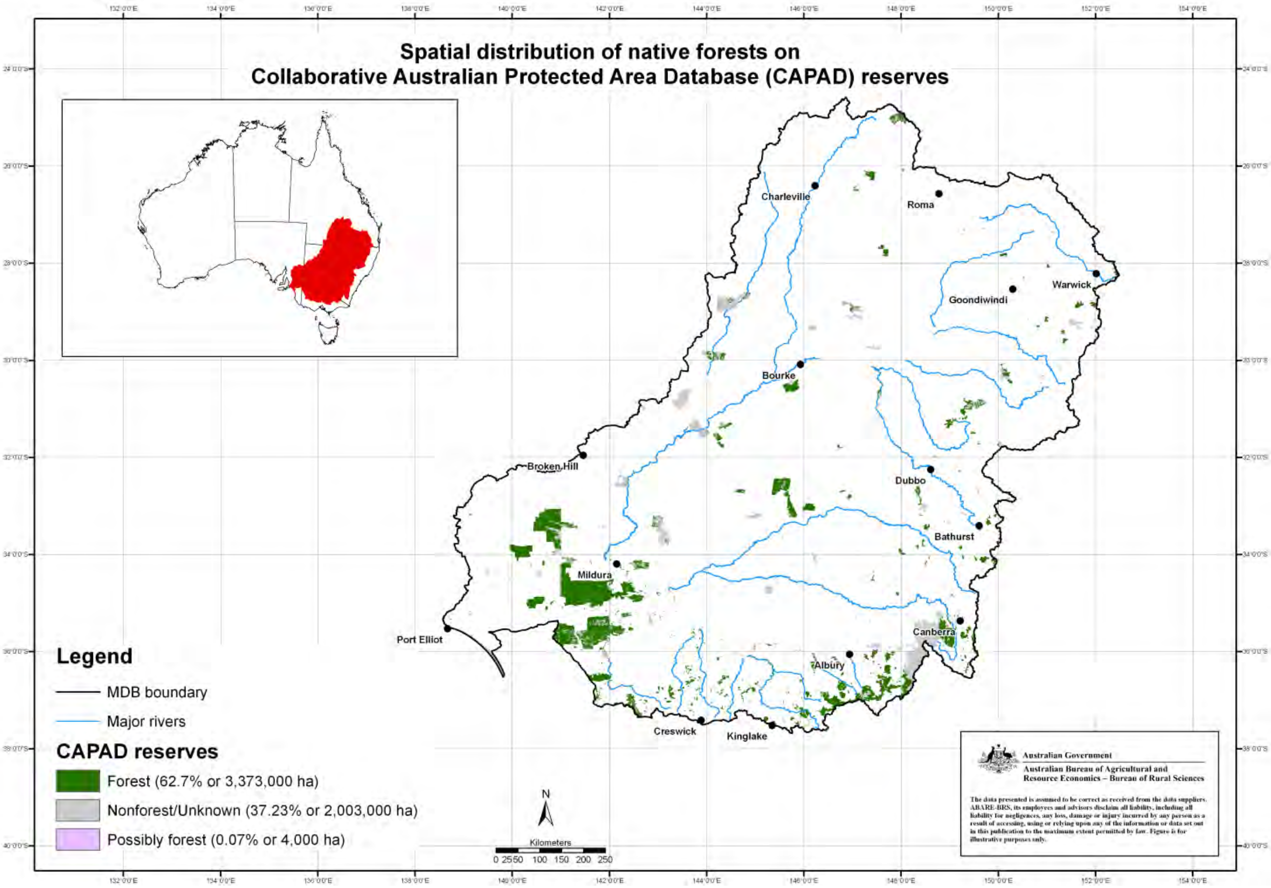


Figure 8.4: Spatial distribution of native forests on CAPAD reserves (source: DEWHA 2006).

The Australian Government Department of Climate Change and Energy Efficiency (DCCEE, previously known as the Australian Greenhouse Office) regularly reports on Australia's total carbon emissions. As part of this reporting process the DCCEE has developed the National Carbon Accounting System (NCAS), which is used to measure forest cover change through a time-series of national data layers based on Landsat satellite imagery from 1972.

Analysis of the 1998 to 2006 NCAS datasets indicate that approximately 2 million hectares of non-forest have been reclassified as forest. These changes are a result of real forest expansion due to re-growth and regeneration. Improved technology and data analysis methods means some vegetation previously considered to be non-forest now meets the DCCEE's definition of forest.

The datasets also indicate that approximately 3.1 million hectares of forest has been reclassified as non-forest (Figure 8.5). This change could be a result of forest loss due to land clearing, forest dieback or bushfires. However, some areas have been reclassified as non-forest because they did not meet the DCCEE's definition of forest as a result of stakeholder feedback, improved remote sensing techniques and/or improved satellite imagery.

Overall the analysis indicates that there has been a net reduction of area reported as forest in the MDB of 1.1 million hectares between 1988 and 2006.

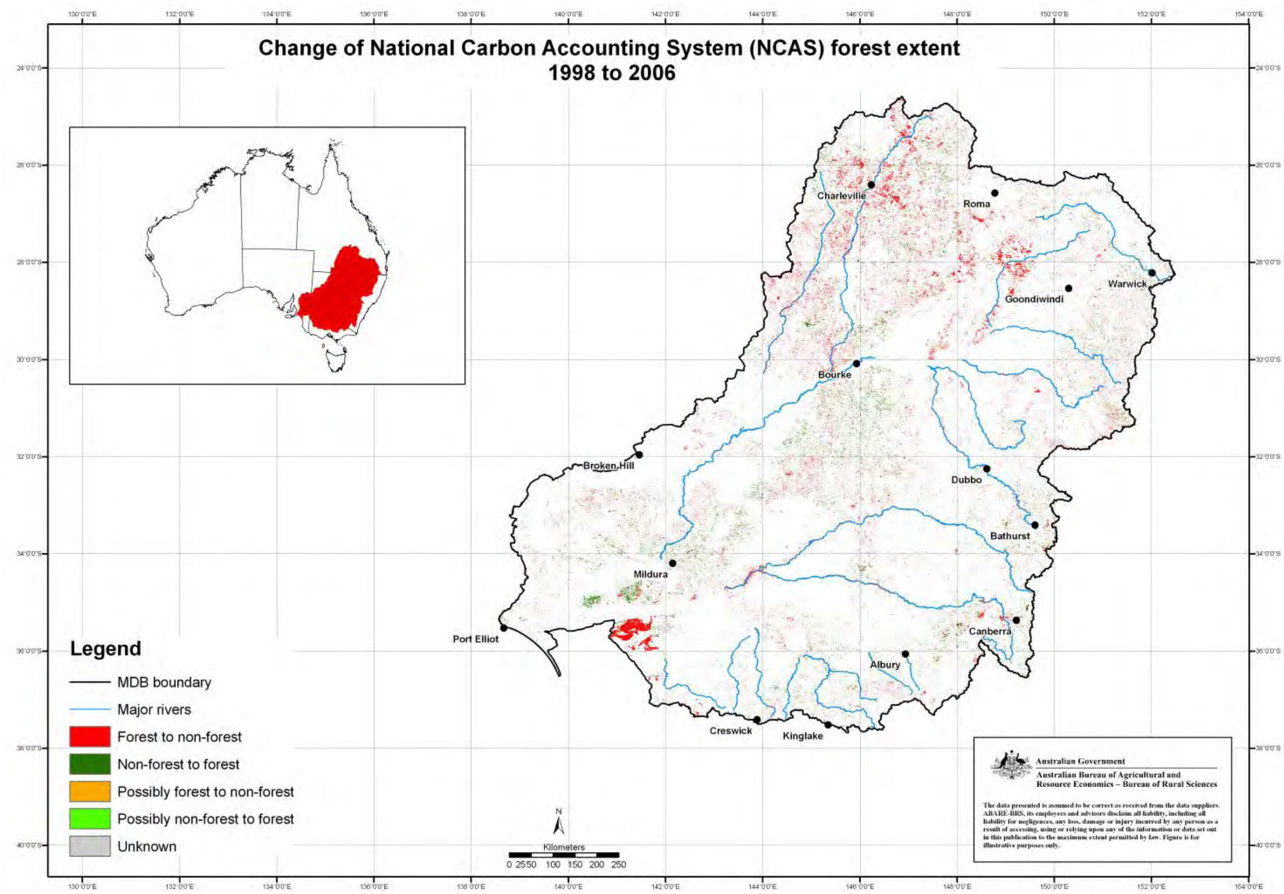


Figure 8.5: Change of NCAS forest extent based on intersecting the NCAS 1998, 2000, 2002, 2004, 2005 and 2006 datasets.

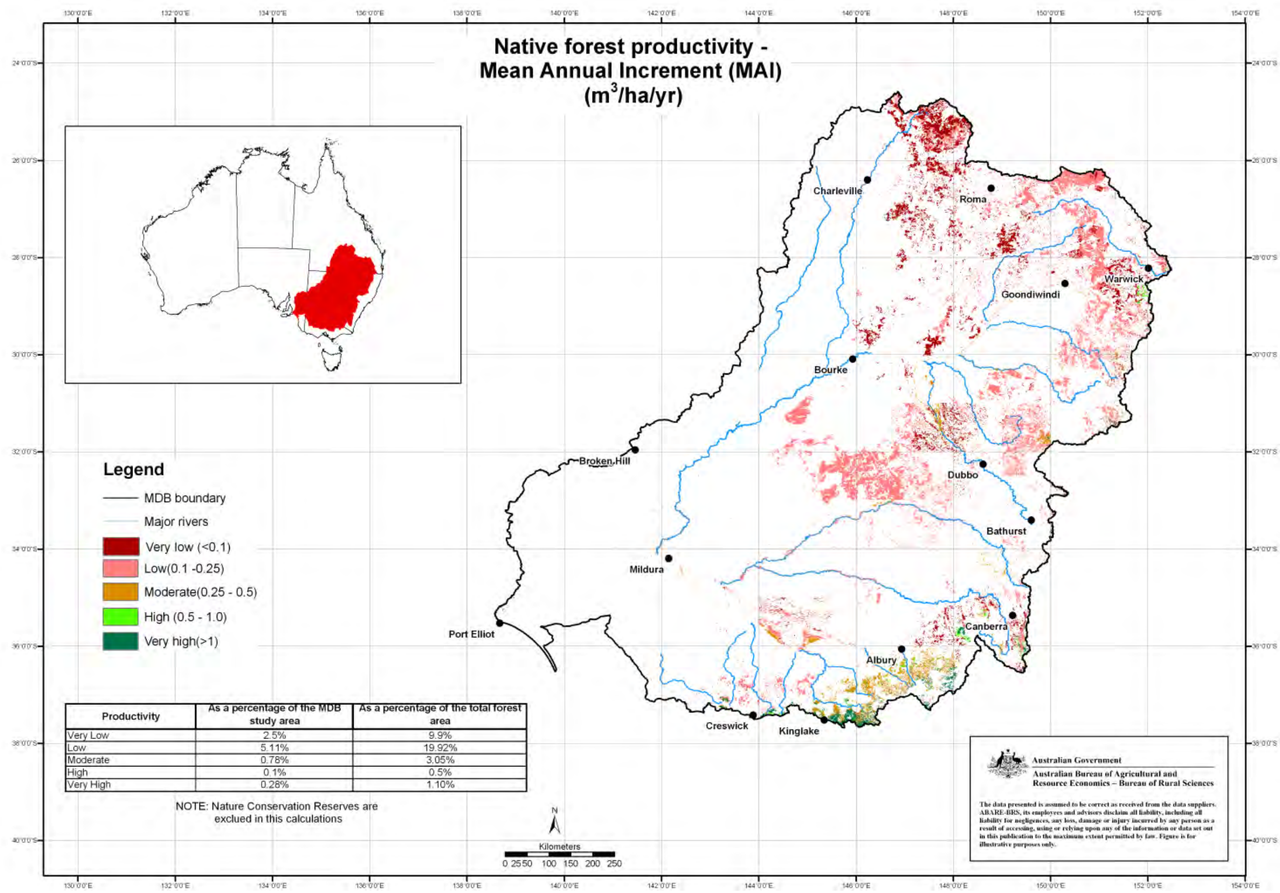
8.3 Native Forest Productivity

Forest productivity is measured as the mean annual increment (MAI) of merchantable timber (sawlog equivalent), which is defined as the average annual increase in wood volume of a forest for a specified period measured from establishment of a forest stand. The growth rates change with different growth phases in a tree's life. Tree growth rates generally decrease with age.

The MAI, as an indication of the productivity of forest area, is influential in timber production management decisions. The MAI provides not only a direct measure of the rate of merchantable timber production across the defined forest area, but also an indirect measure of the biological site productivity for a number of other values.

Forest productivity within the MDB was grouped into five categories (Figure 8.6), ranging from <0.1 m^3/hectare/yr to >1 m^3/hectares/yr. Of the 27.2 million hectares of native forest within the MDB, excluding the nature conservation reserves of 4.2 million hectares, about 30 per cent of forests have low/very low productivity (MAI <0.25 m^3/hectare/yr). About 4.5 per cent of forests are of above moderate productivity with MAI of > 0.25 m^3/hectare/yr. However, productivity of a large proportion (about 65 per cent or 13.5 million hectares) of forests is classed as non-merchantable.

The MAI has been estimated for forests in all catchments of the MDB within five rainfall ranges: up to 300mm, 300 to 500mm, 500 to 700mm, 700 to 900mm and 900 to 1100 mm. These are presented as tables in Appendix 2. Because forests in low rainfall areas are considered not subject to heavy logging regimes due to a low productivity, forests only within the top three rainfall ranges (Figure 8.1) have been used for water yield calculations.



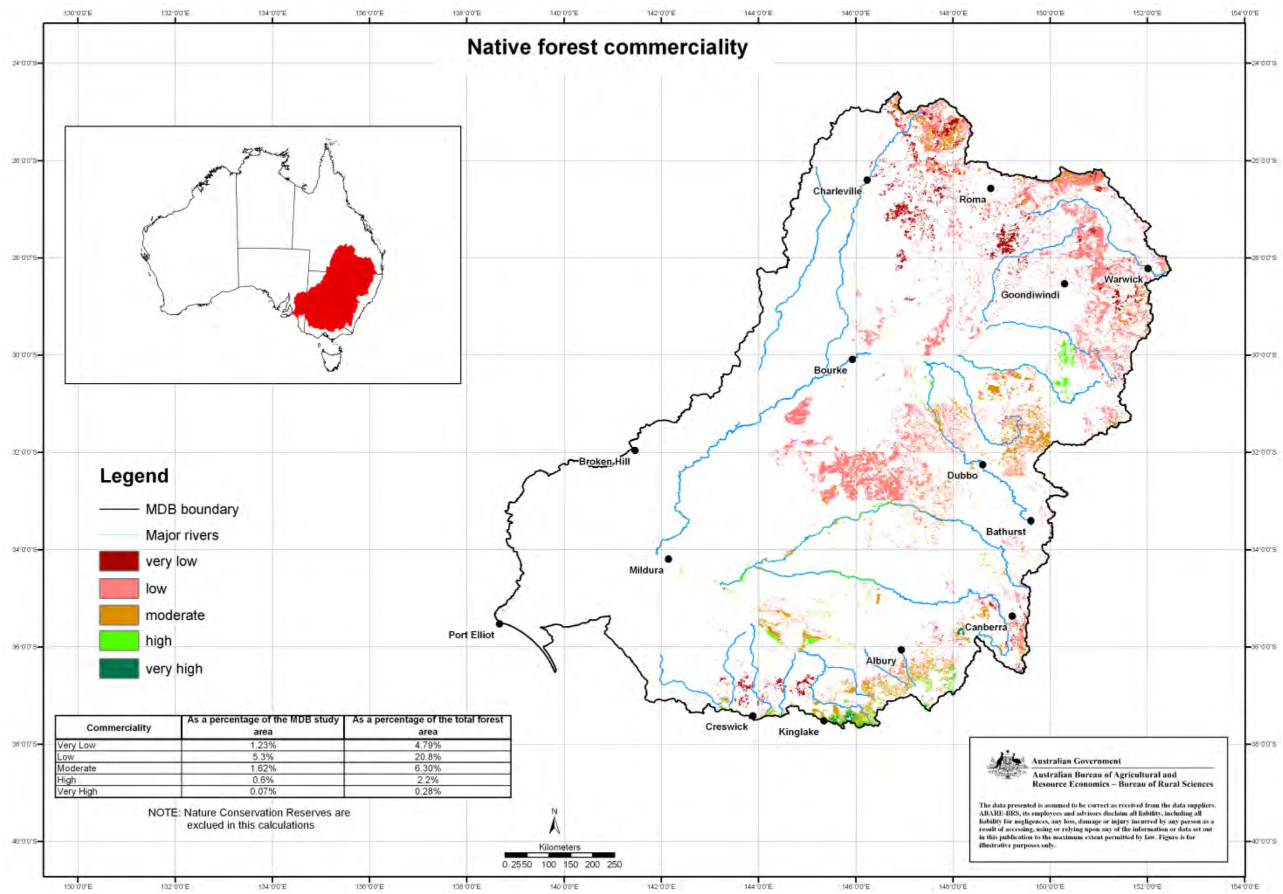
Productivity	As a percentage of the MDB study area	As a percentage of the total forest area
Very Low	2.5%	9.9%
Low	5.11%	19.92%
Moderate	0.78%	3.05%
High	0.1%	0.5%
Very High	0.28%	1.10%

Figure 8.6: Productivity of native forest in the MDB as mean annual increment of merchantable timber (NFI 2010).

8.4 Native Forest Commerciality

Forests have been classified into non-commercial and five commerciality classes (very low to very high). These commerciality classes are based on the proportion of commercial species found in the stand, the stand's productivity (MAI) and the stand's structure (i.e. height and crown cover). Stands with very low to low commerciality contain commercial tree species that produce small volumes of merchantable timber, while stands with high to very high commerciality are comprised of species with high commercial value and produce high volumes of merchantable timber.

Less than one million hectares of forest within the MDB has high to very high commercial value. Similar to productivity estimates, about 30 per cent of the forest has low to very low commerciality value (Figure 8.7). Again, commerciality of a large proportion (about 65 per cent or 13.5 million hectare) of forests is deemed to be non-merchantable.



Commerciality	As a percentage of the MDB study area	As a percentage of the total forest area
Very Low	1.23%	4.79%
Low	5.3%	20.8%
Moderate	1.62%	6.30%
High	0.6%	2.2%
Very High	0.07%	0.28%

Figure 8.7: Commercial value of native forest within the MDB (NFI, 2010).

8.5 Plantation forests in the Murray Darling Basin

The plantation estate within MDB increased from 251,843 hectares in 1997 to 280,945 hectares in 2005. The majority of this expansion occurred in New South Wales (22,135 hectares) and Victoria (13,400 hectares), and were predominantly softwood plantations (Figure 8.8). All of this expansion occurred on previously cleared land with the exception of 282 hectares, where the previous land use was unknown.

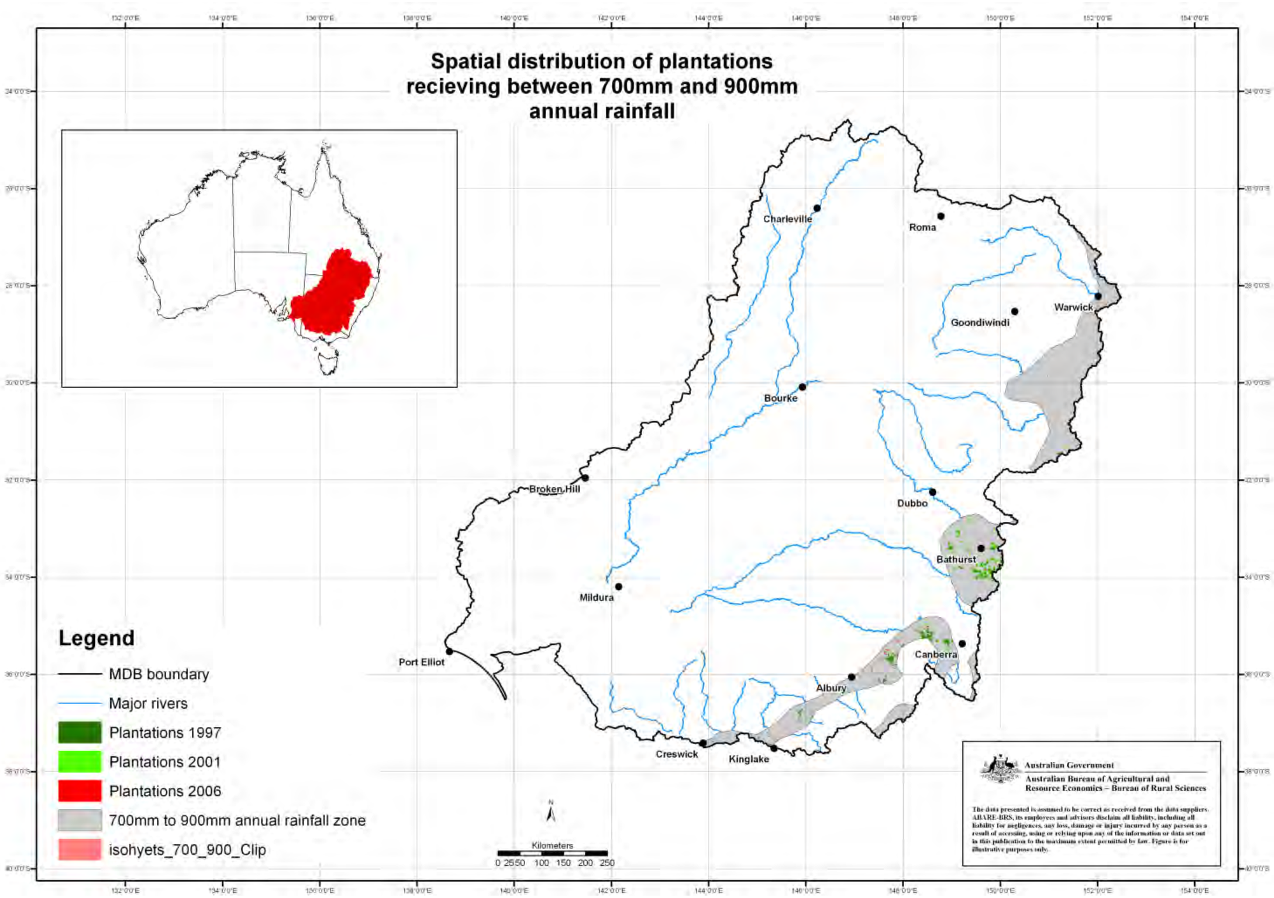


Figure 8.8: Spatial distribution of plantations within MDB during 1997-2006 (Source: National Plantation Inventory 1997 and 2005).

