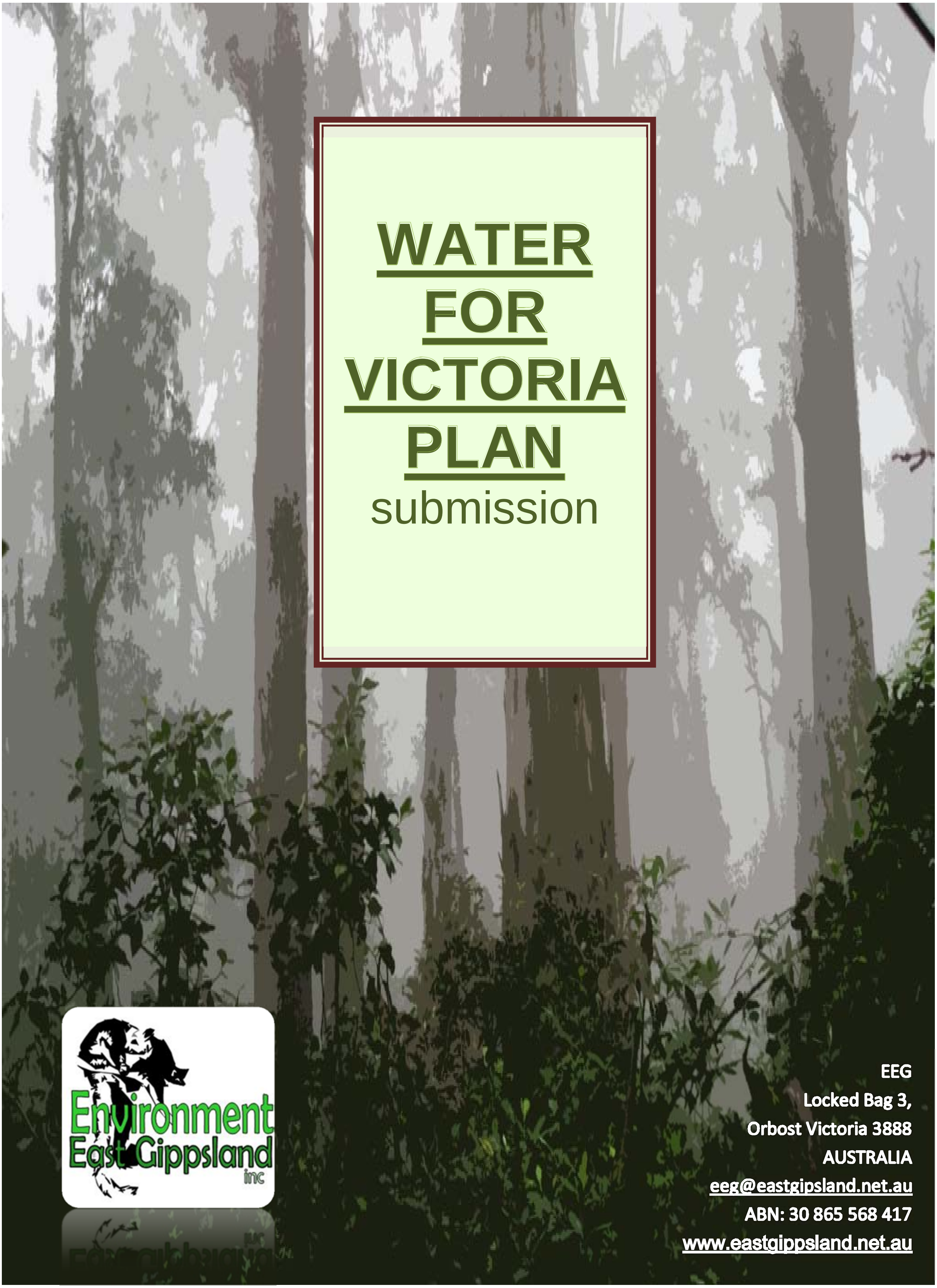

WATER FOR VICTORIA PLAN

submission

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DELWP Water Plan Project Team

Water and Catchments Group

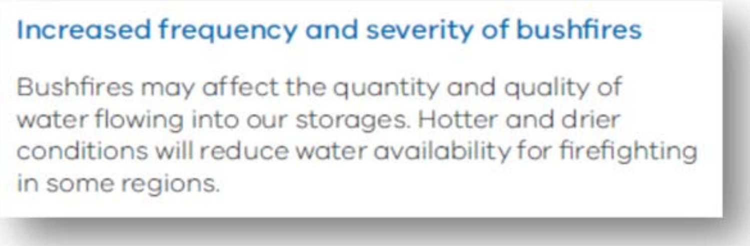
Via email: waterplan@delwp.vic.gov.au

25 May 2016

EEG appreciates this government taking steps to acknowledge and hopefully improve the many environmental issues this state faces. Climate, biodiversity loss and stream health are three of Environment East Gippsland's major concerns.

EEG has a membership of over 400 and a supporter base of over 1,000. We have been working to protect this region's relatively intact ecosystems for over 30 years. We are not new to government processes and plans. This has developed, within our group, an often cynical view of commenting on plans which ultimately do not reflect public concerns, are weakly worded, ambiguous motherhood statements dressed up in a glossy document and/or are ignored as the political landscape changes or new dictates emerge.

This water plan is welcome in that it acknowledges we are in trouble and the situation could worsen. However it does not spell out some of the most obvious threats to our water security (see below). It also emphasises quite a lot of non-urgent 'feel-good' actions such as more monitoring and community education and engagement. While we accept that communities should be brought on board with new changes to improve environmental health of the land, some actions are too urgent to wait for public acceptance to be garnered. .



Increased frequency and severity of bushfires

Bushfires may affect the quantity and quality of water flowing into our storages. Hotter and drier conditions will reduce water availability for firefighting in some regions.

More science – less ambiguity

We applaud the suggestion of more research and science in some areas. This, of course, requires decent funding as inadequate resourcing can negate lofty plans and can be an effective and easily placed obstruction to genuine change.

We would like to see unambiguous effective solutions implemented with solid timelines, decent resourcing and rapidly implemented actions that actually have practical, positive and measurable outcomes.
We find the wording of this plan is extremely cautious and non-committal.

Bushfires and water

The comment above regarding some regions having reduced water availability for firefighting was concerning to us. We are unaware of how fires are fought in the west or drier regions, but from first-hand experience and anecdotal stories in Gippsland and the Otways, the managers of bushfires use very little water on the ground. Instead, fire managers prefer to use additional fire in the landscape to increase the fire edge. This is even when water and a workforce are both available. This practice should be reviewed as it has not assisted in fire suppression from our observations. In light of potential future water scarcities, we would hope that deliberately increasing fire across the land is not adopted as a ‘water-free method’ of fire fighting.

Carbon footprints

We agree with plans to reduce impacts on the climate by lessening the carbon footprint of water authorities. Although when compared to the massive release of ancient stored carbon happening daily, as stands of mature forest are logged and burnt, we consider it a trivial action.

1. Carbon released during a logging coupe burn - Central Highlands.

Forests in relation to water yield and quality

There is no mention we could find of *the* most significant catchment disturbance that impacts on water quantity and quality - clearfell logging.

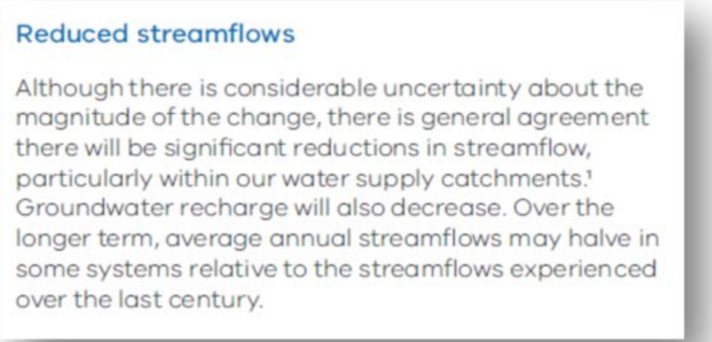
Bushfires are acknowledged as a threat to water yields, but compared to the more extreme impact of clearfell logging it is very minimal. Fire regrowth from mixed forests have a very short term impact on water yield as most larger trees survive fire to resprout quickly. This maintains the age class mix of the forest pre-fire (ash forests respond differently to an intense bushfire).

Forests and water – a long history

A report by the Australia Institute, *LOGGING AND WATER; a study of the effects of logging regimes on water catchment hydrology and soil stability on the eastern seaboard of Australia,* authored by John Dargavel, Clive Hamilton and Pat O’Shaughnessy in November 1995, states:

> *The broad conclusion of this report is that existing assessment processes … do not adequately deal with the potential impacts of logging on water yields and water quality. Conflicts over access to water on the eastern seaboard are likely to become a much more pervasive problem in the next decades as water-intensive activities expand on the coastal strip. If the issue is taken up now there is an opportunity to develop the data bases, methods of analysis and institutions that will help to resolve conflicts before they become entrenched*

Many reports and studies both here and overseas have shown categorically that logging in water catchments, especially in those such as the eastern ranges of Victoria, enormously reduces water yield. This again seems to have been rejected as a major part of the water security equation, just as it was in the 2004 “Our water our future” report. In a process to tackle the impending water crisis and secure Victoria's water for the future, the then Bracks Government adopted all of its own experts’ recommendations except one - that logging be



Reduced streamflows

Although there is considerable uncertainty about the magnitude of the change, there is general agreement there will be significant reductions in streamflow, particularly within our water supply catchments.[1] Groundwater recharge will also decrease. Over the longer term, average annual streamflows may halve in some systems relative to the streamflows experienced over the last century.