8.6 References to Data Sets Used in this Compilation

Specific data sets used in the compilation of this report include the following:

National Forest Inventory (2008): *Tenure of Australia's Forests*, Bureau of Rural Sciences, Canberra.

National Forest Inventory (2010): Potential Productivity of Australia's Native Forests, Bureau of Rural Sciences, Canberra. Not published.

Indigenous Land Corporation (2008): Indigenous owned and managed lands, ILC, Adelaide.

Australian National University (1999):, Version 5 Mean Annual Rainfall. ANU, Canberra.

Geosciences Australia (1997): Australian River Basins, based on GEODATA 250K. GA, Canberra.

Department of Environment, Water, Heritage and the Arts (2006): Collaborative Australian Protected Areas Database, DEWHA, Canberra.

Department of Climate Change (1998-2006): National Carbon Accounting System, DCC, Canberra.

National Forest Inventory (1997): *National Plantation Inventory of Australia,* Bureau of Resource Sciences, Canberra

Woods M.S (2001):. Plantations of Australia 2001. National Forest Inventory, Bureau of Rural Sciences, Canberra.

Parsons M (2006): Plantations of Australia 2006. National Plantation Inventory, Bureau of Rural Sciences, Canberra.

Chapter 9:

Estimation of the Water Losses Attributable to Native Forest Management in the Murray Darling Basin

Fire-killed mountain ash forest, Upper Goulburn River

9.1 Introduction

This Chapter uses the sequence of logic from Chapters 1 to 7 to produce estimates of the water lost from the Murray Darling Basin due to native forest management. This "loss" is the best estimate (albeit a very qualified one) of the difference between the yield from the managed forest and a possible alternative (but very hypothetical) "old growth" forest of relatively low transpirational capacity. These estimates are qualified by considerations of error, the rate at which the forest water yield can "move" to that new state, the value of wood products, and the considerable difficulty of growing a forest on to "old growth" in an environment that appears to be subject to catastrophic periodic fires.

In Chapter 8 the areas of forest and managed forest within the Murray Darling Basin are enumerated. These values provided the statistical basis for computations involving forest areas reported in this Chapter. In turn, these are then used to scale up the estimates reported in Chapter 7.

9.2 Scaling Issues

The forests of the Murray-Darling Basin cover a large area and subject to numerous influences.

1: Large areas of forest within the MDBA area are in relatively low rainfall areas. The low productivity of these forests means that they are not subject to heavy logging. Further, there is no evidence of an age-related water yield decline in these forests. These forests can be excluded from considerations of change induced by native forest management.

2: Large areas of forest land within the Murray-Darling Basin are not subject to intensive forest management. This land is in some form of park, reserve, or private forest.

3: Other than the mountain ash forests and arguably the higher rainfall mixed species forest, there is no evidence of an age-related water yield affect. For many forests, cutting means an increase in water yield rather than a decrease.

Typically, studies such as this scale up some estimate of streamflow loss (in mm) by multiplying by the area of land. For example, if some forest treatment gains or loses 100 mm of water, and this occurs over 10 km^2, then the volume of water is 1 gigalitre. By extrapolating to large areas, impressive volumes of water are cited. The difficulty with all of this is that although the arithmetic is (hopefully) valid, it is actually quite difficult to "realise" this water in a commercial sense. A number of factors come into play. Firstly, most of the change of flow is associated with the period of highest flows when water is classically least valuable (see Bren, Lane, and Hepworth (2010) or Langford (1974) for examples of this). Secondly, other stream processes may mitigate any increase in flow by using the additional water. Thirdly, any change is, by definition, distributed over a wide area which makes the physical task of collection difficult. Thus, although the arithmetic is valid, a gigalitre obtained by changing transpiration by 100 mm over 10 km^2 does not have the same utility as a gigalitre sitting in a reservoir.

An interesting and recent perspective of the issue of gathering additional water yielded by land use change over large areas of catchment is given by Rodriguez, Tomasella, and Linhares (2010). The work was done in the Amazon-Parana catchment in which large scale clearing for dairy development has occurred. Their work looked at whether streamflow increases from clearing for pasture were detectable in larger rivers. They found that the flows were easily detected in the smaller streams (catchment areas <30,000 km^2!), but detection "proved to be difficult at larger scales, suggesting the existence of non-linear effects, which aggregate across scale, compensating small scale effects." Thus, although the water may be released by land use change, it may not be easily collectable.

9.3 Buffer Strips

Bren (1995) examined the geometric properties of buffer strips of varying widths. This included the area of land not logged within logging areas as a function of the width of the buffer. The work was centred around the Tarago catchment of Central Gippsland. This is a high rainfall area carrying mixed species and mountain ash forest and could be viewed as reasonably representative of the type of forest considered in this report. The work found a relationship:

$$y = -0.489 + 0.650\ w - 0.001\ w^2 \qquad (9.1)$$

where y is the percentage of the forest enclosed in the stream buffer strip and w is stream buffer width in metres. For a buffer strip width of 20 m, as found in the Victorian Code of Forest Practice for Timber Production, this means that 12 per cent of the land is enclosed in buffers, or

88 per cent of the land is used in wood production. A buffer factor of 0.88 has been used in the computations below.

9.4 Methodology of Estimation

Chapter 7 contains:

(1) estimates of the absolute difference between old growth and a “normal” 1 km^2 forest as a function of annual rainfall;

(2) estimates of the change in yield as a function of years since the cessation of logging compared with old growth as a function of rainfall.

Tables 9.1 to 9.3 incorporates the data from Chapter 8 to give a tabulation of the areas of forest in three rainfall classes - <700 mm, 700 to 900 mm, and >900 mm. Units used were $km.^2$ The estimates are of forests that carry merchantable volumes. Forests that are not merchantable for the purposes of harvesting are not considered in the analysis.

The methodology consists of multiplying the estimates produced in Chapter 7 by the areas given in Tables 9.1 to 9.3 which, in turn, were derived from the analyses reported in Chapter 8. As such the estimates are basically scaled up or weighted variants of the estimates contained in Chapter 7. The values are then aggregated to produce a final volume.

In providing these estimates the following assumptions were made:

1: In all areas only areas of “medium productivity” and greater have been included. It is unlikely that low productivity areas would be managed for anything but occasional cutting.

2: In areas of less than 700 mm rainfall there is no long-term age-related reduction in streamflow associated with logging. In such environments logging would be expected to increase flows by decreasing transpiration.

3: In areas of 700-900 mm the “mixed species” model was used since the rainfall in these areas is too low to sustain anything but small pockets of mountain ash. Mean rainfall applied in the models was 800 mm.

4: In areas of greater than 900 mm rainfall it was assumed that 50 per cent of the forest is ash and 50 per cent is mixed species. The mean rainfall for these areas was taken as 1,050 mm. Available rainfall maps for the area are not detailed but study of these suggests that this would be close to the rainfall “centroid” for this zone.

5: It is assumed that forests are managed under the “Codes of Forest Practice” extant in Victoria and NSW, and that buffers of 20 metres are used. As discussed in Section 9.3, this equates to a scaling factor of 0.88 for the “effective area of land” involved in forest management.

9.5 Results

Tables 9.1, 9.2 and 9.3 provide a summary of the areas of land involved in each of the major catchments in which forest management may be viewed as possibly having an impact on flows into the Murray-Darling Basin. Table 9.4 contains an aggregation of these by annual rainfall and areas of forest management.

Table 9.5 contains an estimate of the maximum increase in flows attainable in the three catchments selected if logging were to cease and forest areas grew through to old growth. It is reiterated that this is probably unattainable in the sense that the time spans to achieve this are long and the possibilities of growing the regrowth forest to old-growth are low given the fire experience of the past decade.

Table 9.1: Summary of Native Production Forests in the Upper Goulburn Catchment. Forests in reserves are excluded.

Catchment	Cover	Tenure type	Rainfall	MPAI	Area (ha)
Goulburn-Broken	Forest	Leasehold	700 - 900 mm	Very High	100
				Moderate	3,100
				Low	100
			> 900 mm	Very High	300
				Moderate	1,500
				Low	300
		Multiple Use Forest	< 700 mm	Moderate	21,400
				Low	1,300
				Very Low	19,800
			700 - 900 mm	Very High	8,500
				High	2,400
				Moderate	41,600
				Low	1,900
			> 900 mm	Very High	121,800
				High	5,000
				Moderate	87,100
				Low	9,700
				Very Low	1,500
		Unknown/No Data	< 700 mm	Low	600
			700 - 900 mm	Moderate	100
			> 900 mm	Moderate	100
		Other Crown Land	< 700 mm	Low	400
				Very Low	13,600
			700 - 900 mm	Very High	100
				Moderate	900
			> 900 mm	Very High	2,600
				High	100
				Moderate	1,000
				Low	300
		Private Freehold	< 700 mm	Very High	1,200
				High	700
				Moderate	5,500
				Low	6,400
				Very Low	9,100
			700 - 900 mm	Very High	5,900
				High	7,400
				Moderate	31,400
				Low	2,600
				Very Low	400
			> 900 mm	Very High	4,100
				High	3,300
				Moderate	11,700
				Low	1,300
				Very Low	300

Table 9.2: Summary of Native Production Forest in the Ovens-Kiewa Catchment. Forests in reserves are excluded.

Catchment	Cover	Tenure type	Rainfall	MPAI	Area (ha)
Ovens-Kiewa	Forest	Leasehold	700 - 900 mm	Moderate	100
			> 900 mm	Very High	100
				High	400
				Moderate	1,300
				Low	100
		Multiple Use Forest	< 700 mm	Moderate	800
				Low	200
			700 - 900 mm	High	1,400
				Moderate	10,300
				Low	200
			> 900 mm	Very High	11,600
				High	9,700
				Moderate	102,300
				Low	6,700
		Unknown/No Data	< 700 mm	Low	100
			700 - 900 mm	Moderate	100
				Low	100
				Very Low	100
			> 900 mm	Moderate	100
		Other Crown Land	700 - 900 mm	Moderate	200
			> 900 mm	Very High	100
				High	100
				Moderate	600
		Private Freehold	< 700 mm	Moderate	1,100
				Low	3,300
				Very Low	600
			700 - 900 mm	High	1,000
				Moderate	11,700
				Low	3,800
				Very Low	700
			> 900 mm	High	3,000
				Moderate	18,800
				Low	1,800

Table 9.3: Summary of Native Production Forest in the Upper Murray Catchment. Forests in reserves are excluded.

Catchment	Cover	Tenure type	Rainfall	MPAI	Area (ha)
Upper Murray River	Forest	Leasehold	700 - 900 mm	Moderate	500
				Very Low	400
			> 900 mm	High	100
				Moderate	600
				Very Low	2,800
		Multiple Use Forest	700 - 900 mm	Very High	30,800
				High	700
				Moderate	9,700
				Low	3,500
				Very Low	6,200
			> 900 mm	Very High	40,000
				High	12,900
				Moderate	90,800
				Low	12,400
				Very Low	3,400
		Unknown/No Data	700 - 900 mm	Moderate	400
				Very Low	400
			> 900 mm	High	100
				Very Low	100
		Other Crown Land	700 - 900 mm	Very High	1,000
				Moderate	400
				Very Low	1,300
			> 900 mm	Very High	1,600
				High	500
				Moderate	1,800
				Low	300
				Very Low	1,100
		Private Freehold	< 700 mm	Low	600
			700 - 900 mm	Very High	1,100
				High	1,400
				Moderate	10,300
				Low	3,200
				Very Low	22,800
			> 900 mm	Very High	500
				High	6,600
				Moderate	14,100
				Low	3,500
				Very Low	13,800

Table 9.4: Summary of Managed Forest Areas (Km^2) in the three major catchments. This includes forests in the medium to very high productivity classes.

Rainfall	<700 mm	700-900 mm	>900 mm	Total
Goulburn/Broken	214	525	2 139	2 878
Ovens/Kiewa	8	117	1 236	1 361
Upper Murray	0	412	1 437	1 849
Total	222	1 054	4 812	6088
Grand Total			6 088	
Other Forest Categories (Reserves private forest etc.)			7 709	
Total Native Forest			13 797 km^2	

Table 9.5: Maximum increase in annual long-term flows (GL) relative to old-growth if logging was to cease and regrowth areas allowed to grow on to old-growth in over 100 years. This includes an allowance for buffer zones within logging areas.

Rainfall	700-900 mm	>900 mm	Total
Goulburn/Broken	22.4	212.4	234.8
Ovens Kiewa	5.0	122.7	127.7
Upper Murray	17.6	142.7	160.3
Total	45.0	477.8	522.8

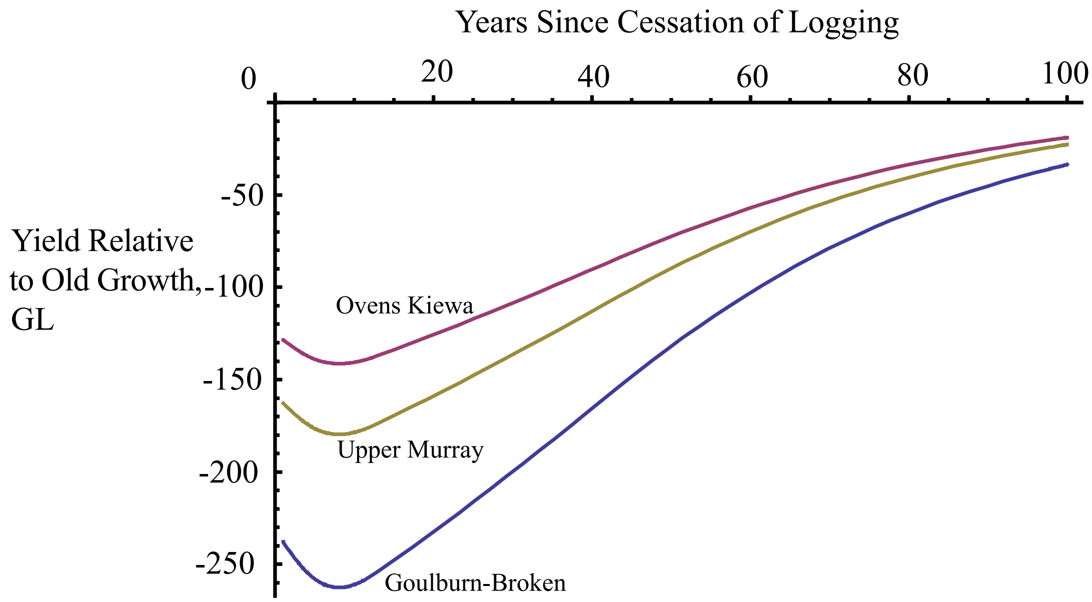


Figure 9.1: Estimated recovery of each of the major catchments if logging was to cease. The volumes shown are the difference in annual yield in Gigalitres per annum between the logged catchments and the yield if the catchment was old-growth.

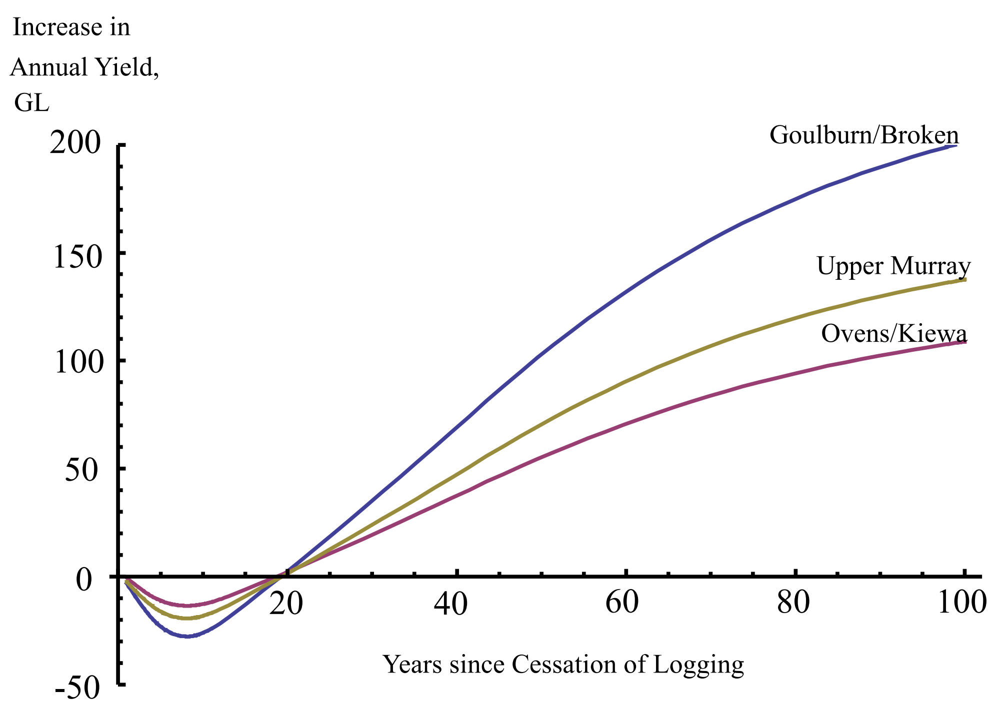


Figure 9.2: Increase in catchment yield (GL per annum) if logging was to cease as a function of years since the cessation of logging.

Table 9.6: Increase in flow in each of the major catchments if logging was to cease and forest was able to grow on to old-growth. This is the information presented in Figure 9.2.

Years since Cessation of Harvesting	Goulburn Broken GL	Ovens Kiewa GL	Upper Murray GL
1	0	0	0
5	-19.8	-10.5	-13.5
10	-22.7	-12.1	-15.5
15	-9.9	-5.4	-6.7
20	5.4	2.7	3.8
25	21.2	11.1	14.61
30	37.4	19.8	25.7
35	54.0	28.7	37.1
40	70.9	37.7	48.7
45	88.0	46.9	60.4
50	104.1	55.4	71.5
55	119.0	63.4	81.7
60	132.6	70.8	91.0
65	145.2	77.6	99.6
70	156.5	83.8	107.2
75	166.5	89.3	114.1
80	175.5	94.2	120.0
85	183.0	98.5	125.2
90	189.9	102.3	129.9
95	195.9	105.7	134.0
100	201.3	108.8	137.7

9.6 Some Comments on These Computations

The estimates presented above are based on the use of the BISY models applied to a rather simple model of forest management which is, in turn, based on statistics of the managed forest area. The BISY model was, in turn, selected as the "best fit" of available data, although reservations were expressed at the paucity of the data on which it was based. The upshot of this is that although the process of modeling is objective and reasonable, the uncertainty associated with the estimates is also large.

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Related to this is the question of whether logging has led to a diminution of water resources in recent years compared with, say, two or three decades ago? This would need to be the subject of a larger study to be definitive. However, the work of historian Peter Evans (Personal Communication and reference to the draft of Mr Evan's new book "Wooden Rails and Green Gold; the story of a century of sawmilling and timber transport along the Yarra Track between Healesville and Woods Point" has clearly shown that intense logging in the Goulburn catchments has occurred from 1900 onwards. The 1939 "Black Friday" fires burnt many sawmills in the Upper Goulburn catchments alone (see the account of the Royal Commission into the 1939 bushfires for an enumeration of these and the presented witness evidence for an account of the logging practices at the time). This statement would apply but with less force to the Upper Ovens and Upper Murray catchments. Hence it is a reasonable assumption that the modern water resource industry has effectively evolved with a logging "signal" embedded in the water outflows. Thus it is unlikely that modern logging is reducing yield relative to, say, three, four, or five decades ago.

The results show that the area with the greatest potential for gain is the Goulburn/Broken catchment. This is the focus of the ACF critique in Volume 2 of this report, and suggestions for further modeling are made in this volume.

Chapter 10

Incorporation of Aspects of Climate Change into the Long Term Impacts of Forest Harvesting

Streamflow measuring weir recording long term changes associated with the combined impacts of fires, plantation, and drought, Croppers Creek, Victoria

10.1 Results in Terms of "Climate Change"

The brief for this task makes considerable reference to "climate change" and, during the preparation of this report there was much discussion about how this might be tackled. In particular this defined two particular aspects:

1: The possibility of changes (both increases and decreases) in average rainfalls experienced, and

2: The possibilities of changed fire risks. The usual consensus was that this would be increased propensity of wild fires. This generally appears to reflect the presence of catastrophic fires in 2003, 2006, and 2009.

However the "firming up" of such estimates by MDBA staff and their consultants proved both frustrating and difficult – reflecting the complexity of the task when applied to large areas of complex terrain. In particular the initial expectation was that new rainfall isohyets for areas in the Murray-Darling Basin would be able to be computed. However, because of uncertainties in the modelling this proved not to be possible

McVicar *et al*. (2010) examined the water use side associated with climate change. They concluded that "A key challenge confronting researchers working at the interface of plant physiology and catchment hydrology is how to "up-scale" known plant physiological processes (such as changes in leaf level water use efficiency) to the catchment level, considering other vegetation changes occurring in the catchment and that catchments are located in a wide-range of thermodynamic conditions (i.e., where annual precipitation > annual potential evaporation and vice versa). This makes developing bottom-up generalisations difficult."

It was thus concluded that a formal modelling approach based on "first principles of climate" was not feasible for this project. A more robust approach was decided upon based on a comment by Ms Rae Moran (Department of Sustainability and Environment, Victoria, Personal Comment 2010). Ms Moran noted that, for the last 13 years, the climate had been rather similar to the upper levels of those predicted under various models of climate change trialled in her work with that department. In particular, the report of Jones and Durack (2005) examined this. The report noted that their "best estimate" was increasing dryness, with up to 35 per cent reduction in average runoff by 2030 and up to 50 per cent by 2050. Their report noted many difficulties in providing their best estimate. Similar difficulties were faced by Feikema *et al*. (2006) in examining impacts of climate change on the water supply to Melbourne and by Lane *et al*.

(2010) in estimating long term impacts of fires and other disturbances on streamflow yields from forested catchments.

Based on the above, it was decided as follows:

1: To view the period from 1997 to 2009 (calendar years) as representative of "climate change" years in which rainfall declines. Average rainfalls in this period were taken as representative of an extreme estimate of what might happen.

2: To view the long-term rainfall over a century or more (including the 1996-2009) calendar year as representative of the long-term average.

3: To use these values to compute percentage change to annual rainfall, and

4: To use the percentage rainfall changes to alter the annual rainfall in the models of Equation 7.5 to derive a new set of functions directly comparable to the "increase in water yields as a function of time" as shown in Figure 9.2.

5: To use these results, in turn, to examine the sensitivity of results to changes (increases or decreases) in rainfall.

10.2 Method

Ultimately the following methodology was adopted:

1: From the Bureau of Meteorology web site, the mean annual rainfall for Victoria from 1900 to 2009 was downloaded. The mean annual rainfall was computed.

2: From this the mean rainfall of the period from 1997 to 2009 (inclusive) was computed.

3: Using the values from (1) and (2) above, the percentage reduction was computed, and

4: This percentage was applied to the 800 mm isohyets and the 1050 mm isohyets.

5: These values were used in the model of Equation 7.5 and the methodology of Section 9.4 to compute new versions of Figure 9.2 showing the results if this percentage reduction in rainfall was achieved.

6: From the above the percentage reduction in streamflow over time was computed. This was then divided by the percentage reduction in rainfall to give a "sensitivity factor" – the percent change in streamflow given by one percent change in rainfall.

Inferences from the results concerning the management of forests were then drawn.

10.3 Results

Figure 10.1 shows the mean Victorian rainfall, as given by the Bureau of Meteorology website. The period of the last 13 years is also shown; it can be seen that this was, indeed, a period of relatively low rainfall. Table 10.1 shows the average rainfalls from 1900 to 2009 and from 1997 to 2009 extracted from this data. If we view those last 13 years as representative of climate change then there is a 13.1 per cent reduction in rainfall associated with the upper level of climate change. This is in accord with the conclusions of Jones and Durack (2005) who examined the likely changes associated with climatic change in north-eastern Victoria.

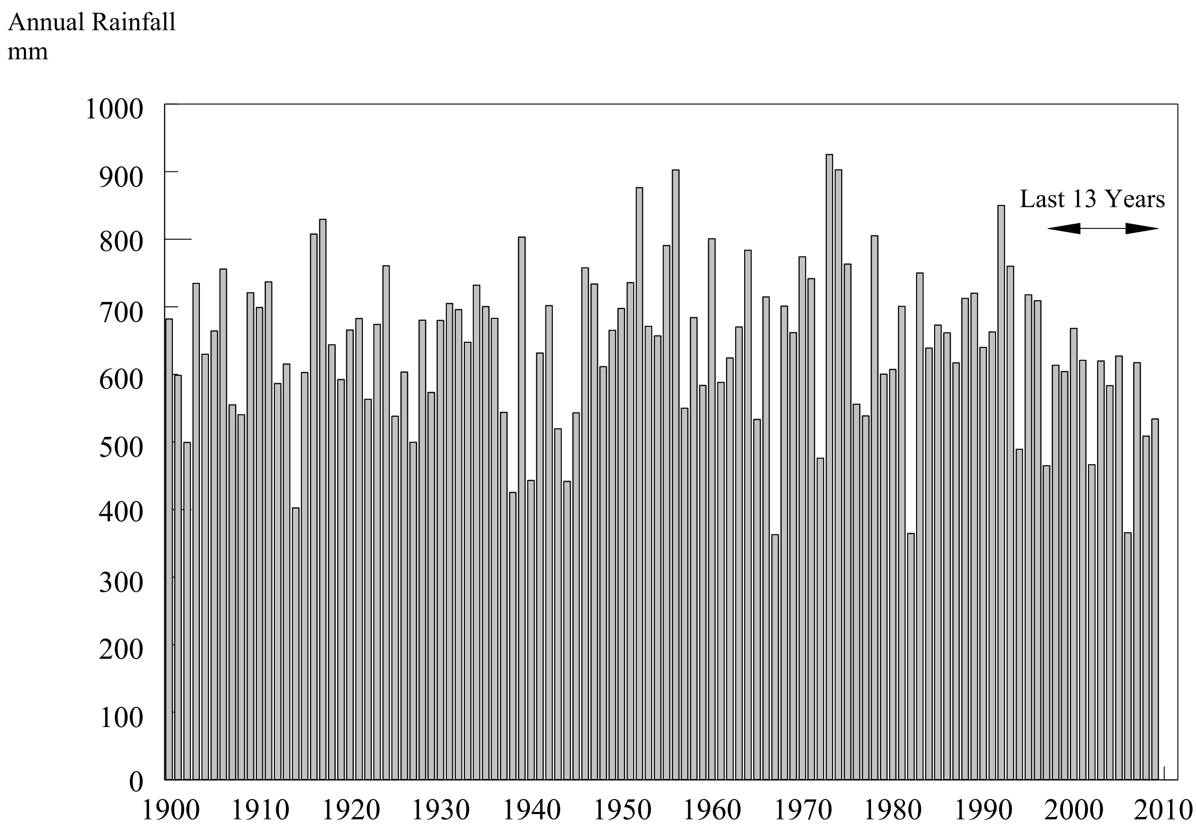

Figure 10.1: Mean Victorian annual rainfall from 1900 to 2009 (Source: Bureau of Meteorology website). The last thirteen years, viewed by some as similar to "Greenhouse impacts", are shown.

Table 10.1: Mean Victorian rainfall from 1900 to 2009 and mean annual rainfall over the last thirteen years.

Period	Average Rainfall mm
1900-2009	645.98
1997-2009	561.0
Per cent Reduction	13.1 per cent

Applying this level of reduction, the 800 mm isohyet becomes a 695 mm isohyet and the 1050 mm isohyet changes to a 913 mm isohyet.

Figure 10.2 shows the "before" and "after" change in water yield associated with a cessation of native forest logging for the three catchments identified as having variations in age-related water yields. It can be seen that the impact of climate change, should it occur, does indeed make a material change in the change in streamflows which may occur as a result of a cessation of logging in the catchments.

Figure 10.3 uses the same model to present the change as the percentage change per unit percentage change in rainfall as a function of years since logging. This is the sensitivity of the streamflow to annual rainfall variations. Using such an approach gives rather erratic behaviour in the first 30 or so years because the base change is small. Hence we have plotted this only from 40 years after the cessation of logging. The results show:

1: For mature forest a 1 per cent change in rainfall usually gives a 2-2.5 per cent change in stream runoff at the rainfalls typically found in Australian forests.

2: For the regrowth forest there is a slightly increased sensitivity. Thus a 1 per cent change in rainfall may yield a 2.5-3 per cent change in runoff. An inference of this is that should such change occur, the logged forest areas would be slightly more sensitive to changes in rainfall. There is some variation between catchments.

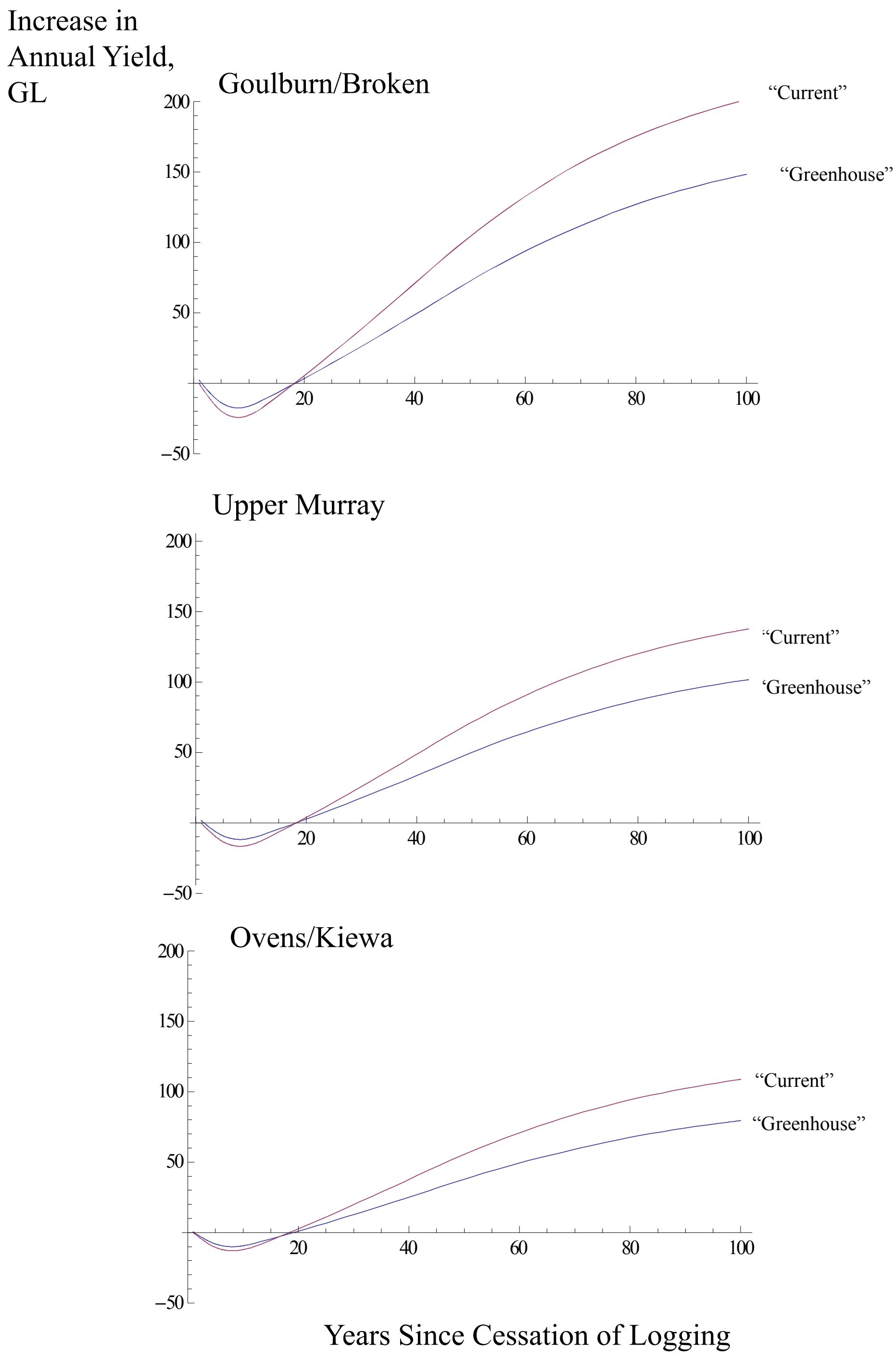

Figure 10.2: Water yield increase as a function of years since cessation of logging for the "current" and "with greenhouse" impacts. The "current" case is also shown in Figure 9.2.

It is hard to be dogmatic as to whether such an enhancement in sensitivity is “good” or “bad.” Firstly, some areas are naturally more sensitive than others. Secondly, if increased flow is “good” then the increased sensitivity yields slightly more rainfall induced flow for a change in rainfall. Thus, should rainfall increase the streamflow yield is greater than that which might otherwise occur. Thirdly, should such a large sustained decrease in rainfall occur across the catchments then the resultant reductions in runoff from all land-use types would lead to major changes in the way water is managed (as did actually happen in this period of low rainfall). Thus the impact of climate change on runoff from managed forest cannot be viewed in isolation from other effects.

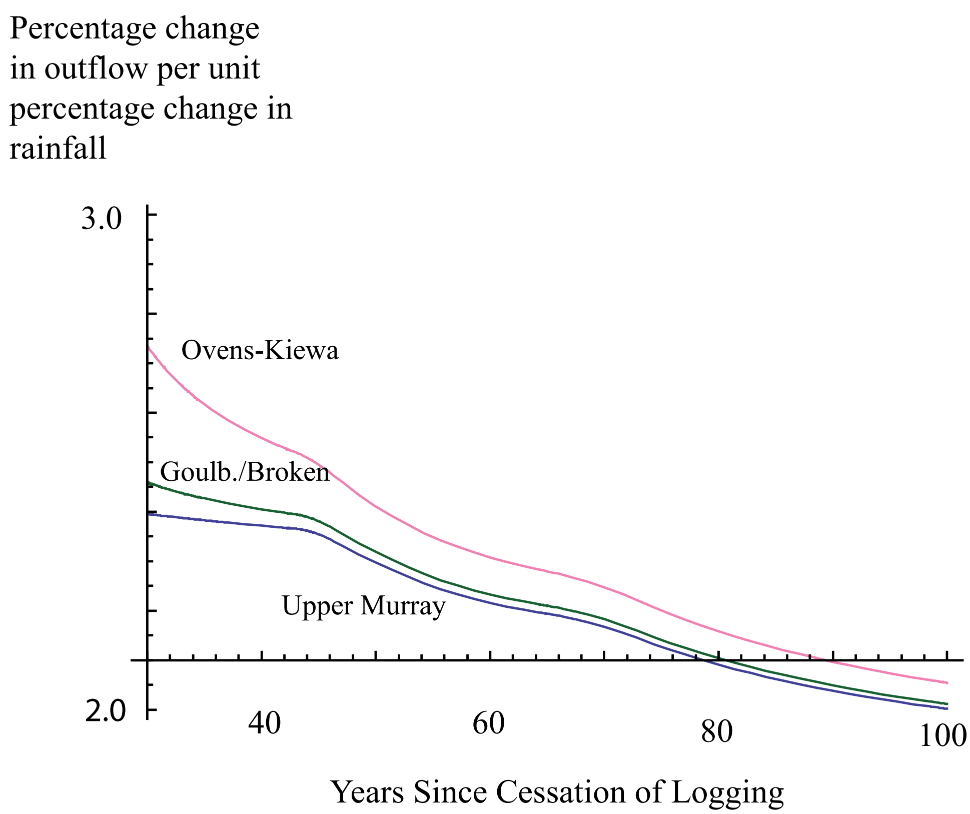

Figure 10.3: Percentage change in outflow per unit percentage change in rainfall as a function of years since logging for the three catchments.

10.4 Impacts of Forest Fires

The other manifestation of climate change may well be a change in the frequency and severity of forest fires. In Victoria it is noteworthy that three “catastrophic” fires have occurred since 2003; before that the last fires of such magnitude or destructiveness were arguably in 1939 and before (although serious fires did occur, they were relatively short-lived). A good review of the topic is that of Hennessy *et al.* (2005). This examines the climate change impacts on fire-weather in south-east Australia. Their report found that combined frequencies of days with very high and extreme forest fire danger index are likely to increase 4-25 per cent by 2020 and 15-70 per cent by 2050. The study also indicated that the window available for prescribed burning may shift and narrow, with times suitable for prescribed burning moving to the winter period. However the report also noted the large number of uncertainties in such an analysis.

A similar theme was tackled in the later work of Lucas, Hennessy, Mills, and Bathols (2007). This examined the occurrence of “bushfire weather” in south-eastern Australia and the projected impact of climate change. The work was presented as an update of the 2005 study cited above, but used a wider range of observations and additional sites. In addition, the (grim) experience of the 2006-2007 fire season was included, as were the international projections from the Integovernmental Panel on Climate Change. Some changes in the analytical methods were also made. Their results found the number of “very high” fire danger days will increase by 5-65 per cent by 2020 and 10-300 per cent. “Very extreme” days will become more common. Their predictions are fairly much in accord with the assumptions made in this chapter concerning the last 13 years.

The occurrence of major fires in 2009 has led to an increased emphasis on fuel-reduction burning. Whether this achieves forest protection is yet to be seen. Increased fuel-reduction burning in Victorian forests has large implications regarding carbon-dioxide emissions, although again it is hard to be dogmatic about it because of the complexity of factors. It remains to be seen whether “growing” forests on to old-growth in an environment subject to catastrophic and devastating fires is a feasible strategy. The accompanying report examining the ACF/Practical Ecology (2009) report has made various recommendations for a fuller analysis. The impact of forest fires and possible enhancement due to greenhouse change should be included in such an analysis; the suggested methodology has two facets. The approaches are:

(i) Incorporation of increased costs of fire protection in any economic analysis. This translates itself into increased fuel reduction burning costs (including overheads of equipment and crews), greater roading, and greater monitoring costs, and

(ii) Incorporation of higher probabilities in Monte Carlo and other analyses so that the full cost of the changed burning is incorporated in any modelling undertaken.

General Comments on the Difficulties of Climate Change Incorporation

In most modelling or "scientific investigations" the assumption is that one variable may change but other variables remain constant. Thus, for instance, in the above discussion there is an implicit assumption that although the rainfall may change, leading to runoff changes, the rest of the environment (social, physical, and economic) remains unchanged. However this is doubtful when it comes to climate change. Thus, in forestry, in the long term such climate change may lead to replacement of mountain ash by lower productivity species, such that forestry would not be as economic a land use. Similarly the productivity of agricultural land may be so reduced that towns could no longer survive as we have known them....in short, all assumptions as to the environment and society as we know it may need modification. For this reason, the results presented above are hedged with qualifications and caveats. It has not been the purpose of these studies to attempt to include such broad-scale effects.

10.5 Conclusions

The analysis of greenhouse impacts was found to be difficult because of the complexity of factors involved. However a Victorian analysis gave some indications of greenhouse change in North-eastern Victoria. In particular the last thirteen years in Victoria were viewed as similar to the upper levels of "climate change." Using this, estimates were made of the reduction in rainfall that might be expected and the impact on results should logging cease. The results showed a sensitivity to this assumption. In general a 1 per cent change in rainfall gave a 2-3 per cent change in the streamflow, with the sensitivity being greater in forests dominated by regrowth. The results also indicated a substantial increase in fire frequency and severity. Any findings about the impact of greenhouse change is always qualified by the complexity of the issue and this report is no exception. Substantial reduction in rainfall associated with climate change would reduce the increases in streamflow associated with logging reductions. However, at the same time, many other factors would come into play

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Chapter 11:

Conclusions and Recommendations

Streamflow measurement, Betsy Creek in the Ovens River headwaters

11.1 Conclusions

This study has examined the evidential basis of water yield change as a consequence of silvicultural management of native forest species in southern Australia. The results of this are applied to determine, as far as possible, the water use consequences of native forest management in the Murray-Darling Basin. In particular, our focus has been with the water yield of such forests and the long-term changes in this.