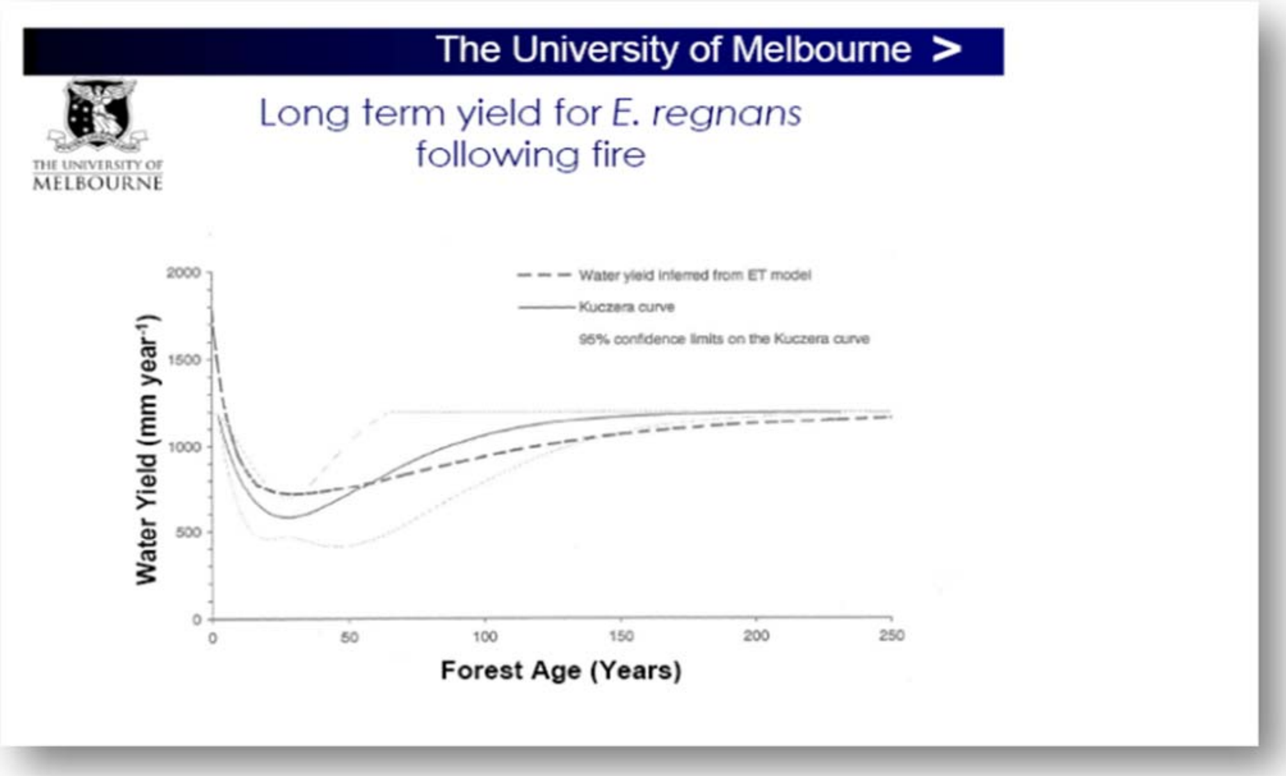
phased out of water catchments by 2010!

A discussion paper released for public comment was based on another document called the *Water Resource Strategy*, which stated we should ban logging in our water supply catchments. The then DSE acknowledged that logging native forests reduced water yields and agreed with the figures and modelling of water and environment experts. So why was it rejected as an option in the discussion paper? Water loss from plantations and fast growing young trees after bushfires were both mentioned but loss of water from logging regrowth was disregarded. EEG is extremely alarmed by what appears to be the same politically influenced process playing out yet again. This is despite even more compelling science that has been added to our knowledge base since 2004.

Basically the research shows the impacts of clearfell logging and the subsequent fast regrowth which literally sucks water catchments dry. This lasts for the best part of 100 years. As logging cycles are on a 20 year (for thinnings) to 40-60 year (clearfell) rotation, this is effectively subjecting our water catchments to permanent drought – on top of climate change caused drought. These two impacts, both human caused, are an equal threat to Victoria's water security. However in the government's latest water plan, climate change received an entire chapter but not one word on the impacts of native forest logging. Water and logging has become a significant issue which can't be ignored.

After VicForests clearfells an area (and profits from it), the regrowing of an area back to a mature forest would take gigalitres away from streams and rivers for decades.
If the logging industry was an irrigator it would be charged for the use of this water.
Economic rationalism should see the government charge VicForests for the use of this valuable natural resource.

In 2008, Stakeholder Reference Group meetings were established as part of the government's "Wood and Water Sustainability Assessment Project". It was as we predicted - a poorly devised process to maintain the status quo.


The University of Melbourne >

Long term yield for *E. regnans* following fire

The group looked at options to address water loss due to logging in catchments. It was a promise by the then Bracks government in its 2004 report "Securing our Water Future Together". It was also to provide studies and investigations, including timber substitution studies, hydrological studies and a water quality review. But as far as we know these were never completed or acted upon.

The report was also non-committal. It wanted totally conflicting outcomes - increasing water yield while maintaining the (over) logging of critical forest habitat and catchments. It spoke of *aiming* – not *achieving*.

Various logging options were tabled, but none suggested ending logging by 2010 as recommended by experts in their ’02 and ’04 reports. We were told that the 2010 option would be "assessed but not presented to government". Why have successive governments been paralysed and unable to carry out this most obvious action to secure water supplies from eastern Victoria?

In 2009, Melbourne's catchments were virtually empty. The government was looking to the skies and to a controversial and expensive desalination plant, but was NOT looking in the direction of the Thomson dam’s catchment, or reviewing out-dated commitments that allow clearfell logging in water catchments.

Logging our forested reserves creates polluted run-off, incredibly thirsty young tree crops and cheap woodchips for paper pulp. Mature native forests create clouds, attract rain, cool the ground, filter rainwater, support wildlife, clean the air, provide excellent recreational activity and are breathtaking beautiful.

Logging = Loss of Water
Read Sturgess and Assoc., June 1992 stated that logging can reduce stream flows by 50% and it may take more than 100 years to restore original flows. Maximum stream flows occur in forests which are very young (up to 3 years old) or very old. Under any cash flow analysis, old growth forests are high value as they produce maximum stream flows.

Snowy River sucked dry by logging
The Thompson catchment is not the only area impacted. A long battle by locals to obtain a 28% release of water from the Jindabyne dam for the Snowy River has been wholly or partly negated by clearfelling its major sub-catchments.

Two reports from the early 90s indicated that logging would cause reduced water yields. They were duly ignored by government, but the predictions are now being realised.

A very relevant report, *The Impact of Forest Harvesting on Water Yield: Modelling Hydrological Changes Detected by Pollen Analysis (Dr R.L. Wilby, University of Derby UK and Dr P.A.Gell, ,Adelaide University, 1994),* supports the Read Sturgess findings.

Wilby and Gell analysed logging in the Delegate catchment, a major sub-catchment of the Snowy. They took core samples of the wetland and used climate data to predict the progressive reduction in annual yields. There would be a 20 to 55% loss of water by 1997-98 and an almost 100% reduction by 2005 (±6years). The rare wetland on this river has dried and been reduced to a fraction of its original size due to almost total clearfelling of its catchment.

Reduced water runoff after bushfires and clearfelling create similar drought-related flowering reactions (pollen release that are picked up in core samples). However, **pollen records show these are much less severe after a bushfire, with clearfelling causing up to 100 times more drought stress than a fire.**

Analysing core samples dating back 10,000 years showed there had been more impact on two indicator plant species in the past 30 years (since clearfell logging began) than in the previous 10,000 years!

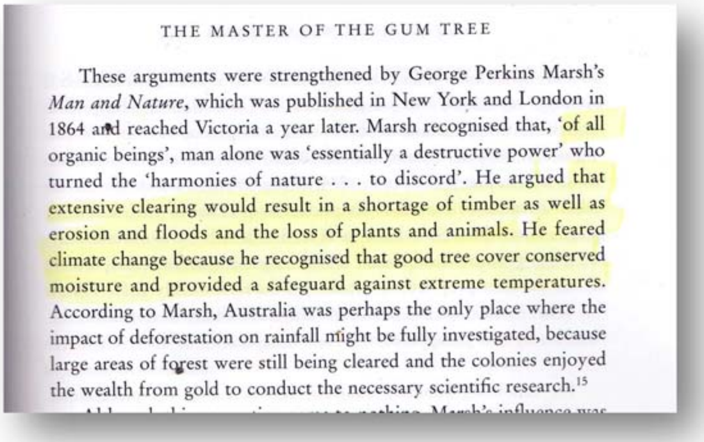
Government logging managers argued that most studies have been on fast regenerating Ash forests, so predictions in catchments of other forest types are unreliable. But forests in the upper Delagate catchment were tall wet mixed forests. If eucalypt regeneration is successful, they regrow quickly and consume large amounts of water.

The Wilby and Gell report predicts that lowest flow rates will occur 30 years after severe catchment disturbance. This is similar to findings of other research carried out in Ash forests. It also suggests it would take over 100 years for normal flows to return.

If forest management remains unaltered, it will negate much of the Snowy River's hard-won (but minimal) environmental flow concessions.

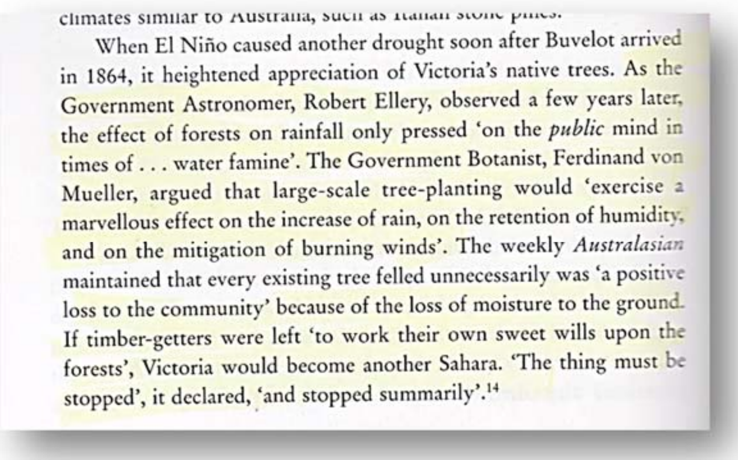
Water and forests – in 1864

Even as long ago as the 1860s, authorities and government bureaucrats were aware of the huge role forests play in attracting rain, conserving ground water and maintaining humidity – added protection from fires and drought.



THE MASTER OF THE GUM TREE

These arguments were strengthened by George Perkins Marsh's *Man and Nature*, which was published in New York and London in 1864 and reached Victoria a year later. Marsh recognised that, 'of all organic beings', man alone was 'essentially a destructive power' who turned the 'harmonies of nature . . . to discord'. He argued that extensive clearing would result in a shortage of timber as well as erosion and floods and the loss of plants and animals. He feared climate change because he recognised that good tree cover conserved moisture and provided a safeguard against extreme temperatures. According to Marsh, Australia was perhaps the only place where the impact of deforestation on rainfall might be fully investigated, because large areas of forest were still being cleared and the colonies enjoyed the wealth from gold to conduct the necessary scientific research.[15]



climates similar to Australia, such as Italian stone pines.

When El Niño caused another drought soon after Buvelot arrived in 1864, it heightened appreciation of Victoria's native trees. As the Government Astronomer, Robert Ellery, observed a few years later, the effect of forests on rainfall only pressed 'on the *public* mind in times of . . . water famine'. The Government Botanist, Ferdinand von Mueller, argued that large-scale tree-planting would 'exercise a marvellous effect on the increase of rain, on the retention of humidity, and on the mitigation of burning winds'. The weekly *Australasian* maintained that every existing tree felled unnecessarily was 'a positive loss to the community' because of the loss of moisture to the ground. If timber-getters were left 'to work their own sweet wills upon the forests', Victoria would become another Sahara. 'The thing must be stopped', it declared, 'and stopped summarily'.[14]

In his book, The Colonial Earth, Tim Bonyhady documents many instances of the early recognition of how closely interdependent forests, water and even fire suppression were.

<u>Suggested solutions:</u>

The impacts of logging and the subsequent decrease in water yield for decades can NOT be ignored any longer. It MUST be included in this plan.

We have a choice between reduced water for millions of rural and metro people or reduced logs for Australian Paper or overseas markets.

Securing a future water supply and a woodchip supply from native forests are not compatible.

Clearfelling began in the early 70s and ramped up in the 80s and 90s. The forests which remain unlogged **as mature or old growth stands are immensely valuable as water factories and carbon stores**. **They must be protected as a priority**. The regrowth from the 70s is nearing 50 years old and water yields beginning to increase again.

Forests and logging industry working for water security

If climate and carbon pollution are stated as issues to be raised and dealt with in regards to water for Victoria, EEG would like to see this government **quickly transition out of logging native forest and destroying these massive land-based carbon stores and water producers/purifiers, to move the handful of jobs into other tasks which improve forest health and cover.**

In Chapter 3: Waterway and catchment health, it proposes among other things:

- *protecting waterways from the adverse impacts of human use*

Removing the biggest human impact would be a great start – industrial logging. By improving catchment management and river health as well, the above dot point could be achieved.

The government must now **review and do everything in its power to transition the logging industry into existing plantations as soon as possible**. The commercial demands of the Maryvale's woodchip mill for years to come, must not trump the water needs of a growing city.

EEG fears the same political influences that have been at play for decades are still dictating government policy on extremely serious matters such as water security.

There is an urgent need to **review all hydrological studies in forested catchments, past and present.** Catchment management authorities cannot prove that logging is *not* affecting water yields.

Commercial irrigators pay for the use of water and VicForests as a commercial enterprise should also have this cost added to their operations. **We believe there is a huge debt to be paid by the industry for the free use of public water over the decades**.

Clearfelling mature forests was assumed by logging agencies to continue until 2030, when all accessible forests would be in a young regrowth stage (and stream flows suffering as a result). The plan to create woodchip crops across eastern Victoria to supply an export and domestic woodchip industry has been dashed as demand has dropped and markets have shifted to other countries.

EEG sees this situation as **an opportunity to now use science and evidence above factional politics and corporate influences.** The **role that forests play in the future of our domestic, rural and environmental water needs MUST be factored into decisions.**

Attached are several documents which have all necessary research, links and evidence to inform the government on this extremely important aspect of any water plan.

Extract from ***LOGGING AND WATER; a study of the effects of logging regimes on water catchment hydrology and soil stability on the eastern seaboard of Australia,*** authored by John Dargavel, Clive Hamilton and Pat O'Shaughnessy in November 1995.

Executive summary

The report

This report considers the impacts of logging in forests on the quantity and quality of water available for users. It considers the impacts of:

- the silvicultural regimes, yield control and scheduling systems used;
- the on-site logging technology and the conduct of operations; and
- the infrastructure of roads required to extract the wood from the forests.

It also considers the economic implications of the effect of logging on water yields and water quality and the lessons for policy makers.

This study is concerned with use of the forested catchments of the eastern seaboard of Australia and is not concerned with urban areas, dryland catchments, agricultural areas, the Murray-Darling Basin.

Impacts of logging

The great variability of Australian rainfall and the occasional occurrence of bushfires poses particular problems for the study of hydrological impacts. Occasional, unpredictable peak rainfall events can outweigh or mask the effects of alternative catchment treatments.

Studies reviewed in this report show that the method of harvesting can greatly influence soil disturbance. Landslips on steep slopes with deep soils can be caused by road cuts and road drainage. Such events have occurred in Australia. In Australia up to 25 per cent of a logging coupe can be covered by snig tracks and landings and this indicates a need for scientifically developed standards for the amount of allowable soil compaction. Overseas and local studies show the major impact that poor roading and harvesting practices can have on stream water quality particularly in steep country with unstable or erodible soils. Erosion mitigation measures can minimise, but not prevent, erosion and the supply of sediment to streams. The amount of compaction can be reduced by limiting traffic and increasing soil organic matter especially in sandy soils.

Streamflow is the residue of rainfall after allowing for evaporation from vegetation, changes in soil storage from year to year and deep drainage to aquifers. Forest management operations can interfere with these processes by:

- changing the type of vegetative cover on a catchment. Experimental results show that these changes can affect evapotranspiration and therefore streamflow;
- changing the soil properties. The ability of the soil to both absorb and

store moisture infiltration can affect the proportion of rainfall delivered. Forest operations which compact the soil can reduce both infiltration and storage capacities.

Following clear felling in both ash and mixed species forests, Nandakumar and Mein estimate that for every 10 per cent of a catchment cleared, a 33 mm increase in runoff can be expected. Flows reach a peak 2 to 3 years after clearing and then decline which, in the case of the Melbourne Water experimental catchments, meant a return to pre-treatment levels in some 5 to 8 years. For ash-type catchments subject to clearfelling and regeneration, water yield continued to decline below pre-treatment levels.

In one experimental catchment, water yield declined to 50 per cent of its pre-treatment level. This finding is compatible to the yield changes reported by Kuczera after wildfire.

Forest management issues

The potential for forest operations to affect water yield and quality, soil and a wide range of environmental values has been reflected in regulations which, over the last twenty years have become increasingly detailed. Where water production is important, they specify that forests are to be managed by appropriate techniques, such as thinning and long rotations. Water quality is protected by limitations on the proportion of a catchment which can be logged in any one year and the specification of appropriate roading and logging practices. Detailed requirements are elaborated for each forest region.

All the Eastern seaboard States have codes of logging practice or regulations in place aimed at protecting forest values including water yield and quality. The Victorian and Tasmanian codes are particularly comprehensive. Currently the Victorian code is being renewed and revised. A review of the perceptions of the Code of Forest Practice held by workers, contractors and supervisors revealed that most timber workers accept the need for codes of practice but that compliance is in practice not as good as it is perceived. Better training for workers is needed, particularly as the pressure to keep up the supply of timber results in logging during inappropriate weather and soil conditions.

If the comprehensive codes of practice now specified were applied at a high standard in all public and private forests, the impacts on water quality would be greatly reduced. The key matters are:

- better road planning, design and maintenance;
- exclusion of 4WD vehicles from roads unsuited to heavy use;
- better use of buffer and filter strips;
- prohibition of logging when soil moisture content is high;
- better logging site rehabilitation;
- better training of supervisors and operators; and
- better designed logging and roading equipment.