The report relies on a number of “paired catchment” studies of water yield carried out from 1968 to the present. With perhaps the exception of those carried out by Melbourne Water and its predecessor organisations, these have not been carried through to fruition. The result is a very incomplete knowledge base, and this particularly leads to large estimates of uncertainty in any such conclusion. As a consequence, a more comprehensive knowledge base must be established in relation to the hydrology of forests.

In this study, the published models of age-related water use variations for Australian native forest types were compared with published results from paired catchment experiments using the Nash-Sutcliffe “Coefficient of Efficiency” as a criterion for selection. The most efficient model of water use change relative to old-growth forest was that of the Victorian “BISY” study, with variants for ash species and mixed species forest. This generally reproduced aspects of most data tested.

The examination of the paired catchment data showed that mountain ash (*Eucalyptus regnans*) generally appears to show an age-related water consumption variation. The question of whether this is shown by other Australian species appears ambiguous. Certainly there is no clear evidence that the “mixed species” forest type in Australia shows such a change. However the model that gave the best fit to data does include such a variation and, hence, was selected. Some recommendations concerning clarification of this and other points on such matters are made below.

A categorisation of the forest types in the Murray-Darling Basin showed that in general the forests had low increments and that most management of most areas of forest would be expected to have little or no impact on flow into the River Murray. The forest areas were categorized by catchments. Three catchments had large areas of forest with probable water yield impacts; these were the Goulburn-Broken catchment and the Ovens-Kiewa catchments in Victoria and the Upper Murray catchment in Victoria/NSW. These all have large areas of forest with commercial forest management and a high rainfall. These areas also have ash-type eucalypts in the higher rainfall zones.

The forest data in this area was categorised into areas receiving less than 700 mm annual rainfall, 700-900 mm annual rainfall, and greater than 900 mm annual rainfall. This categorisation used isohyets derived from past rainfall measurement. Based on the results of paired catchment data and the models, the areas receiving less than 700 mm were viewed as having little potential to exhibit changes in streamflow yield due to forest management.

Two variants of the BISY model (ash and mixed species) were applied to the forest data for the Basin. Maximum difference in annual yield between the managed forest and the same areas of forest as “old growth” were computed. A second set of computations computed the transition assuming that logging stopped and forest was allowed to age until it became old-growth. The latter computations showed an initial yield decline because of the cessation of logging-induced increases in streamflow. After a decade the streamflows increased continually over time.

A number of qualifications are made to this statement. Firstly we believe that the model selected – although giving the highest coefficient of efficiency of the various models tested – probably overestimates the water use of regrowth relative to old-growth. This would, in turn, lead to an overestimate of flow enhancement if logging ceased. Secondly, although logging may induce a water yield change, the area of forest is probably small compared to that influenced by wild-fires. Hence any statement concerning logging is probably eclipsed by catastrophic impacts on larger areas due to wildfires (this however is not a part of this report). Thirdly, water can be viewed as a “joint production” component in the production of wood (and any other plant-based crop). Hence the use of water for growing wood may be an entirely economic use for the water. It is noted that the modern water resource industry has evolved with logging (and fire) present in these catchments so the presence of a “regrowth factor” in the inflow to major dams is not new.

On the basis of the study a number of recommendations are made. These generally are along the lines of doing additional work to bring studies to fruition and to initiate new studies. A pervading theme in these recommendations is our disappointment that work that was initiated two and three decades ago was not adequately completed for publication. There is a hope that this unfortunate position can be remedied to some extent. These recommendations are particularly tempered by the fact that a logging reduction would, at least in the short term, reduce inflows to the dams. It is argued that a useful approach would be to have a plan of resolution of issues over one to two decades, and this is discussed in the recommendations below.

Risk and Future Directions

The work was undertaken under the "Risk Assessment Program" of the Murray-Darling Basin Authority. Given the long-standing involvement of forest harvesting in catchments across the Murray-Darling and the evolution of water resource development in an environment in which logging has been present, we have concluded that the impact of forest harvesting cannot be viewed as a "risk" to the water resources of the Murray-Darling Basin. The conclusion is that impacts of forest harvesting are already embedded in "inflow signals" into the dams of the Murray-Darling Basin and that water management has "evolved" with this form of land management.

The brief asks that the contractor "outlines the management implications/opportunities that could arise from the work. There are two such implications. The first is that by removing forest harvesting as a land-use and giving adequate fire protection, there may be able to be generated a net increase in streamflow from the higher rainfall areas of the Murray-Darling Basin. Whether this would meet economic criteria or criteria of community sustainability is beyond the scope of this report. The question of whether adequate fire protection can be given to allow regrowth to grow into old growth is a question requiring further study.

The second management implication is the existence of large areas of regrowth across these catchments resulting from the 2003, 2006, and 2009 fires. These occur in all land-ownership classifications. Again the relative magnitude of these in area is beyond the scope of this report, we believe that the magnitude of the reduction in flow will be substantial because of the large areas involved. Further, the impact will be relatively synchronous compared to logging, reflecting the widespread occurrence of regeneration in a small time span (2003-2010). The question of future management of these forests and their water use will be an important question.

11.2 Recommendations

1: Overhaul Past Paired Catchment Studies

An effort should be made to "salvage" past paired catchment studies into catchment hydrology if possible, to collate information, to apply uniform analytic techniques and analytic standards, consolidate information, and to systematically develop water yield-forest age curves that reflect the data. This could be done relatively fast – say over a three year time frame. This could include a comprehensive re-examination of the Melbourne Water studies, Yambulla and Karuah projects in NSW, and an examination of the Reefton and Stewarts Creek data in Victoria. This would involve negotiation with the agencies that have been running such experiments. Results from studies such as Croppers Creek, Long Corner Creek and Stewarts Creek in Victoria and Lidsdale in NSW that have a eucalypt component but were concerned with plantation expansion may add to the information.

2: Formally Examine the Scaling Up of Small Catchment Studies to Large Catchments

By definition, small catchment studies are undertaken on small catchments, and (as done here) applied to large catchments. The question of just how "scaleable" results are is difficult and usually ignored; however any formal analysis of small catchment results should address this with an aim of at least seeing if there are recent studies which may help, identifying error limits, and ascertaining whether the yield from small catchments at least approximates the yield obtained on large catchments (given the many issues associated with errors of measurement). The issue is difficult to resolve because of the lack of comparability of the small and large catchments and the lack of data, but it should be formally addressed.

3: Initiate Mixed Species Studies in Victoria

This was identified as an issue in Victoria five decades ago, and at least two paired catchment studies were initiated (but not persevered with) to resolve this. Either using these sites or creating new ones, definitive work should be undertaken to obtain the age-yield characteristics of this forest type. The "Reefton" catchments in the Upper Yarra Valley are well placed for this work, some work has already been done, and at least some statutory issues in undertaking such a project should have been resolved.

4: Develop Alternatives/Supplements to Paired Catchment Work

Scientists view paired catchment studies as a “solid”, unequivocal approach, but they do take a long time and organisational commitment to continue research over a long time period. Plot and shorter term studies using the arrays of “new technologies” that have become available in recent years should be used to supplement such studies.

5 Proper Consideration of Wood and Water Values

In a companion volume to this report (Volume 2), we have provided a critique of an Australian Conservation Foundation report arguing that the value of water foregone exceeds the value of wood produced. The critique comments on the methodology, the choice of discount rates, and the relative valuation of the goods. We agree that there does need to be such an analysis objectively carried out for “competition” between water values and wood values for the Goulburn-Broken catchment and, depending on the findings of this, perhaps the Ovens/Kiewa and the Upper Murray catchments. The same argument applies to other crops since water and biological material classically involve “joint production functions” in which the price of water becomes an important component of the price of food or fibre.

In such an analysis there needs to be a more thorough examination of such aspects using correct methodology, incorporating “random” elements such as forest fires, including costs of forest protection, and using reasonable and “industry-agreed” values for wood and water. In such analyses, partisan or polemic elements should be removed or at least harnessed to providing “best estimates.” Such analysis should include information from Recommendation (1) above since much of that information can be produced relatively fast. The analysis would need to include regional economic and social considerations relating to sustainable development. The author believes that the forest industries must take a lead in such analyses if they are to have the support of the Australian public

6: Putting the Results of this Study into an Overall Perspective

The study ultimately centred on the Upper Murray, the Ovens/Kiewa, and the Goulburn/Broken catchments. Since 2003, the forests of these catchments have been compromised by fires on a scale effectively unseen in Australian history of the last two centuries. It is thought that about 50 per cent of these forest areas have been burnt. It is of relevance to this study to compare the water yield changes induced in these catchments from fire with those that may be induced as a consequence of logging.

7: Water Yield Enhancement Methods of Forest Management

This study has focused on growing regrowth forest to old-growth forest. At least in the case of mountain ash this gives a higher water yield. However in human terms this is a slow process. There is also the question of whether, given climate change and fire intensity it is even possible. Other methods of water yield enhancement include "thinning" of forests and even removal of forest cover. It is feasible that many naturally dense forests will be artificially maintained at a low stocking in the future to enhance water yield. This could be a point of consideration and experimentation in the future.

8: Embracing Complex Climate Change Scenarios

Potential impacts of climate change in the Murray-Darling Basin have the potential to heavily influence forest productivity, fire frequency, and resultant silvicultural practices. Resolution of such issues is beyond the scope of this report. However the authors believe that the forest management authorities must address these issues in order to protect both forest and water resources.

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Appendix 1:

Mathematica Code for Various Models

Colleague John Costenaro cleans the weir notch during routine project servicing.

BISY Model (Absolute and Relative to Old Growth)

```
|  This one is the SKM one for the BISY Study  |
mixedsppabs| age_, p_| :=
  Module| | resfac, aetash, maturefor, fac, response| ,
   a : 1 · 2 | 1410 | p| ;
b : 1 · 0.5 | 1100 | p| ;
c : a · | p | 1410| ;
d : b · | p | 1100| ;
fac3 : 1.0;
etp : | b| d| fac3 p;
etf : | a| c| fac3 p;
dif : | etf · etp| ;
   upperlimit : p · etp;
   maturefor : p · etf;
 aetash : | p1ms · p2ms · p3ms| | E| p5ms| age E^| · age| p5ms| ·
     | p2ms · p3ms · p4ms| | 2| | 1 · E^| · age| p6ms| | · 1| ·
     p3ms | E^| · age| p7ms| · 1| · p4ms;
   p1ms : 795;
 p5ms : 16.1;
   p2ms : 843;
    p6ms : 6.8;
   p3ms : · 439.7;
   p7ms : 17.1;
   p4ms : 403.5;
   dif : etf · etp;
   fac : dif| 213.098;
   resfac : 1000 · aetash · 156.95;
   response : If| | maturefor · fac resfac| | upperlimit, upperlimit,
     | If| | maturefor · fac resfac| | 0, 0, | maturefor · fac resfac| | | |
  | ;
```

```
(* This one is the SKM one for the BISY Study *)
ashabs[age_, p_] := Module[{resfac, aetash, maturefor, fac, response},
   a = 1 + 2 (1410 / p);
b = 1 + 0.5 (1100 / p);
c = a + (p / 1410);
d = b + (p / 1100);
fac3 = 1.0;
etp = (b - d) fac3 p;
etf = (a - c) fac3 p;
dif = (etf - etp);
   upperlimit = p - etp;
   maturefor = p - etf;
 aetash = (p1ms - p2ms - p3ms) (E (p5ms/age) E^(-age / p5ms)) +
     (p2ms + p3ms - p4ms) (2 / (1 + E^(-age / p6ms)) - 1) +
     p3ms (E^(-age / p7ms) - 1) + p4ms;
   p1ms = 1500;
 p5ms = 34;
   p2ms = 800;
    p6ms = 6.0;
   p3ms = 400;
   p7ms = 60;
   p4ms = 300;
   dif = etf - etp;
   fac = dif / 434.6;
   resfac = 2000 - aetash - 1172.36;
   response = If[(maturefor + fac resfac) > upperlimit, upperlimit,
     (If[(maturefor + fac resfac) < 0, 0, (maturefor + fac resfac)])]
  ];
```

```
(* This one is the SKM one for the BISY Study *)
ashrel[age_, p_] := Module[{resfac, aetash, maturefor, fac, response},
   a = 1 + 2 (1410/ p) ;
b = 1 + 0.5 (1100/ p) ;
c = a + (p/ 1410) ;
d = b + (p/ 1100) ;
fac3 = 1.0;
etp = (b/ d) fac3 p;
etf = (a/ c) fac3 p;
dif = (etf - etp) ;
   upperlimit = p - etp;
   maturefor = p - etf;
 aetash = (p1ms - p2ms - p3ms) (E^(p5ms) age E^(- age / p5ms)) +
     (p2ms + p3ms - p4ms) (2 / (1 + E^(- age / p6ms)) - 1) +
     p3ms (E^(- age / p7ms) - 1) + p4ms;

   p1ms = 1500;
 p5ms = 34;
   p2ms = 800;
    p6ms = 6.0;
   p3ms = 400;
   p7ms = 60;
   p4ms = 300;
   dif = etf - etp;
   fac = dif / 434.6;
   resfac = 2000 - aetash - 1172.36;

   response = If[(maturefor + fac resfac) > upperlimit, upperlimit,
     (If[(maturefor + fac resfac) < 0, 0, (maturefor + fac resfac)])] ;
   (response - maturefor)
  ] ;
```

```
(* From the BISY study *)
mixedspprel[age_, p_] :=
  Module[{resfac, aetash, maturefor, fac, response},

a : 1 · 2 (1410 · p) ;
b : 1 · 0.5 (1100 · p) ;
c : a · (p · 1410) ;
d : b · (p · 1100) ;
fac3 : 1.0;
etp : (b · d) fac3 p;
etf : (a · c) fac3 p;
dif : (etf · etp) ;
   upperlimit : p · etp;
   maturefor : p · etf;
 aetash : (p1ms · p2ms · p3ms) (E^(· age p5ms) age E^(· age p5ms) ·
      (p2ms · p3ms · p4ms) (2 (1 · E^(· age p6ms)) · 1) ·
      p3ms (E^(· age p7ms) · 1) · p4ms;
   p1ms : 795;
 p5ms : 16.1;
   p2ms : 843;
    p6ms : 6.8;
   p3ms : · 439.7;
   p7ms : 17.1;
   p4ms : 403.5;
   dif : etf · etp;
   fac : dif / 213.098;
   resfac : 1000 · aetash · 156.95;
   response : If[(maturefor · fac resfac) ) upperlimit, upperlimit,
     (If[(maturefor · fac resfac) ( 0, 0, (maturefor · fac resfac)])] ;
   (response · maturefor)
  ] ;
```

Zhang Curve Forest Runoff

```
zhangforest p_ :
 a  1   2  1410  p ;
b  1   0.5  1100  p ;
c   a   p  1410 ;
d   b   p  1100 ;
fac   1.0;
etp   b  d  fac p;
etf   a  c  fac p;
dif   etf  etp ;
sforest   p   etf
```

Watson Model

```
watson age_, p_  :
   p1ms  1390;
 p5ms  40;
    p2ms  800;
     p6ms  6.0;
     p3ms  370;
    p7ms  100;
    p4ms  220;
    aetash   p1ms   p2ms   p3ms  E  p5ms age E^  age  p5ms
      p2ms   p3ms   p4ms  2  1   E^  age  p6ms     1
      p3ms  E^  age  p7ms   1   p4ms;
    If p  aetash  0, p  aetash, 0  ;
```

Peel Models for Ash and Mixed Species

```
peelash[age_, p_] :=
  (p1ms = 1900;
   p2ms = 1160;
    p3ms = 920;
   p4ms = 550;
p5ms = 40;
    p6ms = 2;
   p7ms = 100;
   aetash = (p1ms - p2ms - p3ms) (E (p5ms) age E^(- age / p5ms) +
     (p2ms + p3ms - p4ms) (2 / (1 + E^(- age / p6ms)) - 1) +
     p3ms (E^(- age / p7ms) - 1) + p4ms;
   If[p - aetash > 0, p - aetash, 0]);
```

```
peelms[age_, p_] :=
  (p1ms = 1520;
   p2ms = 1150;
    p3ms = 410;
   p4ms = 620;
p5ms = 40;
    p6ms = 2;
   p7ms = 130;
   aetash = (p1ms - p2ms - p3ms) (E (p5ms) age E^(- age / p5ms) +
     (p2ms + p3ms - p4ms) (2 / (1 + E^(- age / p6ms)) - 1) +
     p3ms (E^(- age / p7ms) - 1) + p4ms;
   If[p - aetash > 0, p - aetash, 0]);
```

Kuczera Curve Model

```
kuczera[age_, ashpc_] := Module[{k, lmax},
    k = Exp[-3.24]; lmax = 6.15 ashpc;
    If[age > 2, lmax k (age - 2) Exp[1 - k (age - 2)], 0] ];
```

Nash-Sutcliffe Coefficient

```
sutcliffenash[obs_, pred_] :=
  1 - Total[(obs - pred)^2] / Total[(obs - Mean[obs])^2];
```

Ash Area and Mixed Species Area Function

```
sharea[area_, p_] := area * (Sum[ash[age, p], {age, 1, 100}] / 100)
```

```
mixedspparea[area_, p_] := area * (Sum[mixedspprel[age, p], {age, 1, 100}] / 100)
```

Plots for Figure 7.2

```
a1 = Plot[{Sum[ashrel[age, p], {age, 1, 100}] / 100,
    Sum[mixedspprel[age, p], {age, 1, 100}] / 100}, {p, 600, 1500}, PlotRange -> {-250, 0}]
```

```
Plot[{(Sum[ashrel[age, p], {age, 1, 100}] / 100) 100 / zhangforest[p],
  (Sum[mixedspprel[age, p], {age, 1, 100}] / 100) * 100 / zhangforest[p]},
 {p, 600, 1500}, PlotRange -> {-100, 0}]
```

Plots for Figure 7.3

```
(* Ash forest recovery in absolute terms *)
Plot[{Sum[ashrel[age + year - 1, 700] / 100., {age, 1, 100}],
  Sum[ashrel[age + year - 1, 1000] / 100., {age, 1, 100}],
  Sum[ashrel[age + year - 1, 1300] / 100., {age, 1, 100}]},
 {year, 1, 100}, PlotRange -> {-250, 0}]
```

```
(* Mixed Species recovery in absolute terms *)
Plot[{Sum[mixedspprel[age, year - 1, 700] / 100., {age, 1, 100}],
  Sum[mixedspprel[age, year - 1, 1000] / 100., {age, 1, 100}],
  Sum[mixedspprel[age, year - 1, 1300] / 100., {age, 1, 100}]},
 {year, 1, 100}, PlotRange -> {-250, 0}]
```

Plot for Figure 9.1

```
(* Plot for Figure 9.1, with allowance for buffers *)

Plot[{Sum[mixedspprel[age, year - 1, 800] / 100., {age, 1, 100}] 525 (0.88) 1000. +
   (Sum[mixedspprel[age, year - 1, 1050] / 100., {age, 1, 100}] +
      Sum[ashrel[age, year - 1, 1050] / 100., {age, 1, 100}]) 0.5 2139. (0.88) 1000.,

   Sum[mixedspprel[age, year - 1, 800] / 100., {age, 1, 100}] 117 (0.88) 1000. +
   (Sum[mixedspprel[age, year - 1, 1050] / 100., {age, 1, 100}] +
      Sum[ashrel[age, year - 1, 1050] / 100., {age, 1, 100}]) 0.5 1236. (0.88 ) 1000.,

  Sum[mixedspprel[age, year - 1, 800] / 100., {age, 1, 100}] 412. (0.88) 1000. +
   (Sum[mixedspprel[age, year - 1, 1050] / 100., {age, 1, 100}] +
      Sum[ashrel[age, year - 1, 1050] / 100., {age, 1, 100}]) 0.5 (1437. (0.88) 1000.
 },
 {year, 1, 100}, PlotRange -> {-300, 0}]
```

Plot for Figure 9.2

```
|   Plot for Figure 9.2,
with allowance for buffers but expressed as change from the current.
  This is the increase if logging ceased   |
Plot| | 234.8   Sum| mixedspprel| age   year  1, 800|  | 100., | age, 1, 100| |  525  0.88| 1000.  
   | Sum| mixedspprel| age   year  1, 1050|  | 100., | age, 1, 100| |   
       Sum| ashrel| age   year  1, 1050|  | 100., | age, 1, 100| | | 0.5 2139.  0.88| 1000.,

    127.7   Sum| mixedspprel| age   year  1, 800|  | 100., | age, 1, 100| |  117  0.88 | 1000. 
   | Sum| mixedspprel| age   year  1, 1050|  | 100., | age, 1, 100| |   
       Sum| ashrel| age   year  1, 1050|  | 100., | age, 1, 100| | | 0.5 1236.  0.88 | 1000.,

  160.3   Sum| mixedspprel| age   year  1, 800|  | 100., | age, 1, 100| |  412.  0.88| 1000. 
   | Sum| mixedspprel| age   year  1, 1050|  | 100., | age, 1, 100| |   
       Sum| ashrel| age   year  1, 1050|  | 100., | age, 1, 100| | | 0.5  1437.  0.88| 1000.
 | ,
 | year, 1, 100| , PlotRange   | 50, 200| |
```

Plot for Figure 10.1

```
Plot| | 175.62 · Sum| mixedspprel| age · year · 1, 695| | 100., | age, 1, 100| | 525 · 0.88| 1000. ·
  | Sum| mixedspprel| age · year · 1, 913| | 100., | age, 1, 100| | ·
     · Sum| ashrel| age · year · 1, 913| | 100., | age, 1, 100| | | 0.5 2139. · 0.88| 1000.,
  234.8 · Sum| mixedspprel| age · year · 1, 800| | 100., | age, 1, 100| | 525 · 0.88| 1000. ·
  | Sum| mixedspprel| age · year · 1, 1050| | 100., | age, 1, 100| | ·
     · Sum| ashrel| age · year · 1, 1050| | 100., | age, 1, 100| | | 0.5 2139. · 0.88| 1000.

 | ,
 | year, 1, 100| , PlotRange · | · 50, 200| |

Plot| |

   94.99 · Sum| mixedspprel| age · year · 1, 695| | 100., | age, 1, 100| | 117 · 0.88 | 1000. ·
  | Sum| mixedspprel| age · year · 1, 913| | 100., | age, 1, 100| | ·
     · Sum| ashrel| age · year · 1, 913| | 100., | age, 1, 100| | | 0.5 1236. · 0.88 | 1000.,
   127.7 · Sum| mixedspprel| age · year · 1, 800| | 100., | age, 1, 100| | 117 · 0.88 | 1000. ·
  | Sum| mixedspprel| age · year · 1, 1050| | 100., | age, 1, 100| | ·
     · Sum| ashrel| age · year · 1, 1050| | 100., | age, 1, 100| | | 0.5 1236. · 0.88 | 1000.

 | ,
 | year, 1, 100| , PlotRange · | · 50, 200| |

Plot| |
  120.05 · Sum| mixedspprel| age · year · 1, 695| | 100., | age, 1, 100| | 412. · 0.88| 1000. ·
  | Sum| mixedspprel| age · year · 1, 913| | 100., | age, 1, 100| | ·
     · Sum| ashrel| age · year · 1, 913| | 100., | age, 1, 100| | | 0.5 · 1437. · 0.88| 1000.,
  160.3 · Sum| mixedspprel| age · year · 1, 800| | 100., | age, 1, 100| | 412. · 0.88| 1000. ·
  | Sum| mixedspprel| age · year · 1, 1050| | 100., | age, 1, 100| | ·
     · Sum| ashrel| age · year · 1, 1050| | 100., | age, 1, 100| | | 0.5 · 1437. · 0.88| 1000.

 | ,
 | year, 1, 100| , PlotRange · | · 50, 200| |
```

Plot for Figure 10.2

```
plot1 :
 Plot|
  | 100 ·
     | 175.62 ·  Sum| mixedspprel| age ·  year · 1, 695| | 100., | age, 1, 100| |  525 ·
          0.88 | 1000. · | Sum| mixedspprel| age ·  year · 1, 913| | 100., | age, 1, 100| |  ·
            · Sum| ashrel| age ·  year · 1, 913| | 100., | age, 1, 100| | | 0.5 2139. ·
          0.88 | 1000.| |
        | 234.8 ·  Sum| mixedspprel| age ·  year · 1, 800| | 100., | age, 1, 100| |
          525 · 0.88 | 1000. ·
         | Sum| mixedspprel| age ·  year · 1, 1050| | 100., | age, 1, 100| |  ·
            · Sum| ashrel| age ·  year · 1, 1050| | 100., | age, 1, 100| | | 0.5
          2139. · 0.88 | 1000.| · 100| | 13.1


  ,
  | year, 30, 100| |

plot2 :  Plot| | 100 ·
     | | 94.99 ·  Sum| mixedspprel| age ·  year · 1, 695| | 100., | age, 1, 100| |  117 · 0.88 | 1000. ·
          | Sum| mixedspprel| age ·  year · 1, 913| | 100., | age, 1, 100| |  ·
             · Sum| ashrel| age ·  year · 1, 913| | 100., | age, 1, 100| | | 0.5
           1236. · 0.88 | 1000.| |
         |  127.7 ·  Sum| mixedspprel| age ·  year · 1, 800| | 100., | age, 1, 100| |
           117 · 0.88 | 1000. ·
          | Sum| mixedspprel| age ·  year · 1, 1050| | 100., | age, 1, 100| |  ·
             · Sum| ashrel| age ·  year · 1, 1050| | 100., | age, 1, 100| | | 0.5
           1236. · 0.88 | 1000.| | · 100| | 13.1


  ,
  | year, 30, 100| |

plot3 :  Plot| | 100 ·
     | 120.05 ·  Sum| mixedspprel| age ·  year · 1, 695| | 100., | age, 1, 100| |  412. · 0.88 | 1000. ·
         | Sum| mixedspprel| age ·  year · 1, 913| | 100., | age, 1, 100| |  ·
            · Sum| ashrel| age ·  year · 1, 913| | 100., | age, 1, 100| | | 0.5 ·
          1437. · 0.88 | 1000.| |
        | 160.3 ·  Sum| mixedspprel| age ·  year · 1, 800| | 100., | age, 1, 100| |
          412. · 0.88 | 1000. ·
         | Sum| mixedspprel| age ·  year · 1, 1050| | 100., | age, 1, 100| |  ·
            · Sum| ashrel| age ·  year · 1, 1050| | 100., | age, 1, 100| | | 0.5 ·
          1437. · 0.88 | 1000.| · 100| | 13.1


  ,
  | year, 30, 100| |
Show| plot1, plot2, plot3, PlotRange · | 0, 3| |
```

Appendix 2:

Tabulated Areas of Forest in Catchments

Native forest productivity (mean annual increment in m^3/ha/year) of MDB catchments at five isohyets, up to 300mm, 300 – 500mm, 500 – 700mm, 700 – 900mm and 900 – 1100mm.

Key to Tenure Types presented in tables:

LEASE	Leasehold
MUF	Multiple use forests
NCR	Nature Conservation Reserve
ND	No data available
OCL	Other Crown Land
PRIV	Private

AVOCA RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Very High	high	20
		Moderate	low	40
MUF	> 300 - 500 mm	Moderate	high	830
		Low	low	60
		Very Low	very low	6,280
			limited	980
		Not Applicable	NA	1,380
	> 500 - 700 mm	Very High	high	1,530
		Moderate	low	500
		Low	low	4,780
		Very Low	very low	1,020
			limited	190
		Not Applicable	NA	590
NCR	> 300 - 500 mm	Moderate	high	1,260
		Low	high	40
			low	450
		Very Low	very low	13,290
			limited	4,050
		Not Applicable	NA	35,990
	> 500 - 700 mm	Very High	high	90
		Moderate	low	40
		Low	low	4,390
		Very Low	very low	590
			limited	430
		Not Applicable	NA	4,930
ND	> 300 - 500 mm	Moderate	high	10
		Low	high	30
		Very Low	limited	20
		Not Applicable	NA	320
	> 500 - 700 mm	Very Low	very low	10
			limited	10

OCL	> 300 - 500 mm	Moderate	high	10
		Low	low	20
		Very Low	very low limited	120 20
		Not Applicable	NA	1,090
	> 500 - 700 mm	Very High	high	50
		Low	low	900
		Very Low	limited	20
		Not Applicable	NA	270
PRIV	> 300 - 500 mm	Moderate	high	1,060
		Low	low	1,400
		Very Low	very low limited	1,830 3,880
		Not Applicable	NA	42,710
	> 500 - 700 mm	Very High	high	80
		Moderate	low	160
		Low	low	1,290
		Very Low	very low limited	330 780
		Not Applicable	NA	940
Area forested (ha)				**141,110**
Total catchment area (ha)				**1,419,800**
Proportion of area forested				**9.94%**

BEGA RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
MUF	> 700 - 900 mm	Very High	very high	40
		High	High	10
OCL	> 700 - 900 mm	High	High	10
		Moderate	High	10
PRIV	> 700 - 900 mm	Very High	very high	20
Total catchment area (ha)				**90**
Area forested (ha)				**90**
Proportion of area forested				**100%**

BENANEE

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	<= 300mm	Moderate	high	50
		Low	moderate	940
		Very Low	low	70
		Not Applicable	NA	52,670
	> 300 - 500 mm	Moderate	high	350
		Low	high	2,710
			moderate	290
		Very Low	low	280
		Not Applicable	NA	289,500
MUF	<= 300mm	Not Applicable	NA	240
	> 300 - 500 mm	Moderate	high	2,740
		Low	high	410
			low	20
		Very Low	low	540
		Not Applicable	NA	1,620
NCR	<= 300mm	Moderate	high	10
		Not Applicable	NA	1,040
	> 300 - 500 mm	Moderate	high	590
		Low	high	10
			low	90
		Not Applicable	NA	33,020
ND	<= 300mm	Very Low	low	10
	> 300 - 500 mm	Moderate	high	80
		Low	high	170
			low	10
		Not Applicable	NA	140
OCL	<= 300mm	Moderate	high	20
		Low	moderate	20
		Very Low	low	80
		Not Applicable	NA	300

	> 300 - 500 mm	Moderate	high	30
		Low	high	60
		Very Low	low	50
		Not Applicable	NA	1,860
PRIV	<= 300mm	Moderate	high	10
		Not Applicable	NA	40
	> 300 - 500 mm	Moderate	high	630
		Low	high	400
		Very Low	low	50
		Not Applicable	NA	1,640
Area forested (ha)				**392,790**
Total catchment area (ha)				**2,134,300**
Proportion of area forested				**18.40%**

BORDER RIVERS

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Moderate	moderate	590
		Very Low	low	80
		Not Applicable	NA	19,230
	> 500 - 700 mm	Moderate	high moderate	30 1,600
		Low	low	19,510
		Very Low	low limited	133,060 15,690
		Not Applicable	limited sandalwood Unknown NA	620 520 990 13,190
	> 700 - 900 mm	Very High	very high high	550 70
		High	moderate	950
		Moderate	low	200
		Low	moderate low	7,840 25,090
		Very Low	low limited	9,380 3,310
		Not Applicable	Unknown NA	1,490 7,540
MUF	> 500 - 700 mm	Low	low	10,040
		Very Low	low limited	148,550 11,490
		Not	limited	70

		Applicable	sandalwood Unknown NA	410 60 1,030
	> 700 - 900 mm	Very High	very high high	360 30
		High	moderate	2,050
		Moderate	low	10
		Low	moderate low	620 1,510
		Very Low	low limited	370 2,640
		Not Applicable	Unknown NA	40 1,250
	> 900 - 1100 mm	Very High	very high	20
		High	moderate	10
		Low	moderate	10
		Not Applicable	NA	40
NCR	> 500 - 700 mm	Moderate	moderate	480
		Low	low	37,840
		Very Low	low limited	4,150 660
		Not Applicable	Unknown NA	360 530
	> 700 - 900 mm	Very High	very high high	860 40
		High	moderate	9,530
		Moderate	low	50
		Low	moderate	2,840

			low	35,420
		Very Low	low limited	5,290 16,040
		Not Applicable	Unknown NA	80 5,740
	> 900 - 1100 mm	Very High	very high	70
		High	moderate	10
		Very Low	low	130
		Not Applicable	NA	80
ND	> 300 - 500 mm	Moderate	moderate	250
		Not Applicable	NA	80
	> 500 - 700 mm	Moderate	high moderate	70 3,160
		Low	low	770
		Very Low	low limited	10,490 4,960
		Not Applicable	limited sandalwood Unknown NA	780 420 50 1,660
	> 700 - 900 mm	High	high moderate	20 340
		Moderate	low	20
		Low	moderate low	450 1,180
		Very Low	low limited	710 1,140
		Not	Unknown	70

		Applicable	NA	420
OCL	> 300 - 500 mm	Moderate	moderate	220
		Very Low	low	20
		Not Applicable	NA	940
	> 500 - 700 mm	Moderate	high moderate low	140 1,920 10
		Low	moderate low	30 8,700
		Very Low	low limited	3,740 1,010
		Not Applicable	limited sandalwood Unknown NA	80 40 420 8,970
	> 700 - 900 mm	Very High	very high high	40 10
		High	moderate	360
		Moderate	low	70
		Low	moderate low	1,060 10,540
		Very Low	low limited	2,480 1,230
		Not Applicable	Unknown NA	540 3,030
PRIV	> 300 - 500 mm	Moderate	moderate	760
		Not Applicable	NA	1,620
	> 500 - 700 mm	Moderate	high	660

			moderate low	8,490 140
		Low	moderate low	440 87,140
		Very Low	low limited	165,430 58,420
		Not Applicable	limited sandalwood Unknown NA	1,520 1,270 6,640 46,440
	> 700 - 900 mm	Very High	very high high	1,540 540
		High	moderate	19,100
		Moderate	low	1,560
		Low	moderate low	24,020 90,850
		Very Low	low limited	38,360 42,040
		Not Applicable	Unknown NA	7,570 36,380
	> 900 - 1100 mm	Very High	very high	50
		High	moderate	10
		Low	moderate low	30 10
Total catchment area (ha)				**4,803,190**
Area forested (ha)				**1,276,010**
Proportion of area forested				**26.57%**

BRISBANE RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 700 - 900 mm	Very Low	low	100
NCR	> 700 - 900 mm	High	high	20
			moderate	80
		Moderate	high	290
		Very Low	low	100
		Not Applicable	NA	40
	> 900 - 1100 mm	Moderate	high	10
		Not Applicable	NA	20
ND	> 700 - 900 mm	Very Low	low	60
PRIV	> 700 - 900 mm	High	high	10
		Moderate	high	20
		Very Low	low	710
Total catchment area (ha)				**3,150**
Area forested (ha)				**1,460**
Proportion of area forested				**46.35%**

BROKEN RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 700 - 900 mm	Very High	high	10
		Moderate	moderate	1,930
			low	130
		Low	low	110
		Not Applicable	NA	460
	> 900 - 1100 mm	Very High	high	10
		High	high	10
		Moderate	moderate	1,110
			low	20
		Low	low	310
		Not Applicable	NA	100
MUF	> 300 - 500 mm	Moderate	high	20,170
		Low	high	20
			moderate	60
			low	30
	> 500 - 700 mm	Low	low	10
	> 700 - 900 mm	Very High	high	480
		High	high	1,330
			moderate	230
		Moderate	moderate	9,260
			low	7,720
		Low	low	310
		Not Applicable	NA	2,700
	> 900 - 1100 mm	Very High	high	880

		High	high	870
		Moderate	moderate low	7,580 1,370
		Low	low	390
		Not Applicable	NA	3,050
NCR	> 300 - 500 mm	Moderate	high	7,540
		Low	high low	10 100
		Very Low	limited	140
		Not Applicable	NA	350
	> 500 - 700 mm	Moderate	low	200
		Low	low	2,610
		Very Low	very low limited	10 110
		Not Applicable	NA	2,150
	> 700 - 900 mm	Very High	high	220
		High	high	440
		Moderate	moderate low	2,980 3,880
		Low	low	550
		Very Low	very low limited	10 10
		Not Applicable	NA	1,480
	> 900 - 1100 mm	Very High	high	150
		High	high	180
		Moderate	moderate low	770 380
		Low	low	70

		Not Applicable	NA	110
ND	> 300 - 500 mm	Moderate	high	10
		Low	high moderate	70 30
	> 500 - 700 mm	Low	low	10
	> 700 - 900 mm	Moderate	low	120
OCL	> 300 - 500 mm	Moderate	high	20
	> 500 - 700 mm	Low	low	10
		Not Applicable	NA	20
	> 700 - 900 mm	Moderate	moderate low	300 20
		Low	low	10
		Not Applicable	NA	20
	> 900 - 1100 mm	Very High	high	40
		Moderate	moderate	250
PRIV	> 300 - 500 mm	Moderate	high	290
		Low	high low	20 240
		Very Low	limited	10
		Not Applicable	NA	800
	> 500 - 700 mm	Low	low	1,110
		Very Low	limited	470
		Not Applicable	NA	1,750
	> 700 - 900 mm	High	high moderate	560 50
		Moderate	moderate low	920 6,080

		Low	low	490
		Very Low	limited	20
		Not Applicable	NA	820
	> 900 - 1100 mm	High	high	420
		Moderate	moderate low	2,050 830
		Low	low	50
		Not Applicable	NA	260
Total catchment area (ha)				**709,110**
Area forested (ha)				**103,280**
Proportion of area forested				**14.56%**

BURNETT RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Low	moderate	170
			low	50
		Very Low	low	840
			limited	40
MUF	> 500 - 700 mm	Low	moderate	10
			low	230
		Very Low	low	330
			limited	10
NCR	> 700 - 900 mm	Moderate	high	100
		Very Low	low	110
		Not Applicable	NA	20
ND	> 500 - 700 mm	Low	low	10
	> 700 - 900 mm	Moderate	high	10
		Very Low	low	10
PRIV	> 500 - 700 mm	Low	moderate	10
			low	10
		Very Low	low	170
	> 700 - 900 mm	Moderate	high	50
		Very Low	low	20
Total catchment area (ha)				**3,340**
Area forested (ha)				**2,200**
Proportion of area forested				**65.87%**

CAMPASPE RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 700 - 900 mm	High	moderate	10
MUF	> 300 - 500 mm	Low	moderate	10
	> 500 - 700 mm	Low	low	600
		Very Low	very low	7,660
			limited	100
		Not Applicable	NA	1,810
	> 700 - 900 mm	Very High	high	1,930
		High	moderate	2,690
		Moderate	low	420
		Low	low	50
		Not Applicable	NA	680
NCR	> 300 - 500 mm	Moderate	high	130
		Low	high	10
			low	200
		Very Low	limited	220
	> 500 - 700 mm	Very High	high	10
		High	high	60
		Low	low	1,350
		Very Low	very low	6,990
			limited	290
		Not Applicable	NA	5,200
	> 700 - 900 mm	Very High	high	450
		High	high	10
		Moderate	low	50
		Low	low	340
		Not Applicable	NA	560
ND	> 300 - 500 mm	Moderate	high	120
		Low	high	30
			low	10
		Not Applicable	NA	20

	> 500 - 700 mm	Very High	high	10
		Low	low	10
		Very Low	very low	30
			limited	20
OCL	> 500 - 700 mm	Very Low	very low	1,450
			limited	10
		Not Applicable	NA	240
	> 700 - 900 mm	Very High	high	150
		High	moderate	40
		Very Low	limited	20
		Not Applicable	NA	10
PRIV	> 300 - 500 mm	Moderate	high	150
		Low	moderate	10
			low	290
		Very Low	limited	10
		Not Applicable	NA	160
	> 500 - 700 mm	Very High	high	280
		Moderate	low	80
		Low	low	770
		Very Low	very low	3,250
			limited	2,040
		Not Applicable	NA	2,090
	> 700 - 900 mm	Very High	high	3,270
		High	high	130
			moderate	1,390
		Moderate	low	1,830
		Low	low	1,190
		Very Low	limited	150
		Not Applicable	NA	1,570
Total catchment area (ha)				**403,960**
Area forested (ha)				**52,660**
Proportion of area forested				**13.04%**

CASTLEREAGH RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Moderate	high	200
		Low	moderate	2,480
		Very Low	low	620
		Not Applicable	NA	13,840
	> 500 - 700 mm	Moderate	high	310
			moderate	310
		Low	high	820
			moderate	19,590
			low	1,200
		Very Low	low	13,230
			limited	1,200
		Not Applicable	NA	13,800
MUF	> 300 - 500 mm	Low	moderate	2,280
		Very Low	low	20
		Not Applicable	NA	430
	> 500 - 700 mm	Moderate	moderate	20
		Low	moderate	21,070
			low	20
		Very Low	low	330
		Not Applicable	NA	3,170
NCR	> 500 - 700 mm	Moderate	moderate	380
		Low	high	370
			moderate	25,660
			low	360
		Very Low	low	2,300
			limited	1,830
		Not Applicable	NA	43,660
ND	> 300 - 500 mm	Moderate	moderate	40
		Very Low	low	30
	> 500 - 700 mm	Moderate	high	240

			moderate	1,600
		Low	high moderate low	20 290 20
		Very Low	low limited	590 390
		Not Applicable	NA	450
OCL	> 300 - 500 mm	Low	moderate	430
		Very Low	low	470
		Not Applicable	NA	5,450
	> 500 - 700 mm	Very High	high	10
		Moderate	high moderate	430 540
		Low	high moderate low	200 7,500 480
		Very Low	low limited	5,140 680
		Not Applicable	NA	5,170
PRIV	> 300 - 500 mm	Moderate	high moderate	1,180 100
		Low	moderate	8,530
		Very Low	low	2,920
		Not Applicable	NA	62,160
	> 500 - 700 mm	Very High	high	130
		Moderate	high moderate	1,570 7,680
		Low	high moderate low	3,940 94,390 11,810
		Very Low	low limited	67,080 10,730
		Not Applicable	NA	61,790