Economic impacts

In the past, the abundance of water on the eastern seaboard has meant that the water used up as a result of forest growth has not been valued. As other uses emerge which can compete with forest use -- including urban consumption, irrigation, fisheries, recreational activities and natural systems -- then the value of water in alternative uses increases. The question now being asked is whether use of water in forest growth is the most efficient way of using the resource or should it be allocated to other uses.

The concept of 'efficiency' needs to be interpreted to include long-term sustainability. The hydrological evidence reviewed in this report indicates that current logging regimes in the native forests of eastern Australia can result in a decline in water yields.

Other things being equal, an increase in rotation lengths reduces the volume of logs taken out of a forest over time but increases the run-off due to a decline in evapotranspiration.

The major economic study of forests and water was carried out by Read Sturgess for Melbourne Water. The study evaluated economically a range of management options involving different mixes of wood and water production from the Thomson River catchment. The study deals only with timber values and the value of water for Melbourne consumers. Moreover, the results of the study pertain only to the Thomson catchment and should not be extrapolated to other catchments which may have different forest cover, soils, hydrological characteristics and uses. The results of the Thomson catchment are heavily dependent on the prevalence of ash-type forests in the Thomson catchment and the fact that this catchment is very important to the water supply of a large city.

Apart from the hydrological data on which the study was based, key variables in the study included the pricing of water and of logs, and the discount rate employed. The study concluded that among the options considered, the existing management of the Thomson catchment (based on an 80-year rotation) is the most inefficient. The most economic silvicultural options are either a very long rotation (200 years) or a complete end to logging. The conclusion is that, using the estimated prices for timber and water, the loss of timber as the rotation is lengthened is more than compensated for by the increased water yields. If other values were taken into account, in particular ecological values, it is likely that the results would favour long rotations or no logging options more strongly.

However, the Read-Sturgess method of calculating the value of water has been challenged by subsequent authors.

Conclusions

The very substantial differences between catchments in terms of their hydrological characteristics, patterns of land use and array of water users makes it clear that the analysis of forest use and management in relation to water must proceed on a regional scale at which the details can be evaluated properly. The integrated catchment management process now being adopted by most States and the Comprehensive Regional Assessment process being undertaken jointly by the Commonwealth and States, are being carried out at the relevant scale. However, it is far from clear that all important catchments will be included in the former process within the foreseeable future or that water will be considered at all in the Comprehensive Regional Assessments.

In relation to water quantity, it is clear that in some regions water has to be allocated between tree and other crops, and between primary, secondary and domestic use, but the effect of tree crops on water yield is known for only a few sites.

In relation to water quality, it is clear that the most important issues relate to the standard of forest management practice. The major obstacles in some locations are the continued pressure of governments to reduce field staff, lack of training, the unwillingness of industrial companies holding resource rights to pay adequately for high quality work, and the need to upgrade much of the old roading infrastructure.

The broad conclusion of this report is that existing assessment processes, including those being developed for the Comprehensive Regional Assessments, do not adequately deal with the potential impacts of logging on water yields and water quality. Conflicts over access to water on the eastern seaboard are likely to become a much more pervasive problem in the next decades as water-intensive activities expand on the coastal strip. If the issue is taken up now there is an opportunity to develop the data bases, methods of analysis and institutions that will help to resolve conflicts before they become entrenched.

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The impact of forest harvesting on water yield: modelling hydrological changes detected by pollen analysis

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Abstract Forest harvesting practices have been shown to have a hydrological impact that is akin to bushfire regeneration. Fine resolution fossil pollen studies in the upper Delegate River basin, East Gippsland, Australia, have revealed large changes in the reproductive activity of aquatic plants synchronous with the onset of harvesting activities. This paper seeks to establish an explanation for these changes by applying a 2-parameter regional bushfire yield trend model to the wet eucalypt forests above the pollen core site. Using histories of piecemeal coupe (harvesting plot) development, the model was used to reconstruct annual runoff yields between 1970 and 1991 assuming zero harvesting. The results indicated a progressive reduction in simulated annual yields (relative to the zero disturbance scenario) attaining between 20 and 55% loss by 1987/1988. Given the historic rate of harvesting, over a 50% reduction of water yield is expected to occur by 2005 due to factors including enhanced forest transpiration. Such hydrological changes would have significant implications for downstream fauna and flora and for stream dynamics.

Impact des activités sylvicoles sur les écoulements: application d'un modèle hydrologique en vue d'expliquer des modifications palynologiques

Résumé Cet article montre que les conséquences hydrologiques de l'exploitation des forêts sont comparables à celles d'une régénération suivant un incendie. L'étude palynologique fine menée dans le haut bassin de la Delegate River (East Gippsland, Australie) a apporté la preuve d'importantes modifications de l'activité des plantes aquatiques corrélées avec le début des activités sylvicoles. Grâce à l'utilisation d'un modèle (Modified 2-parameter regional bushfire yield trend model; Kuczera, 1985) appliqué à un bassin forestier humide dominé par les Eucalyptus, on a cherché à trouver une explication aux modifications palynologiques observées. En se basant sur l'historique des coupes, le modèle a permis d'estimer l'écoulement qui aurait eu lieu de 1970 à 1991 en l'absence de coupes. Les résultats montrent que par rapport au scénario sans coupe la diminution des écoulements devait atteindre 20 à 55% vers 1987/1988. Compte tenu du développement des coupes on prévoit une nouvelle réduction des écoulements supérieure à 50% d'ici à l'an 2005, due à l'augmentation de la transpiration issue de la forêt. Des modifications hydrologiques d'une telle importance auront des

Open for discussion until 1 April 1995

conséquences sérieuses en aval tant pour l'écologie aquatique que pour la dynamique fluviale.

INTRODUCTION

The study site lies approximately 300 km to the east of Melbourne, Australia, within the Errinundra Plateau and is defined by the watershed of the Delegate River basin upstream of Tea-tree Swamp (Fig. 1). Ladd (1976, 1979a) investigated the Holocene vegetation history using palynological techniques. His 3.2 m core revealed that the regional vegetation changed little during the last 10 000 years. The changes that were evident were attributed to the lateral migration of the Delegate River itself rather than to climatic or anthropogenic factors. The more recent vegetation history was examined under fine resolution by Gill & Stuart (1989) and Gell *et al.* (1993). Two short cores (DRA and DRE) were collected from upstream of the Gunmark Road and a third was taken from below (DRN-A). In each of these cores the onset of a dramatic change in the representation of one of two aquatic taxa is synchronous with the beginning of harvesting activities in the upper basin. The recent changes in these taxa relative to the longer record of Ladd (1976) are summarized in Fig. 2.

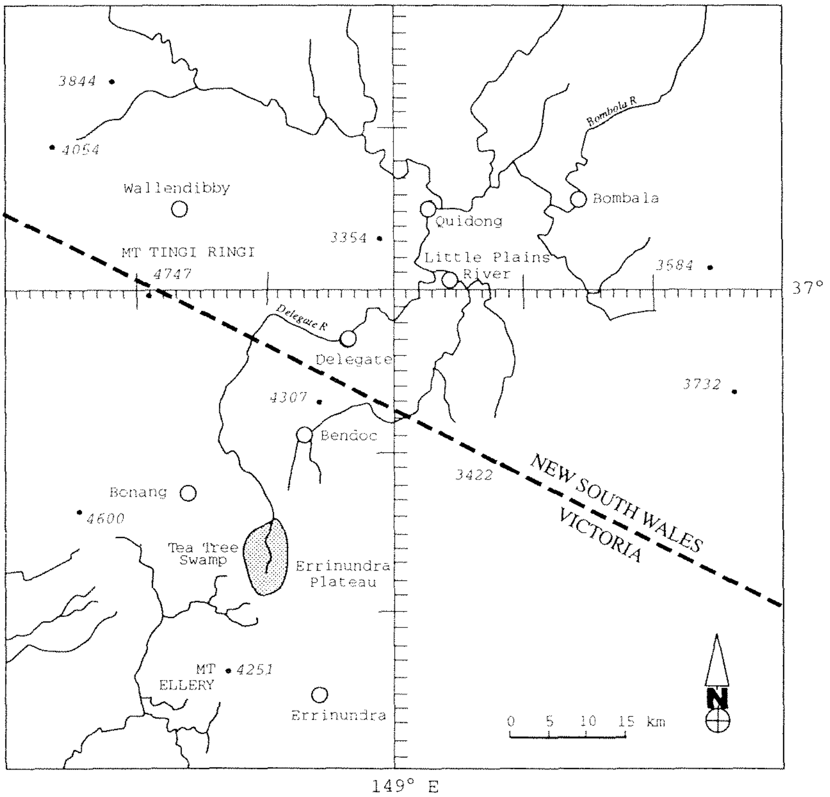

Fig. 1 *Errinundra Plateau and surrounds showing location of observation stations.*

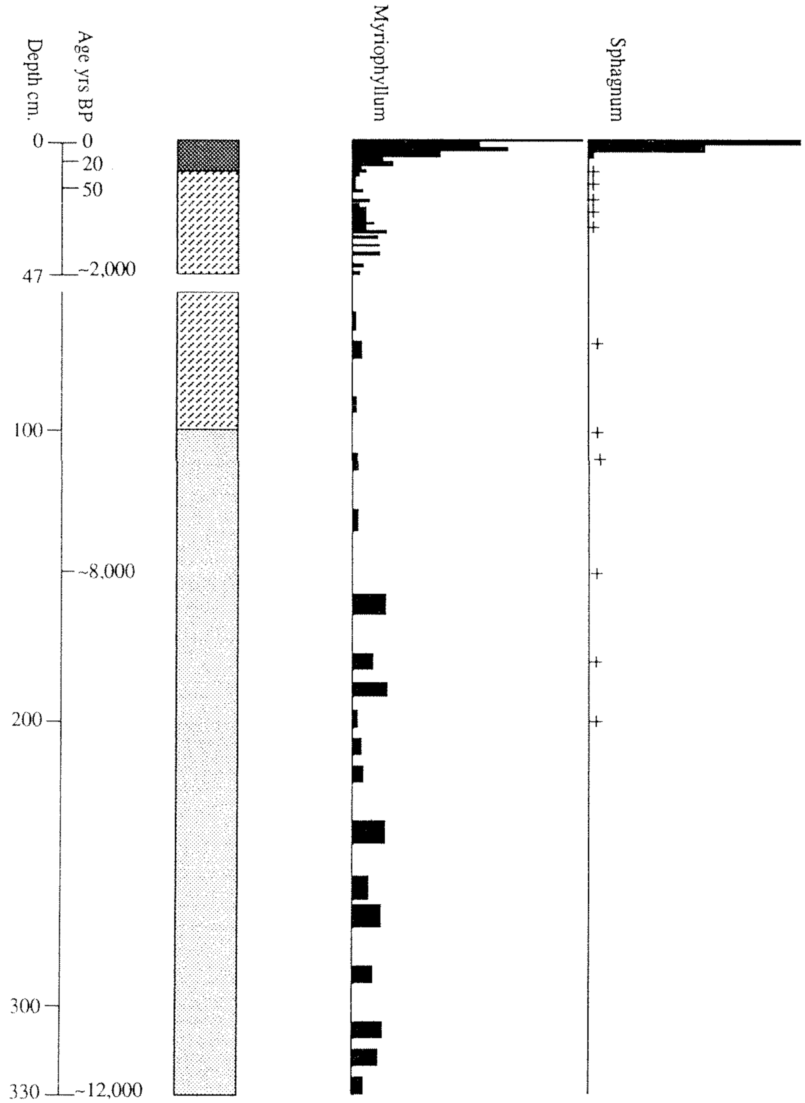

Fig. 2 Recent changes in the frequency of Myriophyllum pollen (core DRN-A) and Sphagnum spores (core DRE) relative to those observed in the longer Holocene record (Ladd, 1976). Aquatic pollen values are expressed as a ratio of Eucalyptus pollen (see Gell et al., 1993).

The two taxa, *Sphagnum cristatum* and *Myriophyllum pedunculatum,* are expected to be sensitive to hydrological changes in the swamp. Orchard (1986) noted that *M. pedunculatum* flowers most profusely in late summer when it is stranded. Gell *et al.* (1993) interpreted the changing reproductive activity of the plants to hydrological changes set off by harvesting practices.

The basin and core site were described in Ladd (1976, 1979a,b), Gell & Stuart (1989) and Gill *et al.* (1993). The basin has a mean annual rainfall total of *ca.* 1800 mm and covers *ca.* 1840 hectares, descending from an altitude of *ca.* 1100 m a.m.s.l to *ca.* 900 m a.m.s.l. at the core site. The mean maximum monthly temperature for the Errinundra Plateau (1050 m) ranges from 20.3°C in January to 6.4°C in July (Featherston *et al.*, 1987). The geology is mainly Ordovician sandstone interspersed with granite outcrops. The principal vegetation type is wet sclerophyll (eucalypt) forest; however, the upper reaches support cool temperate rainforest (Forbes *et al.*,1981) as either small pure stands or a sub-canopy to emergent eucalypts which are valued for timber.

DATA SOURCES

Figure 3 shows the annual rate of oldgrowth forest harvesting between 1970 and 1988 obtained from detailed survey maps of coupes (harvesting plots) in the upper Delegate River basin (Department of Conservation, Forests & Lands, 1988). The maps were digitized and the felled areas calculated using the ARC/INFO Geographical Information System. Table 1 lists the cumulative percentage area cleared since 1970. These data indicate that by 1988 approximately 45% of the basin had been harvested with over 10% being taken in 1987 alone.

***Table 1** Percentage harvested area of the basin upstream of Tea-tree Swamp 1970-1988 (Department of Conservation, Forests & Lands, 1988)*

Year	Felled %	Cumulative %	Year	Felled %	Cumulative %
1970	4.6	4.6	1980	0.3	20.0
1975	3.1	7.7	1981	4.5	24.5
1976	2.5	10.2	1983	5.8	30.3
1977	3.4	13.6	1985	1.6	31.9
1978	4.3	17.9	1987	10.9	42.8
1979	1.8	19.7	1988	2.4	45.2

Annual runoff totals for Tea-tree Swamp for the 40-year period 1952-1991 were obtained from the New South Wales Department of Water Resources hydrological records for: the Delegate River at Delegate (37°2′S, 148°55′E) and at Quidong (36°54′S, 149°2′E); and for the Little Plains River at Wellesley (37°S, 149°5′E). The contribution of the Little Plains River was subtracted from the record at Quidong to produce an estimate of the annual discharge from the upper 506 km^2 of the Delegate River between 1952 and 1991. This series was regressed against the shorter data set at Delegate. The resultant linear equation:

$$y = 1.046x + 36.5 \qquad r^2 = 0.92 \tag{1}$$

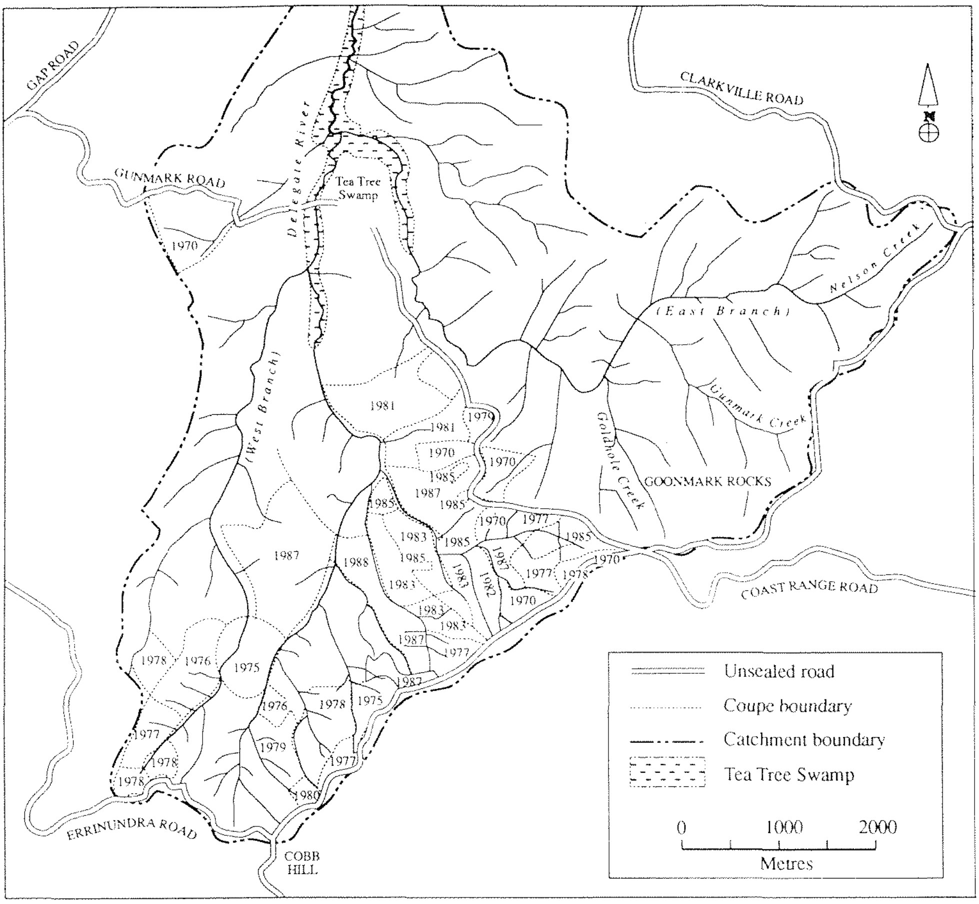

***Fig. 3** Delegate River basin and its logging history (from Gell& Stuart, 1989).*

was then used to extend the existing record at Delegate back to 1952. Although several kilometres downstream of the harvested sub-catchment, this record at Delegate was considered to be a very conservative estimate of annual runoff passing through Tea-tree Swamp. This is because the orographic effect of the uplands would tend to enhance the rainfall and hence runoff of the Swamp relative to the lower altitude site at Delegate. Flow statistics for the Errinundra River (a neighbouring, south-facing basin) suggest that the mean annual flows of the Delegate River at Tea-tree Swamp may be underestimated by as much as 200 mm per year between 1973 and 1982. However, part of this discrepancy may be attributed to lower rainfall inputs and higher evaporation losses on the north-facing, leeward slopes of the Delegate River. The observed flows at Delegate and the reconstructed record for Tea-tree Swamp 1952-1991 are shown in Fig. 4.