Total catchment area (ha)				**1,742,390**
Area forested (ha)				**533,680**
Proportion of area forested				**30.63%**

CLARENCE RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 700 - 900 mm	Very High	very high	10
		Low	moderate low	10 10
MUF	> 700 - 900 mm	Very High	very high	20
		High	moderate	10
		Low	moderate	50
	> 900 - 1100 mm	Low	moderate	10
		Not Applicable	NA	20
NCR	> 700 - 900 mm	Very High	very high	40
		High	moderate	80
		Low	moderate	90
		Not Applicable	NA	10
	> 900 - 1100 mm	Not Applicable	NA	10
ND	> 700 - 900 mm	High	moderate	30
OCL	> 700 - 900 mm	High	moderate	40
PRIV	> 700 - 900 mm	Very High	very high	20
		High	moderate	100
		Low	moderate low	100 40
		Very Low	low limited	10 10
		Not Applicable	NA	10
	> 900 - 1100 mm	Very High	very high	10

		Low	moderate	10
Total catchment area (ha)				**1,950**
Area forested (ha)				**750**
Proportion of area forested				**38.46%**

CONDAMINE-CULGOA RIVERS

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Moderate	high moderate	440 620
		Low	low	7,200
		Very Low	low limited	261,640 109,740
		Not Applicable	limited sandalwood NA	20 6,490 1,057,710
	> 500 - 700 mm	Moderate	high	950
		Low	moderate low	135,190 13,640
		Very Low	low limited	437,450 168,740
		Not Applicable	limited sandalwood NA	1,770 28,030 135,380
	> 700 - 900 mm	High	high	10
		Low	low	10
		Very Low	moderate low	10 460
		Not Applicable	sandalwood NA	10 20
MUF	> 300 - 500 mm	Low	low	420
		Very Low	low	1,450
		Not Applicable	NA	5,220

	> 500 - 700 mm	Low	moderate low	76,440 9,770
		Very Low	low limited	210,150 37,830
		Not Applicable	limited sandalwood NA	20 80 8,600
	> 700 - 900 mm	Moderate	moderate	60
		Very Low	low	830
NCR	> 300 - 500 mm	Very Low	low limited	17,940 14,960
		Not Applicable	sandalwood NA	320 23,360
	> 500 - 700 mm	Moderate	high	200
		Low	moderate	2,800
		Very Low	low limited	36,060 7,090
		Not Applicable	limited sandalwood NA	10 1,040 2,600
	> 700 - 900 mm	High	high moderate	440 2,530
		Moderate	high	4,710
		Low	moderate low	130 180
		Very Low	low limited	7,150 20
		Not Applicable	NA	1,050
	> 900 - 1100	High	moderate	50

	mm			
		Moderate	high	660
		Not Applicable	NA	160
ND	> 300 - 500 mm	Moderate	high moderate	130 180
		Low	low	790
		Very Low	low limited	10,200 6,630
		Not Applicable	sandalwood NA	1,160 35,210
	> 500 - 700 mm	Low	moderate low	4,650 4,190
		Very Low	low limited	38,910 13,590
		Not Applicable	limited sandalwood NA	40 3,820 12,240
	> 700 - 900 mm	High	high moderate	50 60
		Moderate	high	40
		Low	moderate low	390 280
		Very Low	low limited	1,230 60
		Not Applicable	sandalwood NA	30 30
	> 900 - 1100 mm	High	moderate	10
		Moderate	high	20

OCL	> 300 - 500 mm	Moderate	high moderate	130 110
		Low	low	1,470
		Very Low	low limited	6,150 4,720
		Not Applicable	sandalwood NA	410 27,550
	> 500 - 700 mm	Low	moderate low	300 350
		Very Low	low limited	9,260 3,340
		Not Applicable	limited sandalwood NA	30 530 2,480
	> 700 - 900 mm	High	high moderate	40 110
		Moderate	high	250
		Low	moderate low	120 10
		Very Low	low	280
	> 900 - 1100 mm	Moderate	high	20
PRIV	> 300 - 500 mm	Moderate	high moderate	590 220
		Low	low	5,970
		Very Low	low limited	81,770 92,350
		Not Applicable	sandalwood NA	8,390 353,920
	> 500 - 700 mm	Low	moderate	26,630

			low	21,000
		Very Low	moderate low limited	20 436,750 171,830
		Not Applicable	limited sandalwood NA	2,130 26,380 137,290
	> 700 - 900 mm	High	high moderate	1,000 2,390
		Moderate	high moderate low	1,880 270 60
		Low	moderate low	4,630 1,500
		Very Low	moderate low limited	150 66,040 2,030
		Not Applicable	limited sandalwood NA	150 380 340
	> 900 - 1100 mm	High	moderate	80
		Moderate	high	330
		Not Applicable	NA	30
Total catchment area (ha)				**16,258,140**
Area forested (ha)				**4,477,960**
Proportion of area forested				**27.54%**

COOPER CREEK

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Not Applicable	sandalwood	10
	> 500 - 700 mm	Low	moderate	10
		Very Low	low	30
			limited	100
		Not Applicable	sandalwood	80
			NA	90
PRIV	> 500 - 700 mm	Not Applicable	sandalwood	20
Total catchment area (ha)				**1,970**
Area forested (ha)				**340**
Proportion of area forested				**17.26%**

DARLING RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	<= 300mm	Moderate	high	2,630
		Low	high	1,270
			low	3,190
		Very Low	low	5,250
		Not Applicable	NA	458,170
	> 300 - 500 mm	Moderate	high	2,090
		Low	low	454,460
		Very Low	low	5,120
		Not Applicable	NA	2,937,900
MUF	<= 300mm	Moderate	high	20
		Not Applicable	NA	270
	> 300 - 500 mm	Moderate	high	50
		Low	moderate	3,690
			low	1,830
		Very Low	low	20
		Not Applicable	NA	38,410
NCR	<= 300mm	Very Low	low	110
		Not Applicable	NA	39,550
	> 300 - 500 mm	Low	low	5,140
		Not Applicable	NA	67,110

ND	<= 300mm	Moderate	high	860
		Low	high	110
		Very Low	low	2,730
		Not Applicable	NA	1,960
	> 300 - 500 mm	Moderate	high	290
		Very Low	low	30
		Not Applicable	NA	1,890
OCL	<= 300mm	Moderate	high	160
		Low	high	40
		Very Low	low	200
		Not Applicable	NA	2,480
	> 300 - 500 mm	Moderate	high	70
		Low	moderate	4,230
			low	1,360
		Very Low	low	150
		Not Applicable	NA	37,020
PRIV	<= 300mm	Moderate	high	1,570
		Low	high	250
		Very Low	low	1,710
		Not Applicable	NA	2,490
	> 300 - 500 mm	Moderate	high	560
		Low	low	6,150
		Very Low	low	510
		Not Applicable	NA	34,160

Total catchment area (ha)				**11,282,000**
Area forested (ha)				**4,127,260**
Proportion of area forested				**36.58%**

FITZROY RIVER (QLD)

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Moderate	high	220
		Low	moderate	250
		Very Low	low	1,520
			limited	470
		Not Applicable	limited	10
			NA	20
MUF	> 500 - 700 mm	Low	moderate	90
		Very Low	low	150
			limited	60
NCR	> 500 - 700 mm	Moderate	high	100
		Low	moderate	10
		Very Low	low	610
			limited	160
ND	> 500 - 700 mm	Very Low	low	10
			limited	10
OCL	> 500 - 700 mm	Very Low	low	20
			limited	10
PRIV	> 500 - 700 mm	Low	moderate	300
		Very Low	low	560
			limited	180
		Not Applicable	sandalwood	10
			NA	10
Total catchment area (ha)				**8,680**
Area forested (ha)				**4,780**
Proportion of area forested				**55.07%**

GOULBURN RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 1100 mm	Very High	very high	10
			high	210
		Moderate	moderate	10
	> 700 - 900 mm	Very High	high	80
		Moderate	moderate	850
			low	180
		Low	low	10
	> 900 - 1100 mm	Very High	high	110
		Moderate	moderate	180
			low	180
		Low	low	10
MUF	> 1100 mm	Very High	very high	23,390
			high	36,890
		High	high	90
			moderate	980
		Moderate	moderate	21,610
		Low	moderate	10
			low	1,570
		Very Low	low	490
		Not Applicable	NA	9,040
	> 300 - 500 mm	Moderate	high	1,080
		Low	moderate	30
			low	1,040
		Very Low	very low	480
		Not Applicable	NA	90
	> 500 - 700 mm	Moderate	moderate	80

			low	30
		Low	low	80
		Very Low	very low limited	19,110 170
		Not Applicable	NA	1,700
	> 700 - 900 mm	Very High	very high high	690 7,330
		High	high moderate low	250 50 570
		Moderate	moderate low	23,200 1,400
		Low	low	1,640
		Not Applicable	NA	480
	> 900 - 1100 mm	Very High	very high high moderate	17,920 42,200 460
		High	high moderate low	2,670 100 320
		Moderate	moderate low	55,360 1,220
		Low	moderate low	40 7,690
		Very Low	low	940
		Not Applicable	NA	51,030
NCR	> 1100 mm	Very High	very high high	3,760 1,260
		Moderate	moderate	470

		Low	low	10
		Very Low	limited	20
		Not Applicable	NA	2,440
	> 300 - 500 mm	Moderate	high	660
		Low	low	6,100
		Very Low	very low limited	10 30
		Not Applicable	NA	700
	> 500 - 700 mm	Very High	high moderate	330 160
		High	high low	30 30
		Moderate	moderate low	120 120
		Low	low	2,840
		Very Low	very low limited	13,160 640
		Not Applicable	NA	4,170
	> 700 - 900 mm	Very High	very high high	1,800 5,350
		High	high low	320 3,090
		Moderate	moderate low	3,780 1,070
		Low	low	850
		Very Low	limited	30
		Not Applicable	NA	840
	> 900 - 1100 mm	Very High	very high	810

			high moderate	9,570 460
		High	high moderate low	2,200 230 1,320
		Moderate	moderate low	18,410 5,850
		Low	low	10,340
		Very Low	limited	50
		Not Applicable	NA	17,260
ND	> 300 - 500 mm	Low	high moderate low	40 30 380
	> 500 - 700 mm	Very High	high	10
		Low	low	10
		Very Low	very low	10
		Not Applicable	NA	10
	> 700 - 900 mm	Very High	high	10
	> 900 - 1100 mm	Moderate	low	50
OCL	> 1100 mm	Very High	very high high	210 70
		Moderate	moderate	80
		Low	low	10
		Not Applicable	NA	180
	> 300 - 500 mm	Low	low	10
		Very Low	very low	60
		Not Applicable	NA	20
	> 500 - 700 mm	Low	low	350

		Very Low	very low limited	13,080 480
		Not Applicable	NA	1,930
	> 700 - 900 mm	Very High	high	110
		Moderate	moderate low	520 30
		Very Low	low	10
		Not Applicable	NA	90
	> 900 - 1100 mm	Very High	very high high	830 1,380
		High	high low	100 10
		Moderate	moderate	690
		Low	low	310
		Very Low	low	10
		Not Applicable	NA	3,740
PRIV	> 1100 mm	Very High	very high high	290 860
		High	moderate	50
		Moderate	moderate	1,370
		Low	low	20
		Very Low	limited	60
		Not Applicable	NA	20
	> 300 - 500 mm	Moderate	high	290
		Low	moderate low	50 1,750
		Very Low	very low limited	100 30

		Not Applicable	NA	820
	> 500 - 700 mm	Very High	high moderate	850 340
		High	high low	240 450
		Moderate	moderate low	1,530 3,380
		Low	low	3,270
		Very Low	very low limited	6,940 1,460
		Not Applicable	NA	5,850
	> 700 - 900 mm	Very High	very high high moderate	40 5,720 160
		High	high moderate low	1,560 120 5,040
		Moderate	moderate low	16,700 7,530
		Low	low	2,040
		Very Low	low limited	10 330
		Not Applicable	NA	1,610
	> 900 - 1100 mm	Very High	very high high moderate	340 2,450 150
		High	high moderate low	570 730 1,450

		Moderate	moderate low	4,840 2,580
		Low	low	1,230
		Very Low	limited	240
		Not Applicable	NA	1,150
Total catchment area (ha)				**1,679,830**
Area forested (ha)				**567,510**
Proportion of area forested				**33.78%**

GWYDIR RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Moderate	moderate	920
		Very Low	low	200
		Not Applicable	NA	3,930
	> 500 - 700 mm	Moderate	moderate	880
		Low	high	2,710
			low	3,270
		Very Low	low	2,670
			limited	10
		Not Applicable	Unknown	110
			NA	14,930
	> 700 - 900 mm	High	moderate	10
		Moderate	low	1,400
		Low	high	8,740
			moderate	190
			low	25,050
		Very Low	low	3,300
			limited	2,000
		Not Applicable	Unknown	1,100
			NA	5,520
MUF	> 500 - 700 mm	Low	high	70
			low	150
		Not Applicable	Unknown	10
	> 700 - 900 mm	Moderate	low	210
		Low	high	800
			low	4,460
		Very Low	low	40
			limited	90
		Not Applicable	Unknown	130
			NA	200
NCR	> 500 - 700 mm	Moderate	moderate	1,330

		Low	high	3,690
			low	2,960
		Very Low	low	4,470
			limited	10
		Not Applicable	Unknown	40
			NA	670
	> 700 - 900 mm	High	moderate	70
		Moderate	moderate	4,760
			low	1,100
		Low	high	2,060
			moderate	100
			low	10,250
		Very Low	low	1,240
			limited	2,120
		Not Applicable	Unknown	140
			NA	2,320
ND	> 300 - 500 mm	Moderate	moderate	410
		Not Applicable	NA	220
	> 500 - 700 mm	Moderate	moderate	680
		Low	high	120
			low	110
		Very Low	low	650
			limited	10
		Not Applicable	Unknown	10
			NA	970
	> 700 - 900 mm	Moderate	low	100
		Low	high	260
			moderate	60
			low	1,130
		Very Low	low	430
			limited	190
		Not Applicable	Unknown	40
			NA	430

OCL	> 300 - 500 mm	Moderate	moderate	990
		Very Low	low	50
		Not Applicable	NA	5,760
	> 500 - 700 mm	Moderate	moderate	930
		Low	high	680
			low	5,080
		Very Low	low	1,150
			limited	50
		Not Applicable	Unknown	160
			NA	7,330
	> 700 - 900 mm	High	moderate	10
		Moderate	moderate	10
			low	1,100
		Low	high	2,020
			moderate	150
			low	7,920
		Very Low	low	3,500
			limited	1,300
		Not Applicable	Unknown	480
			NA	3,850
PRIV	> 300 - 500 mm	Moderate	moderate	1,720
		Very Low	low	300
		Not Applicable	NA	13,000
	> 500 - 700 mm	Moderate	moderate	3,530
		Low	high	17,230
			moderate	270
			low	16,980
		Very Low	low	9,830
			limited	80
		Not Applicable	Unknown	1,030
			NA	61,100
	> 700 - 900 mm	High	moderate	820
		Moderate	moderate	1,990

			low	12,320
		Low	high moderate low	41,530 2,300 68,760
		Very Low	low limited	30,760 27,900
		Not Applicable	Unknown NA	5,290 50,340
Total catchment area (ha)				**2,658,060**
Area forested (ha)				**535,850**
Proportion of area forested				**20.16%**

HAWKESBURY RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
MUF	> 500 - 700 mm	Low	low	10
		Not Applicable	Unknown	30
	> 700 - 900 mm	Very High	very high	10
			high	10
		High	high	20
		Low	low	20
		Very Low	low	30
		Not Applicable	Unknown	60
			NA	60
NCR	> 700 - 900 mm	Very High	high	140
		High	high	50
		Low	low	10
		Very Low	low	50
		Not Applicable	Unknown	70
			NA	30
OCL	> 500 - 700 mm	Low	low	30
	> 700 - 900 mm	Very High	high	20
		Low	low	20
		Not Applicable	Unknown	50
PRIV	> 500 - 700 mm	Low	low	110
		Very Low	low	40
		Not Applicable	NA	10
	> 700 - 900 mm	Very High	high	30
		High	high	10

		Moderate	moderate	10
		Low	low	40
		Very Low	low	10
		Not Applicable	Unknown	90
	> 900 - 1100 mm	Very High	high	10
Total catchment area (ha)				**3,480**
Area forested (ha)				**1,080**
Proportion of area forested				**31.03%**

HOPKINS RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
NCR	> 500 - 700 mm	Low	low	30
		Not Applicable	NA	10
Total catchment area (ha)				**190**
Area forested (ha)				**40**
Proportion of area forested				**21.05%**

HUNTER RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Not Applicable	Unknown	70
MUF	> 500 - 700 mm	Not Applicable	Unknown NA	70 20
	> 700 - 900 mm	Very High	very high	60
		Very Low	low	20
		Not Applicable	NA	10
NCR	> 500 - 700 mm	Very High	very high	10
		Low	low	10
		Very Low	low	40
		Not Applicable	Unknown	180
	> 700 - 900 mm	Low	low	60
		Very Low	low	10
OCL	> 500 - 700 mm	Low	low	10
		Very Low	low	120
		Not Applicable	Unknown NA	120 60
PRIV	> 500 - 700 mm	Moderate	moderate	10
		Low	moderate low	30 40
		Very Low	low	30
		Not Applicable	Unknown NA	270 20
	> 700 - 900 mm	Low	low	50
		Very Low	low	10
Total catchment area (ha)				**2,320**
Area forested (ha)				**1,330**
Proportion of area forested				**57.33%**

KIEWA RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 1100 mm	Very High	high	60
		Moderate	moderate	250
		Not Applicable	NA	260
	> 700 - 900 mm	Moderate	moderate low	40 30
		Not Applicable	NA	70
	> 900 - 1100 mm	Moderate	moderate	20
MUF	> 1100 mm	Very High	very high high	290 2,290
		High	high moderate	280 20
		Moderate	moderate low	8,400 30
		Low	low	1,120
		Not Applicable	NA	9,580
	> 700 - 900 mm	High	high moderate	20 610
		Moderate	moderate low	590 2,740
		Low	low	60
		Not Applicable	NA	1,750
	> 900 - 1100 mm	Very High	very high high	10 860

		High	moderate	2,770
		Moderate	moderate low	4,360 4,970
		Low	low	540
		Not Applicable	NA	6,330
NCR	> 1100 mm	Very High	very high high	650 2,640
		High	moderate	170
		Moderate	moderate	1,580
		Low	low	320
		Not Applicable	NA	12,230
	> 700 - 900 mm	High	moderate	480
		Moderate	moderate low	10 2,150
		Low	low	30
		Not Applicable	NA	10
	> 900 - 1100 mm	Moderate	moderate low	20 50
ND	> 700 - 900 mm	Moderate	low	60
		Low	low	70
		Very Low	limited	50
		Not Applicable	NA	20
OCL	> 1100 mm	Very High	high	40
		High	high	30
		Moderate	moderate	120
		Low	low	10
		Not Applicable	NA	1,050

	> 700 - 900 mm	Moderate	moderate	120
		Low	low	10
		Not Applicable	NA	290
PRIV	> 1100 mm	High	high moderate	40 30
		Moderate	moderate low	1,430 40
		Low	low	330
		Not Applicable	NA	560
	> 500 - 700 mm	Moderate	low	50
		Low	low	40
		Very Low	limited	190
	> 700 - 900 mm	High	moderate	450
		Moderate	moderate low	340 3,170
		Low	low	860
		Very Low	limited	230
		Not Applicable	NA	140
	> 900 - 1100 mm	High	high moderate	10 490
		Moderate	moderate low	630 1,710
		Low	low	260
		Not Applicable	NA	480
Total catchment area (ha)				**190,570**
Area forested (ha)				**82,040**
Proportion of area forested				**43.05%**

LACHLAN RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	<= 300mm	Not Applicable	NA	21,040
	> 300 - 500 mm	Moderate	high	8,350
			moderate	220
		Low	high	6,070
			moderate	12,970
			low	489,990
		Very Low	low	14,570
			limited	110
		Not Applicable	Unknown	20
			NA	394,210
	> 500 - 700 mm	Moderate	moderate	930
		Low	high	260
			moderate	800
			low	430
		Very Low	low	790
			limited	10
		Not Applicable	Unknown	18,950
			NA	160
	> 700 - 900 mm	Very High	high	110
		High	high	40
		Moderate	very high	10
			moderate	260
		Low	moderate	350
			low	4,010
		Not Applicable	Unknown	21,150
MUF	> 300 - 500 mm	Moderate	high	380
			moderate	40
		Low	high	310
			moderate	22,860
			low	4,830