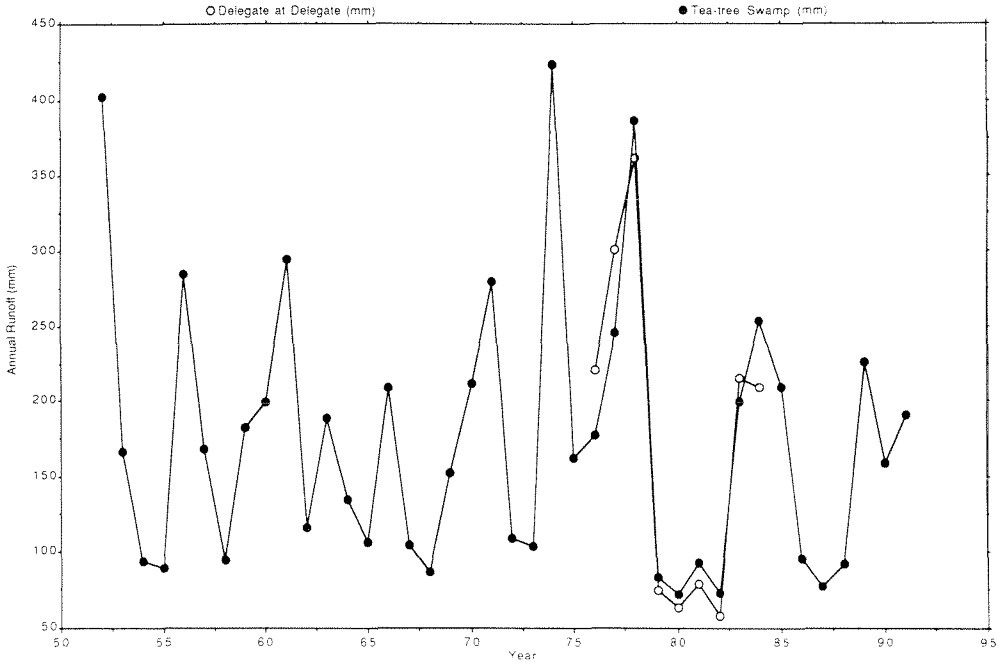

Fig. 4 Estimated annual runoff of the Delegate River at Tea-tree Swamp (1952-1991).

THE REGIONAL YIELD TREND MODEL

Extensive research into the hydrological effects of the 1939 bushfires on Melbourne's water supply catchments has revealed a close relationship between the age of an eucalyptus forest and the streamflow that it yields (Rosenthal, 1962). Work subsequently undertaken by Langford (1975, 1976) established that the conversion of oldgrowth Mountain Ash (*Eucalyptus regnans*) forest to an established regrowth forest induces statistically significant long-term reductions in streamflow starting 3-5 years after the fire and attaining a maximum 15-20 years later. Given that the canopy interception of an oldgrowth eucalyptus forest has been shown to be 4% higher than that for 35 year old regrowth (Langford & O'Shaughnessy, 1980), the yield reductions have been attributed to increased transpiration arising from the rapid post-fire growth rate and self-thinning tendency of eucalyptus stands.

This concept of *reducing* streamflow with forest clearance is in exact opposition to the generally accepted response of humid environments (e.g. Hornbeck *et al.*, 1970). Results obtained from the Picaninny catchment in the Coranderk Experimental Area, Melbourne (O'Shaughnessy & Jayasuriya, 1991) have highlighted the dependency of predicted yield reductions following clearfelling/regeneration on the rapid and successful regrowth of eucalyptus stands. Measurements of transpiration flows (sap flow) indicate that stand water use is strongly related to the amount of sapwood area per unit area of forest.

Empirical studies (Rogers & Hinckley, 1979) have shown that the canopy conductance is proportional to the product of the average leaf conductance and the leaf area index (which in turn is a function of the stand basal area). Measurements of rates of basal area increment and total sapwood area suggest that this stand factor reaches a peak at age 10-20 years and then declines to about a third of its peak value at age 60 years (Kuczera, 1985). Assuming that average leaf conductance is not strongly age-dependent, it may be concluded that the shape of the yield trend curve following a bushfire or harvesting should parallel the trend in stand basal area increment.

The observed hydrological changes following the 1939 fires have been formally described in the regional bushfire yield trend model developed by Kuczera (1985). This model has two components derived simultaneously via multiple non-linear regression. The first, a climate-dependent part, related a long-term rainfall series from the Maroondah Dam to reliable streamflow records from six catchments within the Melbourne Water supply area (plus the contiguous Murrindindi and Thomson catchments). The second element related the reduction in average basin yield below that of an oldgrowth forest to the age of the eucalyptus forest using the analogy of an impulse response of two connected linear reservoirs:

$$Y_t = L_{\max} K(t-2)e^{1-K(t-2)} \quad \text{if } t > 2 \text{ else } Y_t = 0 \tag{2}$$

where Y_t is the average yield reduction below oldgrowth yield (mm) t years after the bushfire or harvesting phase, $L_{\max}$ is the maximum yield reduction (mm) and $1/K$ is the time to maximum yield reduction in years. Regional relationships were subsequently developed between the two parameters $L_{\max}$ and K, and forest descriptors such as the percentage basin area covered by regrowth eucalyptus (EUC%). The two values yielding the minimum prediction variance were:

(a) Maximum yield reduction:
$L_{\max} = 6.15$ EUC% (mm)
$SDL_{\max} = (733 + 0.244\ \mathrm{EUC}^2)^{1/2}$ (mm)
(b) Natural logarithm of the response:
$\log K = -3.24$
$SD_{\log K} = 0.34$

According to Kuczera (1985), two factors should be considered when selecting a yield response model. Firstly, immediately after a fire or clearance the interception and transpiration of the patch will be radically altered due to defoliation, and secondly, the top-soil may be compacted by machinery. Both factors can result in a short-term increase in runoff. However, because this increase was not statistically detectable in the residual plots of the Melbourne Water data, it was arbitrarily assumed that the *average* basin yield would remain unchanged for two years after a fire or clearance. In the longer term, as the regenerating forest approaches maturity, it was assumed to attain a new hydrological equilibrium.

METHODOLOGY

The basic 2-parameter model was modified in order to accommodate the piecemeal (as opposed to instantaneous) harvesting of the basin's oldgrowth forest. The yield reductions associated with non-synchronous coupe development were modelled independently using the same equation and the aggregate impact calculated for any given year. Clearly a coupe that was harvested in 1975 will be at a different point on the hypothetical yield reduction curve in 1990 than a coupe that was felled in 1985.

The two regionalized parameter values ($L_{max} = 615$ EUC and $\log K = -3.24$) were used to compute the worst-case annual yield reduction arising from the historic sequence of forest harvesting upstream of the Tea-tree Swamp (Table 1). Multiple simulations were undertaken in order to determine the sensitivity of the model output to the two parameter values, to define 95% confidence intervals, to examine the impact of piecemeal clearance(s) and to assess the possibility that flows could be significantly reduced as a direct consequence of the forest regeneration.

Interannual variations in precipitation and temperature are also expected to play significant roles in controlling the observed interannual pattern of runoff. Linear regression analyses were therefore undertaken using the annual flow series of Tea-tree Swamp *vs.* the annual rainfall and mean temperature data for Bombala Post Office (705 m a.m.s.l.) between 1952 and 1991. Particular attention was paid to the residual flow statistics of the harvesting period (1970 onwards).

RESULTS

Figure 5 shows the simulated yield reduction arising from the historic harvesting rates to 1988 for the period 1970-2100 with select values of L_{max} and $\log K = -3.24$. The 95% confidence limits for $\log K$ were found to place the timing of the maximum yield reduction between 1998 and 2034. Multiple simulations were undertaken because of the uncertainty in the true value of L_{max} for the basin and also because the original yield reduction model was developed for regrowth forest in the Melbourne area. These simulations indicated that an $L_{max} = 400$ EUC would be sufficient to consume the pre-harvesting mean runoff. The maximum yield reduction of 270 ($\pm$ 30) mm arising from the worst-case regime is anticipated for the year 2010. In this case, up to 100% of the *mean* pre-disturbance flow could have been lost by the regrowth as early as 1992. Had all 45% of the harvesting occurred in 1970, a maximum reduction of 280 mm was found to occur 12 years earlier in 1998.

Figure 6 compares the actual annual yields 1952-1991 with those reconstructed by the model assuming zero harvesting and historic felling using $L_{max} = 200$ EUC and $L_{max} = 615$ EUC. For both values of L_{max} the model predicts a rapid departure of the two trends particularly after 1978. As Fig. 7

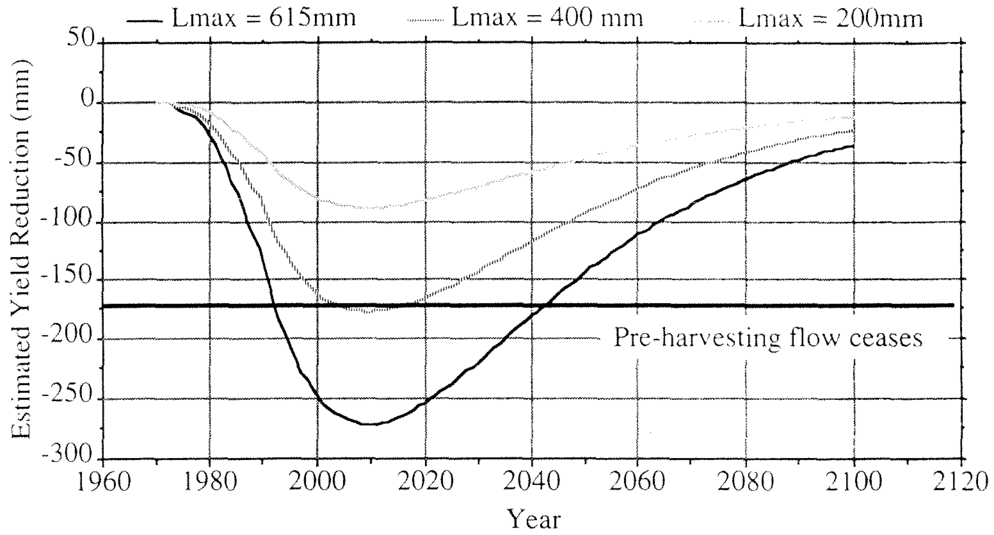

***Fig. 5** Simulated yield reduction curves for Tea-tree for selected L_{max} values.*

indicates, by 1987/1988 the ratio of non-felled to felled runoff represents a 35-55% loss of the annual runoff whilst the mean reduction for the period 1970-1991 was 13-22%. Given that the pre-disturbance mean annual runoff entering Tea-tree Swamp was approximately 170 mm, it is evident from Fig. 5 that the inflow could cease shortly after the turn of the century (2005) assuming the intermediate value of L_{max} = 400 EUC. For L_{max} = 200 EUC, the corresponding yield reduction would be greater than 50% In all cases, a gradual recovery of flow would be expected to occur after 2015.

Although the predicted yield reductions for L_{max} = 400 EUC and L_{max} = 600 EUC exceed the pre-harvesting mean runoff, in practice a 100% loss of flow is unlikely to occur since localized buffer strips and saturated zones would be expected to continue to contribute some runoff. This suggests that the most realistic value for L_{max} is in the region of 200 EUC. Such uncertainty regarding the parameter values highlights the limitations of applying "lumped" models to catchments exhibiting spatial heterogeneity of vegetation removal and regrowth.

The above results should also be considered within the context of the regression analyses which revealed a high dependency of the annual runoff series on the prevailing meteorological conditions. The annual rainfall total and mean annual temperature at Bombala explained 68% and 36% of the annual variation in the runoff of Tee-tree Swamp respectively. However, the residual time series shown in Fig. 8(a) & (b) provide limited evidence for declining flows from 1977 onwards coincident with the period of most intensive forest harvesting. The effect is most pronounced in the very dry periods of 1979-1982 and 1986-1988. These trends are also evident in the interannual variation in the runoff proportion (ROP), the ratio of annual runoff to rainfall (Fig. 8(c)).

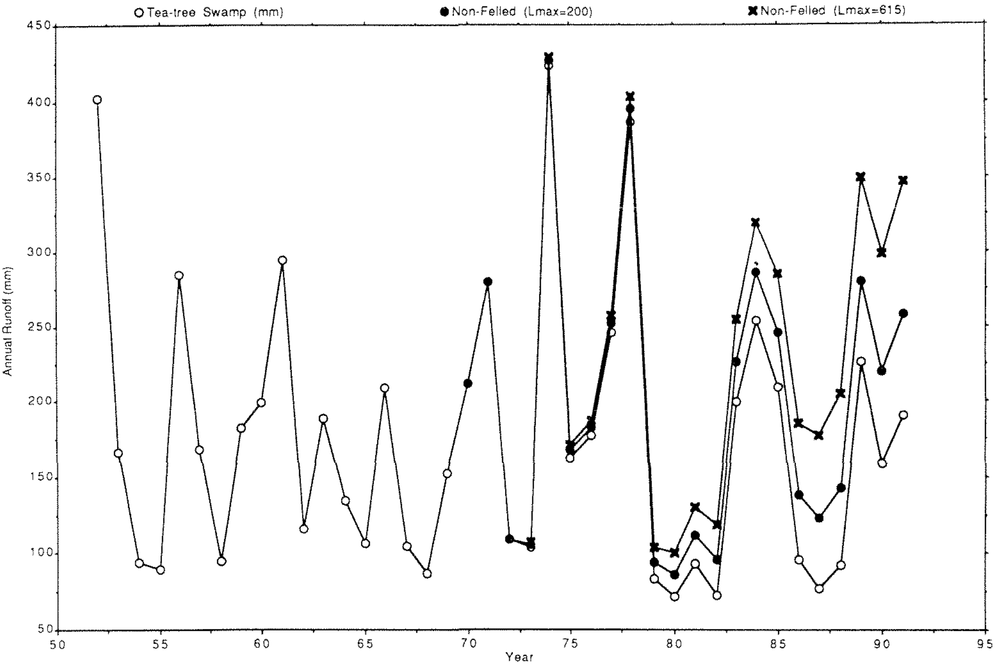

Fig. 6 *Comparison of the actual annual yield determined for Tea-tree Swamp and those reconstructed assuming no harvesting (for selected L_{max} values).*

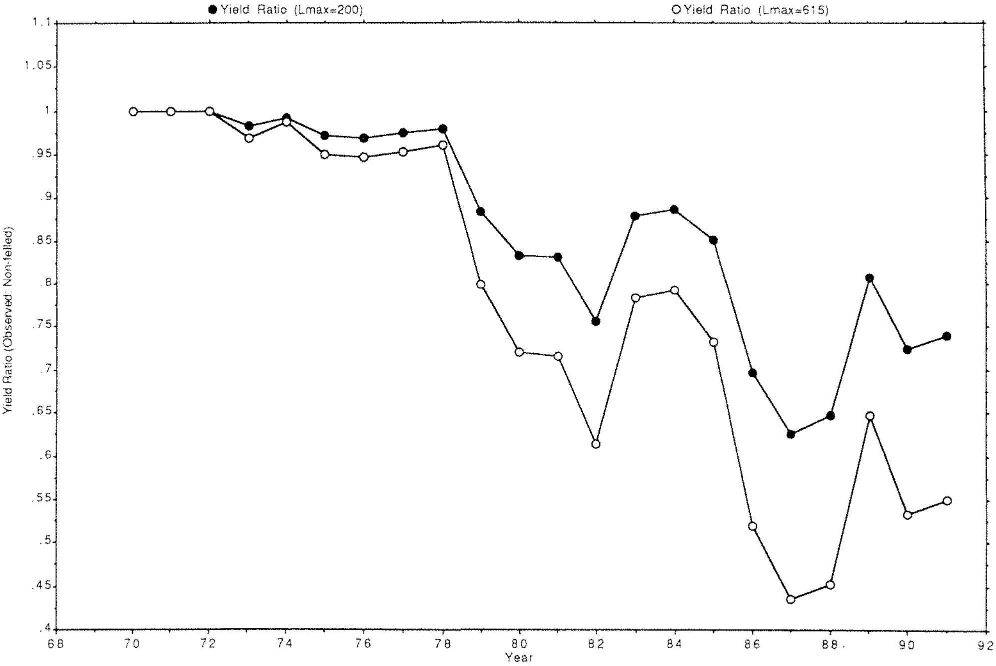

Fig. 7 *Ratio of simulated (non-felled) to observed (felled) runoff at Tea-tree Swamp (for selected L_{max} values).*

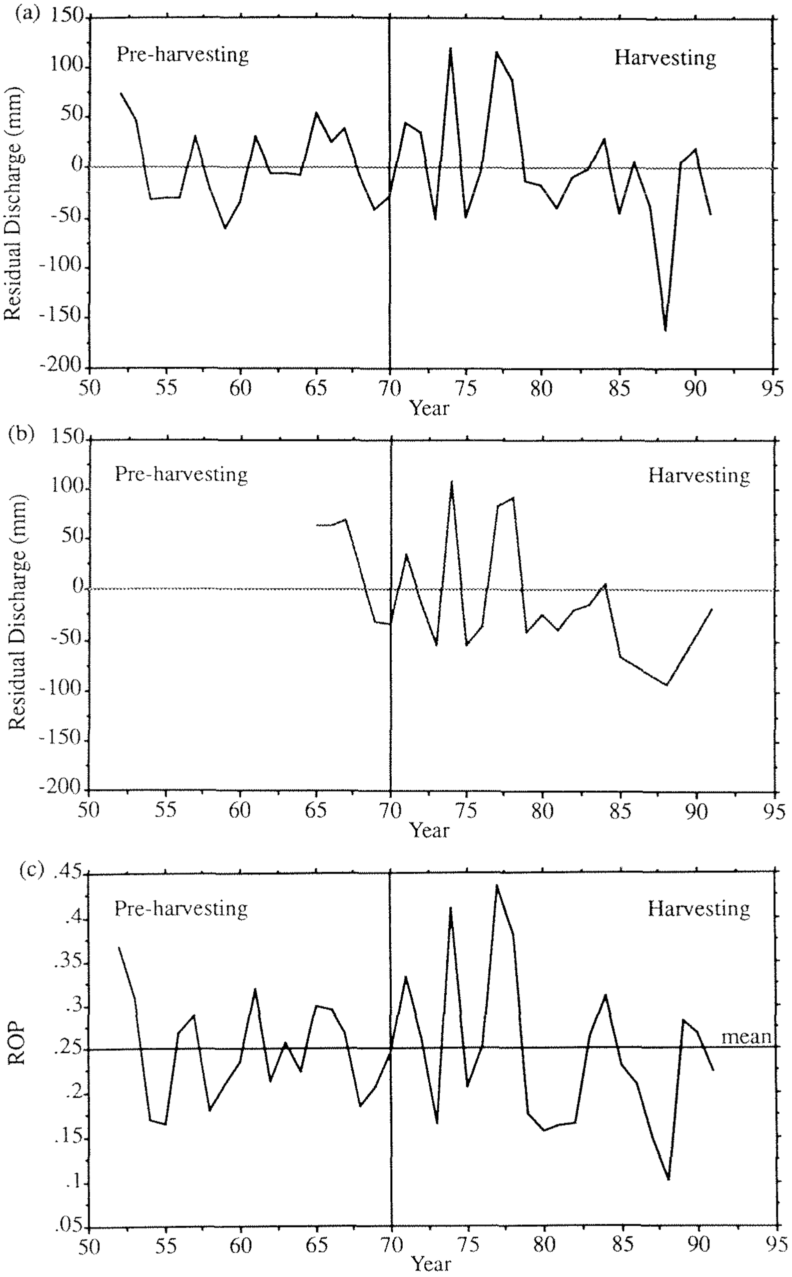

***Fig.** 8 Residual discharge and runoff series for Tea-tree Swamp (a) runoff vs. rainfall only; (b) runoff versus rainfall and temperature; and (c) ratio of annual runoff-rainfall.*