		Very Low	low	20,760
		Not Applicable	NA	6,290
	> 500 - 700 mm	Moderate	moderate	30
		Low	high moderate	120 470
		Very Low	low	2,200
		Not Applicable	Unknown NA	12,760 310
	> 700 - 900 mm	Moderate	moderate	30
		Low	low	4,750
		Not Applicable	Unknown	10,330
NCR	> 300 - 500 mm	Moderate	high moderate	70 40
		Low	high moderate low	130 290 79,860
		Very Low	low	430
		Not Applicable	NA	155,340
	> 500 - 700 mm	Moderate	moderate	300
		Low	low	1,000
		Not Applicable	Unknown NA	32,830 130
	> 700 - 900 mm	Very High	high	490
		High	high	100
		Low	low	6,420
		Very Low	low	10
		Not Applicable	Unknown NA	30,140 1,170
ND	> 300 - 500 mm	Moderate	high moderate	2,880 60
		Low	high moderate	5,440 7,830
		Very Low	low	20

			limited	20
		Not Applicable	NA	3,190
	> 500 - 700 mm	Moderate	moderate	170
		Low	high	590
			moderate	350
			low	30
		Very Low	low	60
		Not Applicable	Unknown	1,140
	> 700 - 900 mm	Moderate	moderate	30
		Low	moderate	10
			low	300
		Not Applicable	Unknown	1,540
OCL	<= 300mm	Not Applicable	NA	40
	> 300 - 500 mm	Moderate	high	1,950
			moderate	370
		Low	high	1,750
			moderate	18,110
			low	200
		Very Low	low	13,030
			limited	220
		Not Applicable	Unknown	20
			NA	14,500
	> 500 - 700 mm	Moderate	high	40
			moderate	1,340
		Low	high	350
			moderate	1,070
			low	920
		Very Low	low	2,810
			limited	220
		Not Applicable	Unknown	16,140
			NA	680
	> 700 - 900 mm	Moderate	moderate	190
		Low	moderate	460

			low	4,250
		Not Applicable	Unknown	17,840
			NA	40
PRIV	<= 300mm	Not Applicable	NA	90
	> 300 - 500 mm	Moderate	high	8,530
			moderate	2,280
		Low	high	12,450
			moderate	60,450
			low	110,520
		Very Low	low	64,730
			limited	730
		Not Applicable	Unknown	90
			NA	92,120
	> 500 - 700 mm	Moderate	high	20
			moderate	23,920
		Low	high	3,800
			moderate	5,300
			low	11,580
		Very Low	low	8,480
			limited	180
		Not Applicable	Unknown	180,420
			NA	2,190
	> 700 - 900 mm	Very High	high	210
		High	high	190
		Moderate	moderate	6,320
		Low	moderate	1,130
			low	15,580
		Very Low	low	60
		Not Applicable	Unknown	133,080
			NA	10
Total catchment area (ha)				**9,087,420**
Area forested (ha)				**2,255,690**
Proportion of area forested				**24.82%**

LAKE GEORGE

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Low	low	2,200
		Very Low	low	150
		Not Applicable	NA	30
MUF	> 500 - 700 mm	Very Low	low	30
NCR	> 500 - 700 mm	Very High	high	1,270
		High	high	50
		Low	low	480
ND	> 500 - 700 mm	Low	low	10
		Very Low	low	10
			limited	10
OCL	> 500 - 700 mm	Low	low	900
		Very Low	low	240
			limited	80
		Not Applicable	Unknown	20
			NA	80
PRIV	> 500 - 700 mm	Very High	high	430
			moderate	20
		High	high	100
			moderate	10
		Low	low	5,310
		Very Low	low	3,040
			limited	1,690
		Not Applicable	Unknown	250
			NA	470
Total catchment area (ha)				**94,160**
Area forested (ha)				**16,880**
Proportion of area forested				**17.93%**

LODDON RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Low	low	30
		Not Applicable	NA	90
	> 700 - 900 mm	Very High	high	40
		High	moderate	10
		Moderate	low	60
		Low	low	310
		Very Low	very low	10
		Not Applicable	NA	80
MUF	> 300 - 500 mm	Moderate	high	16,670
			moderate	10
		Low	moderate	40
			low	540
		Very Low	very low	18,710
			limited	2,170
		Not Applicable	NA	5,690
	> 500 - 700 mm	Moderate	low	210
		Low	low	1,370
		Very Low	very low	21,110
			limited	1,610
		Not Applicable	NA	6,070
	> 700 - 900 mm	Very High	high	5,150
			moderate	840
		High	moderate	2,750
		Moderate	low	980
		Low	low	2,350
		Very Low	very low	10
		Not Applicable	NA	4,480
NCR	> 300 - 500 mm	Moderate	high	1,980
		Low	high	30
			low	580

		Very Low	very low limited	11,590 7,760
		Not Applicable	NA	22,800
	> 500 - 700 mm	High	high	60
		Low	low	550
		Very Low	very low limited	12,450 1,750
		Not Applicable	NA	7,510
	> 700 - 900 mm	Very High	high moderate	200 10
		Moderate	low	520
		Low	low	1,980
		Very Low	limited	10
		Not Applicable	NA	2,510
ND	> 300 - 500 mm	Low	high moderate	20 40
		Very Low	very low limited	20 20
		Not Applicable	NA	180
	> 500 - 700 mm	Very Low	very low limited	80 10
		Not Applicable	NA	60
	> 700 - 900 mm	Very High	high	20
		Moderate	low	30
		Low	low	60
		Not Applicable	NA	20
OCL	> 300 - 500 mm	Moderate	high	260
		Low	low	70
		Very Low	very low limited	490 560
		Not Applicable	NA	1,090
	> 500 - 700 mm	Low	low	10
		Very Low	very low	920

			limited	580
		Not Applicable	NA	890
	> 700 - 900 mm	Very High	high	60
		Moderate	low	90
		Low	low	100
		Not Applicable	NA	100
PRIV	> 300 - 500 mm	Moderate	high moderate	930 10
		Low	low	660
		Very Low	very low limited	6,050 4,760
		Not Applicable	NA	14,470
	> 500 - 700 mm	Moderate	low	120
		Low	low	1,140
		Very Low	very low limited	8,040 4,190
		Not Applicable	NA	6,510
	> 700 - 900 mm	Very High	high moderate	3,070 60
		High	high moderate	110 400
		Moderate	low	920
		Low	low	1,850
		Very Low	low very low limited	10 10 110
		Not Applicable	NA	2,310
Total catchment area (ha)				**1,563,370**
Area forested (ha)				**225,190**
Proportion of area forested				**14.40%**

LOGAN-ALBERT RIVERS

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
NCR	> 900 - 1100 mm	Moderate	high	40
		Not Applicable	NA	20
ND	> 900 - 1100 mm	Moderate	high	10
PRIV	> 900 - 1100 mm	Moderate	high	10
Total catchment area (ha)				**90**
Area forested (ha)				**80**
Proportion of area forested				**88.89%**

LOWER MURRAY RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	<= 300mm	Moderate	high	100
		Very Low	low	20
		Not Applicable	NA	939,760
	> 300 - 500 mm	Not Applicable	NA	38,070
	> 500 - 700 mm	High	moderate	10
		Moderate	low	10
		Not Applicable	NA	50
MUF	<= 300mm	Moderate	high	570
		Very Low	low	40
			very low	30
		Not Applicable	NA	120
	> 500 - 700 mm	High	low	10
		Very Low	limited	20
		Not Applicable	NA	10
NCR	<= 300mm	Moderate	high	310
		Very Low	very low	20
		Not Applicable	NA	287,150
	> 300 - 500 mm	Not Applicable	NA	3,880
	> 500 - 700 mm	High	low	140
		Very Low	limited	40
		Not Applicable	NA	1,730
ND	<= 300mm	Moderate	high	70
		Very Low	very low	10
		Not Applicable	NA	2,730
	> 300 - 500 mm	Not Applicable	NA	1,650
	> 500 - 700 mm	High	low	30
		Moderate	low	20
		Very Low	limited	80
		Not Applicable	NA	160
OCL	<= 300mm	Not Applicable	NA	2,730

	> 300 - 500 mm	Not Applicable	NA	3,640
	> 500 - 700 mm	High	low	30
		Moderate	low	10
		Very Low	limited	120
		Not Applicable	NA	360
PRIV	<= 300mm	Moderate	high	790
		Very Low	low	40
		Not Applicable	NA	43,260
	> 300 - 500 mm	Not Applicable	NA	67,300
	> 500 - 700 mm	High	moderate low	140 650
		Moderate	low	330
		Very Low	limited	2,420
		Not Applicable	NA	6,670
Total catchment area (ha)				**5,819,140**
Area forested (ha)				**1,405,330**
Proportion of area forested				**24.15%**

MACLEAY RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
PRIV	> 700 - 900 mm	Very Low	limited	10
Total catchment area (ha)				**1,930**
Area forested (ha)				**10**
Proportion of area forested				**0.52%**

MACQUARIE-BOGAN RIVERS

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Moderate	high	3,770
			moderate	5,520
		Low	moderate	5,740
			low	57,310
		Very Low	low	125,150
			limited	940
		Not Applicable	NA	562,930
	> 500 - 700 mm	Very High	high	20
		Moderate	high	300
			moderate	2,180
		Low	high	160
			moderate	9,630
			low	1,830
		Very Low	low	16,100
			limited	370
		Not Applicable	Unknown	10,720
			NA	6,480
	> 700 - 900 mm	Very High	high	30
		Low	moderate	50
			low	2,060
		Very Low	low	70
		Not Applicable	Unknown	22,830
			NA	230
MUF	> 300 - 500 mm	Moderate	moderate	730
		Low	moderate	1,230
			low	60

		Very Low	low	16,220
		Not Applicable	NA	4,260
	> 500 - 700 mm	Very High	very high	70
		Moderate	moderate	80
		Low	moderate low	3,070 390
		Very Low	low	3,940
		Not Applicable	Unknown NA	4,000 380
	> 700 - 900 mm	Very High	very high high moderate	330 1,370 30
		High	high	140
		Low	moderate low	390 3,660
		Very Low	low limited	6,170 20
		Not Applicable	Unknown NA	11,910 790
	> 900 - 1100 mm	Very High	high	10
		Very Low	limited	10
NCR	> 300 - 500 mm	Moderate	high	5,690
		Very Low	low	1,080
		Not Applicable	NA	2,510
	> 500 - 700 mm	Very High	very high high	80 350
		Moderate	moderate	80
		Low	high	140

			moderate low	10,260 9,450
		Very Low	low limited	2,930 30
		Not Applicable	Unknown NA	16,440 27,750
	> 700 - 900 mm	Low	moderate low	310 6,170
		Very Low	low	520
		Not Applicable	Unknown NA	11,250 300
ND	> 300 - 500 mm	Moderate	high moderate	500 2,490
		Low	moderate low	160 1,350
		Very Low	low	310
		Not Applicable	NA	4,340
	> 500 - 700 mm	Moderate	high moderate	100 2,090
		Low	moderate low	370 10
		Very Low	low limited	250 260
		Not Applicable	Unknown NA	1,070 510
	> 700 - 900 mm	Very High	high	10
		Low	moderate low	10 70
		Not	Unknown	1,630

		Applicable		
OCL	> 300 - 500 mm	Moderate	high moderate	1,470 3,610
		Low	moderate low	3,710 6,440
		Very Low	low limited	26,830 30
		Not Applicable	NA	30,390
	> 500 - 700 mm	Very High	very high high	110 10
		Moderate	high moderate	170 1,580
		Low	high moderate low	230 5,240 1,510
		Very Low	low limited	9,670 490
		Not Applicable	Unknown NA	16,620 6,310
	> 700 - 900 mm	Very High	very high high	10 40
		High	high	10
		Low	moderate low	10 560
		Very Low	low	120
		Not Applicable	Unknown NA	17,490 40
	> 900 - 1100 mm	Very High	high	30
		High	high	10

PRIV	> 300 - 500 mm	Moderate	high moderate	16,780 48,870
		Low	moderate low	15,050 82,560
		Very Low	low limited	246,380 40
		Not Applicable	NA	271,570
	> 500 - 700 mm	Very High	very high high	170 1,040
		Moderate	high moderate	1,190 28,320
		Low	high moderate low	1,610 79,940 10,000
		Very Low	low limited	104,020 6,500
		Not Applicable	Unknown NA	117,010 54,140
	> 700 - 900 mm	Very High	very high high	20 780
		High	high	100
		Moderate	low	40
		Low	moderate low	70 7,490
		Very Low	low	1,300
		Not Applicable	Unknown NA	159,360 430
	> 900 - 1100 mm	Very High	high	140
		High	high	50

		Very Low	limited	10
Total catchment area (ha)				**7,477,660**
Area forested (ha)				**2,392,270**
Proportion of area forested				**31.99%**

MALLEE

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	<= 300mm	Not Applicable	NA	2,740
	> 300 - 500 mm	Not Applicable	NA	11,190
MUF	<= 300mm	Moderate	high	100
		Very Low	very low	10
		Not Applicable	NA	28,850
	> 300 - 500 mm	Moderate	high	190
		Low	high	20
			low	320
		Very Low	limited	90
		Not Applicable	NA	172,600
NCR	<= 300mm	Moderate	high	470
		Very Low	limited	890
		Not Applicable	NA	49,700
	> 300 - 500 mm	Moderate	high	1,430
		Low	high	110
			low	3,550
		Very Low	limited	30
		Not Applicable	NA	950,580
ND	<= 300mm	Moderate	high	170
		Not Applicable	NA	670
	> 300 - 500 mm	Low	high	50
		Not Applicable	NA	3,040
OCL	<= 300mm	Moderate	high	10
		Not Applicable	NA	4,460
	> 300 - 500 mm	Moderate	high	20
		Low	high	20
			low	50
		Not Applicable	NA	8,240
PRIV	<= 300mm	Moderate	high	70
		Very Low	limited	1,110

		Not Applicable	NA	33,340
	> 300 - 500 mm	Moderate	high	100
		Low	low	120
		Very Low	limited	70
		Not Applicable	NA	111,580
Total catchment area (ha)				**4,145,300**
Area forested (ha)				**1,385,990**
Proportion of area forested				**33.44%**

MANNING RIVER

Tenure Type	Rainfall	MPAI Group	Commerciality	Area (ha)
PRIV	> 700 - 900 mm	Very High	high	20
		Very Low	limited	10
Total catchment area (ha)				**190**
Area forested (ha)				**30**
Proportion of area forested				**15.79%**

MANNING RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
PRIV	> 700 - 900 mm	Very High	high	20
		Very Low	limited	10
Total catchment area (ha)				**190**
Area forested (ha)				**30**
Proportion of area forested				**15.79%**

MARIBYRNONG RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
MUF	> 700 - 900 mm	High	moderate	10
PRIV	> 700 - 900 mm	Very High	high	30
		Not Applicable	NA	10
Total catchment area (ha)				**210**
Area forested (ha)				**50**
Proportion of area forested				**23.81%**

MOONIE RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Very Low	low	2,150
		Not Applicable	NA	22,510
	> 500 - 700 mm	Very Low	low	22,890
			limited	23,550
		Not Applicable	limited	50
			sandalwood	280
			NA	1,660
MUF	> 300 - 500 mm	Not Applicable	NA	340
	> 500 - 700 mm	Very Low	low	28,640
			limited	1,060
		Not Applicable	sandalwood	10
			NA	180
NCR	> 500 - 700 mm	Very Low	low	1,920
			limited	4,000
		Not Applicable	limited	1,520
			NA	50
ND	> 300 - 500 mm	Very Low	low	30
			limited	20
		Not Applicable	NA	380
	> 500 - 700 mm	Very Low	low	5,120
			limited	9,050
		Not Applicable	limited	60
			sandalwood	170
			NA	1,900
OCL	> 300 - 500 mm	Very Low	low	20
		Not Applicable	NA	150
	> 500 - 700 mm	Very Low	low	1,360
			limited	1,840
		Not Applicable	sandalwood	260
			NA	710

PRIV	> 300 - 500 mm	Very Low	low limited	200 670
		Not Applicable	NA	120
	> 500 - 700 mm	Very Low	low limited	30,240 101,210
		Not Applicable	limited sandalwood NA	330 1,840 8,140
Total catchment area (ha)				**1,434,290**
Area forested (ha)				**274,630**
Proportion of area forested				**19.15%**

MURRAY-RIVERINA

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Moderate	high	340
		Low	high	270
			moderate	1,330
		Very Low	low	1,850
		Not Applicable	NA	1,100
MUF	> 300 - 500 mm	Moderate	high	3,530
		Low	high	3,280
			moderate	72,130
		Very Low	low	1,850
		Not Applicable	NA	1,940
	> 500 - 700 mm	Not Applicable	NA	330
NCR	> 300 - 500 mm	Moderate	high	2,630
		Low	high	290
			low	60
		Very Low	limited	10
		Not Applicable	NA	10
	> 500 - 700 mm	Low	low	10
ND	> 300 - 500 mm	Moderate	high	760
		Low	high	1,560
			moderate	4,610

			low	10
		Very Low	low	440
		Not Applicable	NA	380
	> 500 - 700 mm	Low	high	20
OCL	> 300 - 500 mm	Moderate	high	350
		Low	high moderate	130 2,040
		Very Low	low	4,160
		Not Applicable	NA	340
	> 500 - 700 mm	Low	low	190
		Not Applicable	Unknown NA	10 120
PRIV	> 300 - 500 mm	Moderate	high	7,850
		Low	high moderate low	2,040 43,980 20
		Very Low	low	32,520
		Not Applicable	NA	7,080
	> 500 - 700 mm	Low	high low	100 2,030
		Not Applicable	Unknown NA	430 90
	> 700 - 900	Low	low	80

	mm			
Total catchment area (ha)				**1,503,720**
Area forested (ha)				**202,300**
Proportion of area forested				**13.45%**

MURRUMBIDGEE RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Moderate	high	1,360
		Low	high	3,960
			moderate	680
			low	80
		Very Low	low	1,350
		Not Applicable	Unknown	70
			NA	11,740
	> 500 - 700 mm	Very High	very high	220
			high	70
			moderate	450
		High	moderate	2,290
		Moderate	moderate	2,700
		Low	moderate	90
			low	4,160
		Very Low	low	2,590
			limited	5,750
			Unknown	120
		Not Applicable	Unknown	2,560
			NA	17,840
	> 700 - 900 mm	Very High	very high	220
			high	140
			moderate	360
		High	high	30
			moderate	1,610
		Moderate	moderate	240
		Low	moderate	70
			low	8,370

		Very Low	moderate low limited Unknown	1,150 4,560 4,910 3,580
		Not Applicable	Unknown NA	1,050 7,700
	> 900 - 1100 mm	High	moderate	60
		Low	moderate	190
		Very Low	low Unknown	220 710
MUF	> 300 - 500 mm	Moderate	high	1,770
		Low	high moderate low	10,660 15,900 200
		Very Low	low limited	430 30
		Not Applicable	NA	7,490
	> 500 - 700 mm	Very High	high moderate	10 10
		Low	moderate low	10 160
		Very Low	low limited	570 190
		Not Applicable	Unknown NA	370 500
	> 700 - 900 mm	Very High	very high high moderate	230 3,270 1,080
		High	high	30

			moderate	5,470
		Moderate	moderate	290
		Low	moderate	1,040
			low	1,630
		Very Low	moderate	5,120
			low	6,620
			limited	1,370
			Unknown	2,940
		Not Applicable	Unknown	190
			NA	3,050
	> 900 - 1100 mm	Very High	very high	7,490
		High	moderate	4,110
		Low	moderate	6,070
		Very Low	moderate	30
			low	4,870
			limited	190
			Unknown	2,580
		Not Applicable	NA	13,010
NCR	> 300 - 500 mm	Moderate	high	190
		Low	high	50
			moderate	60
			low	10
		Very Low	limited	40
		Not Applicable	Unknown	190
			NA	12,210
	> 500 - 700 mm	Very High	very high	660
			high	1,170
			moderate	460
		High	high	20

			moderate	2,030
		Moderate	moderate	1,250
		Low	moderate low	140 16,080
		Very Low	low limited Unknown	7,970 7,320 3,390
		Not Applicable	Unknown NA	2,850 17,940
	> 700 - 900 mm	Very High	very high high moderate	20 6,530 2,780
		High	high moderate	20 17,660
		Moderate	moderate	6,500
		Low	moderate low	2,080 77,420
		Very Low	moderate low limited Unknown	8,670 25,340 4,470 8,800
		Not Applicable	Unknown NA	170 43,870
	> 900 - 1100 mm	Very High	very high high moderate	6,310 4,000 120
		High	moderate	22,790
		Moderate	moderate	380
		Low	moderate	48,490
		Very Low	moderate	80

			low limited Unknown	14,040 340 7,490
		Not Applicable	NA	83,680
ND	> 300 - 500 mm	Moderate	high	1,310
		Low	high moderate	10,130 1,010
		Very Low	low limited	180 10
		Not Applicable	NA	3,400
	> 500 - 700 mm	High	moderate	110
		Moderate	moderate	10
		Low	moderate low	10 230
		Very Low	low limited	90 340
		Not Applicable	Unknown NA	160 360
	> 700 - 900 mm	High	moderate	70
		Low	low	190
		Very Low	moderate low limited Unknown	30 70 480 10
		Not Applicable	Unknown NA	60 230
	> 900 - 1100 mm	Low	moderate	30
		Very Low	limited	10

			Unknown	20
		Not Applicable	NA	20
OCL	> 300 - 500 mm	Moderate	high moderate	1,170 10
		Low	high moderate low	2,880 1,470 40
		Very Low	low	2,070
		Not Applicable	Unknown NA	30 7,040
	> 500 - 700 mm	Very High	moderate	290
		High	moderate	310
		Moderate	moderate	390
		Low	moderate low	70 3,950
		Very Low	low limited Unknown	2,530 2,110 170
		Not Applicable	Unknown NA	3,130 6,360
	> 700 - 900 mm	Very High	very high high moderate	50 70 120
		High	high moderate	40 390
		Moderate	high moderate	10 10
		Low	moderate low	30 1,160
		Very Low	moderate	360

			low limited Unknown	1,170 1,410 680
		Not Applicable	Unknown NA	360 3,560
	> 900 - 1100 mm	High	moderate	100
		Low	moderate	120
		Very Low	low limited Unknown	240 10 390
		Not Applicable	NA	120
PRIV	> 300 - 500 mm	Moderate	high moderate	12,450 60
		Low	high moderate low	32,610 12,570 110
		Very Low	low limited	23,440 10
		Not Applicable	Unknown NA	510 78,510
	> 500 - 700 mm	Very High	very high high moderate	280 530 1,520
		High	high moderate	40 6,140
		Moderate	moderate	7,640
		Low	moderate low	430 44,140
		Very Low	low	13,560

			limited	23,180
			Unknown	3,030
		Not Applicable	Unknown	53,590
			NA	66,010
	> 700 - 900 mm	Very High	very high	2,100
			high	1,880
			moderate	2,730
		High	high	10
			moderate	4,590
		Moderate	high	10
			moderate	1,990
		Low	moderate	370
			low	21,900
		Very Low	moderate	6,360
			low	12,150
			limited	17,110
			Unknown	27,590
		Not Applicable	Unknown	9,780
			NA	41,160
	> 900 - 1100 mm	Very High	very high	90
			high	10
		High	moderate	1,980
		Low	moderate	2,290
		Very Low	low	2,600
			limited	310
			Unknown	6,700
		Not Applicable	NA	1,430
Total catchment area (ha)				**8,161,490**

Area forested (ha)				**1,276,800**
Proportion of area forested				**15.64%**

NAMOI RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Moderate	high	1,470
			moderate	950
		Not Applicable	NA	18,660
	> 500 - 700 mm	Very High	high	30
		Moderate	high	2,820
			moderate	960
		Low	high	5,290
			moderate	14,690
			low	18,060
		Very Low	low	6,480
			limited	1,430
		Not Applicable	Unknown	3,340
			NA	36,780
	> 700 - 900 mm	Very High	very high	450
			high	610
		High	moderate	380
		Moderate	low	90
		Low	moderate	400
			low	5,270
		Very Low	low	100
			limited	380
		Not Applicable	Unknown	5,590
			NA	820
	> 900 - 1100 mm	Very High	high	40
		High	moderate	10

MUF	> 500 - 700 mm	Moderate	high	130
		Low	high moderate low	8,560 43,820 100
		Very Low	low limited	870 9,420
		Not Applicable	Unknown NA	350 55,160
	> 700 - 900 mm	Very High	very high high moderate	650 1,090 10
		High	moderate	1,500
		Low	moderate low	460 2,430
		Very Low	low limited	10 60
		Not Applicable	NA	950
	> 900 - 1100 mm	Very High	high	10
NCR	> 500 - 700 mm	Very High	high	210
		Moderate	high moderate	1,820 3,460
		Low	high moderate low	9,740 77,560 1,100
		Very Low	low limited	7,960 14,730
		Not Applicable	Unknown NA	4,670 56,500
	> 700 - 900 mm	Very High	very high	30

			high	20
		High	moderate	50
		Moderate	moderate low	4,830 10
		Low	moderate low	30 1,870
		Very Low	low limited	10 10
		Not Applicable	Unknown NA	920 120
	> 900 - 1100 mm	Very High	very high high	20 550
		High	moderate	100
		Very Low	limited	80
		Not Applicable	NA	80
ND	> 300 - 500 mm	Moderate	high moderate	100 110
		Not Applicable	NA	160
	> 500 - 700 mm	Moderate	high moderate	2,330 40
		Low	high moderate low	50 330 180
		Very Low	low limited	500 660
		Not Applicable	Unknown NA	520 1,440
	> 700 - 900 mm	Low	moderate	30

			low	250
		Not Applicable	Unknown NA	630 10
OCL	> 300 - 500 mm	Moderate	high moderate	520 80
		Not Applicable	NA	8,370
	> 500 - 700 mm	Very High	high	10
		Moderate	high moderate	1,580 140
		Low	high moderate low	1,070 5,010 3,870
		Very Low	low limited	3,510 1,430
		Not Applicable	Unknown NA	2,700 18,770
	> 700 - 900 mm	Very High	very high high	160 190
		High	moderate	120
		Moderate	low	10
		Low	moderate low	100 2,750
		Very Low	low limited	50 170
		Not Applicable	Unknown NA	4,570 420
PRIV	> 300 - 500 mm	Moderate	high moderate	3,360 350
		Not	NA	27,160

		Applicable		
	> 500 - 700 mm	Very High	high	190
		Moderate	high moderate	10,270 4,600
		Low	high moderate low	32,900 64,960 39,990
		Very Low	low limited	30,780 5,290
		Not Applicable	Unknown NA	67,570 133,840
	> 700 - 900 mm	Very High	very high high moderate	2,810 3,950 20
		High	moderate	2,690
		Moderate	moderate low	100 780
		Low	high moderate low	70 4,800 68,920
		Very Low	low limited	1,310 3,460
		Not Applicable	Unknown NA	82,420 7,520
	> 900 - 1100 mm	Very High	very high high	10 170
		High	moderate	80
		Very Low	limited	30
		Not Applicable	NA	40

Total catchment area (ha)				**4,197,380**
Area forested (ha)				**1,100,540**
Proportion of area forested				**26.22%**

OVENS RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 1100 mm	Moderate	moderate	40
		Low	low	60
		Not Applicable	NA	90
	> 700 - 900 mm	Moderate	low	10
		Not Applicable	NA	20
	> 900 - 1100 mm	Very High	high	10
		High	high moderate	240 110
		Moderate	moderate low	390 580
		Low	low	20
		Not Applicable	NA	410
MUF	> 1100 mm	Very High	very high high	100 3,680
		High	high	70
		Moderate	moderate low	29,290 20
		Low	low	2,680
		Not Applicable	NA	45,550
	> 500 - 700 mm	Moderate	low	810
		Low	low	180
		Not Applicable	NA	50
	> 700 - 900 mm	High	high	270

			moderate	500
		Moderate	moderate low	380 6,540
		Low	low	90
		Not Applicable	NA	190
	> 900 - 1100 mm	Very High	very high high	80 4,240
		High	high moderate	4,750 1,780
		Moderate	moderate low	36,640 18,660
		Low	low	2,320
		Not Applicable	NA	41,320
NCR	> 1100 mm	Very High	very high high	50 4,310
		High	high	390
		Moderate	moderate	7,270
		Low	low	900
		Not Applicable	NA	23,360
	> 500 - 700 mm	Moderate	low	2,430
		Low	low	11,450
		Very Low	very low limited	10 570
		Not Applicable	NA	2,510
	> 700 - 900 mm	High	moderate	40
		Moderate	moderate low	70 7,720
		Low	low	1,820

		Very Low	limited	160
		Not Applicable	NA	4,460
	> 900 - 1100 mm	Very High	very high high	560 3,230
		High	high moderate	2,420 400
		Moderate	moderate low	23,860 2,990
		Low	low	1,940
		Not Applicable	NA	36,100
ND	> 500 - 700 mm	Low	low	60
		Not Applicable	NA	10
	> 900 - 1100 mm	High	high	30
		Moderate	moderate low	20 60
OCL	> 1100 mm	Very High	high	20
		Moderate	moderate	20
		Not Applicable	NA	450
	> 500 - 700 mm	Very Low	limited	20
	> 700 - 900 mm	Moderate	low	50
		Low	low	10
		Not Applicable	NA	50
	> 900 - 1100 mm	High	high	20
		Moderate	low	390
		Not	NA	570

		Applicable		
PRIV	> 1100 mm	High	high	140
		Moderate	moderate low	1,900 20
		Low	low	410
		Not Applicable	NA	710
	> 500 - 700 mm	Moderate	high low	70 970
		Low	low	3,240
		Very Low	very low limited	10 400
		Not Applicable	NA	1,820
	> 700 - 900 mm	High	high moderate	170 300
		Moderate	moderate low	130 8,040
		Low	low	2,930
		Very Low	limited	480
		Not Applicable	NA	1,250
	> 900 - 1100 mm	Very High	high	30
		High	high moderate	1,780 480
		Moderate	moderate low	6,070 6,940
		Low	low	760
		Very Low	limited	10
		Not Applicable	NA	3,850
Total catchment area (ha)				**795,740**

Area forested (ha)				**385,880**
Proportion of area forested				**48.49%**

PAROO RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	<= 300mm	Low	low	280
		Very Low	limited	20
		Not Applicable	NA	329,760
	> 300 - 500 mm	Very Low	low	100
			limited	650
		Not Applicable	NA	597,650
NCR	<= 300mm	Low	low	170
		Very Low	limited	10
		Not Applicable	NA	38,870
	> 300 - 500 mm	Very Low	limited	30
		Not Applicable	NA	5,040
ND	<= 300mm	Not Applicable	NA	2,700
	> 300 - 500 mm	Very Low	limited	110
		Not Applicable	NA	20,160
OCL	<= 300mm	Not Applicable	NA	1,640
	> 300 - 500 mm	Very Low	limited	20
		Not Applicable	NA	7,300
PRIV	<= 300mm	Low	low	20
		Not Applicable	NA	3,890
	> 300 - 500 mm	Very Low	limited	230
		Not Applicable	NA	92,000
Total catchment area (ha)				**7,388,940**
Area forested (ha)				**1,100,650**
Proportion of area forested				**14.90%**

SHOALHAVEN RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Very Low	low	40
MUF	> 700 - 900 mm	Very High	high	100
		Moderate	moderate	120
		Not Applicable	NA	30
NCR	> 500 - 700 mm	Very High	high	80
	> 700 - 900 mm	Very High	high	170
			moderate	10
		High	moderate	10
		Moderate	moderate	250
		Not Applicable	NA	80
PRIV	> 500 - 700 mm	Very High	high	30
		Low	low	50
		Very Low	low	90
Total catchment area (ha)				**1,130**
Area forested (ha)				**1,060**
Proportion of area forested				**93.81%**

SNOWY RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
NCR	> 700 - 900 mm	Very High	very high	30
			high	40
		Not Applicable	NA	210
	> 900 - 1100 mm	Very High	very high	10
		Not Applicable	NA	620
Total catchment area (ha)				**1,410**
Area forested (ha)				**910**
Proportion of area forested				**64.54%**

TAMBO RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
MUF	> 700 - 900 mm	Very High	very high	10
			high	50
			moderate	10
		Low	low	40
		Not Applicable	NA	10
NCR	> 700 - 900 mm	Very High	moderate	10
OCL	> 700 - 900 mm	Not Applicable	NA	20
Total catchment area (ha)				**160**
Area forested (ha)				**150**
Proportion of area forested				**93.75%**

THOMSON RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
MUF	> 1100 mm	Very High	very high	10
			high	10
	> 900 - 1100 mm	Very High	very high	10
			high	130
		Not Applicable	NA	230
NCR	> 900 - 1100 mm	Not Applicable	NA	160
Total catchment area (ha)				**580**
Area forested (ha)				**550**
Proportion of area forested				**94.83%**

TUROSS RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
MUF	> 700 - 900 mm	Very High	high	20
			moderate	10
		High	high	10
NCR	> 700 - 900 mm	Very High	high	50
			moderate	20
		High	moderate	20
		Low	low	10
		Very Low	limited	20
PRIV	> 500 - 700 mm	Very High	moderate	20
		High	moderate	10
		Not Applicable	Unknown	10
			NA	30
	> 700 - 900 mm	Very High	very high	10
			moderate	10
		Low	low	40
		Very Low	limited	100
		Not Applicable	Unknown	70
Total catchment area (ha)				**590**
Area forested (ha)				**460**
Proportion of area forested				**77.97%**

UPPER MURRAY RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Very Low	Unknown	10
		Not Applicable	Unknown	20
	> 700 - 900 mm	Moderate	moderate	460
			low	80
		Very Low	low	180
			limited	160
			Unknown	70
		Not Applicable	NA	860
	> 900 - 1100 mm	High	high	10
			moderate	50
		Moderate	moderate	620
		Low	low	10
		Very Low	low	1,100
			limited	570
			Unknown	1,100
		Not Applicable	NA	520
MUF	> 1100 mm	Very High	very high	290
			high	5,240
		High	high	370
			moderate	50
		Moderate	moderate	7,060
		Low	low	1,280
		Not Applicable	NA	13,150
	> 700 - 900 mm	Very High	very high	2,650

			high	22,010
			moderate	6,120
		High	moderate	670
		Moderate	moderate	7,750
			low	1,890
		Low	low	3,480
		Very Low	low	3,980
			limited	590
			Unknown	1,640
		Not Applicable	Unknown	70
			NA	36,570
	> 900 - 1100 mm	Very High	very high	9,080
			high	24,720
			moderate	540
		High	high	2,390
			moderate	10,080
		Moderate	moderate	76,370
			low	7,400
		Low	moderate	30
			low	11,170
		Very Low	low	2,880
			limited	280
			Unknown	270
		Not Applicable	NA	126,180
NCR	> 1100 mm	Very High	very high	550
			high	2,910
		High	moderate	10
		Moderate	moderate	500
		Low	low	120
		Not	NA	18,060

		Applicable		
	> 500 - 700 mm	Low	low	90
		Very Low	limited Unknown	50 100
		Not Applicable	Unknown	10
	> 700 - 900 mm	Very High	very high high moderate	1,830 13,080 6,250
		High	high moderate low	30 1,890 1,220
		Moderate	moderate low	8,280 3,510
		Low	low	3,070
		Very Low	low limited Unknown	13,910 6,710 11,170
		Not Applicable	plantation Unknown NA	20 320 64,750
	> 900 - 1100 mm	Very High	very high high moderate	37,900 12,440 3,200
		High	high moderate low	370 30,150 740
		Moderate	moderate low	39,970 1,910
		Low	moderate low	8,890 3,970

		Very Low	low	29,060
			limited	1,670
			Unknown	3,850
		Not Applicable	Unknown	120
			NA	101,900
ND	> 700 - 900 mm	Very High	high	10
		High	moderate	10
		Moderate	moderate	20
			low	400
		Very Low	limited	400
			Unknown	10
		Not Applicable	NA	60
	> 900 - 1100 mm	Very High	high	10
		High	high	20
			moderate	80
		Moderate	moderate	10
		Low	moderate	20
			low	10
		Very Low	low	60
			limited	60
			Unknown	10
		Not Applicable	Unknown	10
			NA	10
OCL	> 1100 mm	Very High	high	10
		Not Applicable	NA	510
	> 500 - 700 mm	Low	low	20
		Not Applicable	Unknown	170

	> 700 - 900 mm	Very High	very high high moderate	10 450 540
		Moderate	moderate	400
		Low	low	20
		Very Low	low limited Unknown	180 430 730
		Not Applicable	NA	900
	> 900 - 1100 mm	Very High	high	1,600
		High	high moderate	150 330
		Moderate	moderate low	1,770 20
		Low	moderate low	50 230
		Very Low	low limited Unknown	490 240 390
		Not Applicable	NA	5,800
PRIV	> 1100 mm	Not Applicable	NA	120
	> 500 - 700 mm	Low	low	560
		Very Low	Unknown	30
		Not Applicable	Unknown	1,410
	> 700 - 900 mm	Very High	very high high moderate	20 270 790
		High	high	10

			moderate	1,380
		Moderate	moderate low	3,120 7,110
		Low	low	3,160
		Very Low	low limited Unknown	4,400 7,270 11,140
		Not Applicable	Unknown NA	880 13,180
	> 900 - 1100 mm	Very High	very high high moderate	50 280 130
		High	high moderate	180 6,390
		Moderate	moderate low	8,220 5,830
		Low	moderate low	1,000 2,500
		Very Low	low limited Unknown	7,720 2,600 3,460
		Not Applicable	NA	9,910
Total catchment area (ha)				**1,530,200**
Area forested (ha)				**946,420**
Proportion of area forested				**61.85%**

WARREGO RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 300 - 500 mm	Low	low	2,180
		Very Low	low	16,450
			limited	1,780
		Not Applicable	limited	12,690
			sandalwood	6,020
			NA	735,250
	> 500 - 700 mm	Moderate	high	20
		Low	moderate	53,020
			low	4,970
		Very Low	low	234,140
			limited	81,080
		Not Applicable	limited	10,790
			sandalwood	20,580
			NA	147,340
MUF	> 500 - 700 mm	Low	moderate	11,190
		Very Low	low	25,330
			limited	1,300
		Not Applicable	sandalwood	240
			NA	3,050
NCR	> 300 - 500 mm	Very Low	low	70
			limited	80
		Not Applicable	NA	3,760
	> 500 - 700 mm	Moderate	high	10
		Low	moderate	260
		Very Low	low	12,590
			limited	10,880
		Not Applicable	sandalwood	1,490
			NA	1,240
ND	> 300 - 500 mm	Low	low	890
		Very Low	low	660

			limited	420
		Not Applicable	limited sandalwood NA	4,180 270 41,390
	> 500 - 700 mm	Low	moderate low	990 150
		Very Low	low limited	5,790 3,790
		Not Applicable	limited sandalwood NA	1,390 660 19,670
OCL	> 300 - 500 mm	Low	low	1,460
		Very Low	low limited	290 100
		Not Applicable	NA	15,390
	> 500 - 700 mm	Very Low	low limited	510 400
		Not Applicable	limited sandalwood NA	200 670 7,040
PRIV	> 300 - 500 mm	Low	low	2,380
		Very Low	low limited	6,420 950
		Not Applicable	limited sandalwood NA	11,080 2,860 154,090
	> 500 - 700 mm	Low	moderate low	1,930 220
		Very Low	low limited	4,230 8,160
		Not Applicable	limited sandalwood NA	7,920 2,390 61,590

Total catchment area (ha)				**6,292,620**
Area forested (ha)				**1,768,330**
Proportion of area forested				**28.10%**

WERRIBEE RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
MUF	> 700 - 900 mm	High	moderate	10
Total catchment area (ha)				**10**
Area forested (ha)				**10**
Proportion of area forested				**100.00%**

WIMMERA-AVON RIVERS

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
LEASE	> 500 - 700 mm	Very High	high	10
		Moderate	low	20
		Not Applicable	NA	230
MUF	> 300 - 500 mm	Very Low	very low	1,450
			limited	220
		Not Applicable	NA	27,630
	> 500 - 700 mm	Very High	very high	80
			high	7,560
		Moderate	high	30
			low	4,450
		Low	low	2,760
		Very Low	very low	150
			limited	540
		Not Applicable	NA	6,750
NCR	> 300 - 500 mm	Moderate	high	820
		Low	low	580
		Very Low	very low	2,800
			limited	2,500
		Not Applicable	NA	261,290
	> 500 - 700 mm	Very High	high	580
		High	moderate	6,030
		Moderate	high	160
			low	12,870
		Low	low	6,610
			very low	1,300
		Very Low	very low	1,370
			limited	820
		Not Applicable	NA	50,350
ND	> 300 - 500 mm	Moderate	high	50
		Very Low	limited	40

		Not Applicable	NA	310
	> 500 - 700 mm	Very High	high	30
		Not Applicable	NA	140
OCL	> 300 - 500 mm	Very Low	limited	20
		Not Applicable	NA	2,090
	> 500 - 700 mm	High	moderate	10
		Low	low	160
		Very Low	very low	90
		Not Applicable	NA	400
PRIV	> 300 - 500 mm	Moderate	high	750
		Low	low	190
		Very Low	very low	570
			limited	780
		Not Applicable	NA	74,870
	> 500 - 700 mm	Very High	high	440
		High	moderate	300
		Moderate	high	310
			low	1,450
		Low	low	1,670
			very low	40
		Very Low	very low	500
			limited	1,790
		Not Applicable	NA	19,200
Total catchment area (ha)				**3,029,340**
Area forested (ha)				**506,160**
Proportion of area forested				**16.71%**

YARRA RIVER

Tenure Type	Rainfall	MAI Group	Commerciality	Area (ha)
MUF	> 1100 mm	Very High	very high	30
NCR	> 1100 mm	Very High	very high	160
Total catchment area (ha)				**190**
Area forested (ha)				**190**
Proportion of area forested				**100.00%**