Table 2 compares the meteorological and hydrological characteristics of selected three-year sub-periods prior to, at the onset of, and following forest harvesting. Despite very similar climatic conditions, the first two periods displayed a marked decline in the mean runoff from 127 to 80 mm year^{-1}.

Table 2 Comparison of the meteorological and hydrological characteristics for selected sub-periods in Tea-tree Swamp prior to, at the onset of, and following forest harvesting

	1965-1968	1979-1982	1986-1988
Area harvested (%)	0	20.0	42.8
Rainfall (mm)	482	484	625
Mean maximum °C	21.6	19.3	-
Mean minimum °C	5.3	5.1	-
Runoff (mm)	127	80	89
Runoff (% rainfall)	20.5	16.5	14.2

Between 1965-1968 and 1979-1982 the area of harvested forest increased from 0 to 20%. By the period 1986-1988 the harvested area was in excess of 40% of the catchment and the runoff yield had declined to 14% of the incident rainfall amount.

DISCUSSION

The modified 2-parameter yield model predicts significant reductions in the annual flows entering Tea-tree Swamp even during the most recent 20 years. However, these results should be regarded only as best estimates of the likely impact of the historic rate of oldgrowth forest harvesting for the following reasons.

Firstly, due to the lack of available hydrometric data for Tea-tree Swamp, it was necessary to estimate the baseline flows from downstream sites. This introduced additional uncertainties due to differences in altitude, land-use, rainfall and surface water abstraction between upland and lowland sites. With increasing distance from the areas of forest harvesting the magnitude of any observed impact was likely to be diluted by downstream tributary influences. Data from the Errinundra River suggest that this uncertainty may be as high as 200 mm per year. However, this ignores factors such as the north-facing aspect and leeward topography of the upper Delegate River basin, both of which would result in significant reductions in flow relative to the Errinundra River. Furthermore, the yield reduction simulations predicted a maximum loss of flow of 270 mm which still represents a total loss of flow even if it is estimated to within ±100 mm of the true figure. In practice, flow is unlikely to cease entirely due to localized runoff contributions from unharvested buffer strips and saturated zones.

Secondly, the hypothetical yield reduction curve (Fig. 5) is an idealized representation of reality which is yet to be fully validated. Indeed Kuczera (1985) conceded that another 30 to 40 years of data are required to support fully the long-term recovery in yields assumed by the model. Nonetheless, existing data sets for the Watts, Graceburn, Donnellys, Sawpit and Murrindindi drainage basins (Melbourne region) clearly demonstrate declining yields following the 1939 fires; of greater uncertainty is the rate and timing of the yield recoveries.

Thirdly, it was assumed that the regional values for the parameters L_{max} and K are valid and transferable to the Delegate River drainage basin. The climatic variables are certainly comparable (Featherston *et al.,* 1987) as are the forest composition, forest regeneration behaviour and basin topography.

Fourthly, hot crown fires (wildfires) and oldgrowth forest harvesting are assumed to have a comparable hydrological impact. Given that both processes give rise to rapid defoliation and favour forest regeneration, this does not appear unreasonable. However, it must be recognized that there is considerable uncertainty in the selection of an appropriate value for L_{max}. Nevertheless, Fig. 5 indicates that even an L_{max} value of 200 EUC mm would result in a significant reduction of flow entering Tea-tree Swamp by the turn of the century.

Fifthly, efficient and rapid forest regeneration is assumed to occur following harvesting. Field surveys suggest that this may not necessarily be the case for all the upper Delegate River sub-catchments. However, recent regeneration estimates show that over 60% of coupes in the region regenerated successfully during the study period (Hemer, 1992). Additionally, even where eucalypt regeneration is deemed to be less than "successful", vigorous regeneration of other vegetation usually occurs.

Sixthly, the basic model assumes that the yield reductions occur independently, and are not constrained by climatic variables. Using published figures for the temperature regime of the Errinundra Plateau (Featherston *et al.,* 1987) and Linacre's (1977) equation, it was possible to estimate the monthly potential evaporation rates for the region. These data indicate that transpiration rates would not be limited by either the current rainfall or temperature regimes.

Finally, the forests were assumed to be in hydrological equilibrium prior to harvesting; that is to say, at point $t = 0$ on the yield reduction curve. This is valid since there were no extensive, high intensity fires or significant clearances reported for the basin prior to 1969/1970 (Gell & Stuart, 1989; Westaway *et al.,* 1990). The morphology of the remaining oldgrowth forest stands in the basin suggested that most, if not all, of the basin supported forests of a minimum age of 150 years at the beginning of harvesting.

The modelling results provide a plausible explanation for the changes in the pollen record of the aquatic taxon, *Myriophyllum pedunculatum.* The increase in the frequency of pollen of this species, known to flower most profusely in low water levels in the swamp (Orchard, 1986), is consistent with the low and declining yields (identified by the hydrological records and estimated by the models) evident in Fig. 6. Less is known of the reproductive ecology of *Sphagnum cristatum;* its spore cases are rarely observed. It was observed sporing, however, on the swamp in February 1991 and, like the preceding species, it may be responding here to high stress conditions in late summer which have become frequent in the last two decades.

The timing of the modelled changes does not coincide precisely with the dated changes of the pollen record. The changes in the *Myriophyllum* pollen and the *Sphagnum* spores were dated using lead-210 up to 1965, while the very low flow values did not occur until 1979. This could be explained by minor inaccuracies in the dating or by the impact of roading and other activities preceding 1970, or both. Furthermore, the summer flows may have been critical and masked by the annual flow values. What is very clear however is that the basin's morphology and climate rendered it very sensitive to the hydrological changes induced by forestry operations. The logging of 45% of the basin is sufficient to explain the most dramatic changes identified in the Holocene pollen record of the core site.

Tea-tree Swamp has sufficient botanical and geomorphological qualities to render it of national significance (D. Cameron, Victorian State Government botanist, personal communication). It supports several rare and threatened plant species and partly sits within the boundary of the Errinundra National Park. The modelling estimates warn that the Delegate River at Tea-tree Swamp may experience significant flow reductions as early as 1999. If this were to occur it would be reasonable to expect the peat in Tea-tree Swamp to dry. This will jeopardize the significant qualities of the site, at least by placing the aquatic flora in drought stress and perhaps even exposing the peat to the threat of direct burning.

This research has highlighted the need for lengthy and homogeneous hydrological data sets in regions subject to timber harvesting. A strong case could also be made for the establishment of paired watershed studies in order to compare the hydrological responses of neighbouring harvested and pristine sites. Whilst the availability of such data would not obviate the need for yield response models, they would greatly increase understanding of the timing and magnitude of forest regeneration impacts.

In the absence of lengthy hydrological data sets it is also difficult to exclude the possibility of climate change or even *El Nino* impacts on the flow record (Whetton *et al.,* 1990). For example, a longer data set would clarify the extent to which the two periods of very low annual runoff (1979-1982 and 1986-1988) shown in Fig. 6 were the product of quasi-periodic variations in rainfall (Stone & Auliciems, 1992). For the 40-year period 1952-1991 the annual rainfall amount measured at Bombala Post Office (705 m a.m.s.l.) explained over 68% of the inferred annual yield of the Delegate River at Tea-tree Swamp. However, during this period the maximum and mean predicted yield reductions associated with the coupe developments were 46 mm and 19 mm respectively. In other words, the impact of the forestry had not yet attained a level that exceeds natural variations which could be attributed to climate alone.

This study has stressed the value of linking fine-resolution palaeoecological studies with modelling studies of modern processes. Rarely are long term pre- and post-logging hydrological studies implemented and so the modelling of the effects from climate/yield models are often the only lines of evidence available.

The significance of the estimated impact of clearfelling revealed in this study warns of the potential impact of extensive clearfelling in catchments which are hydrologically sensitive. Modelling studies such as these ought to be employed more widely before logging commences so as to evaluate the extent to which the harvesting of one resource (e.g. timber) is in conflict with the conservation of another (e.g. water).

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10.0 Logging and the Thomson Water Catchment

10.1 Introduction

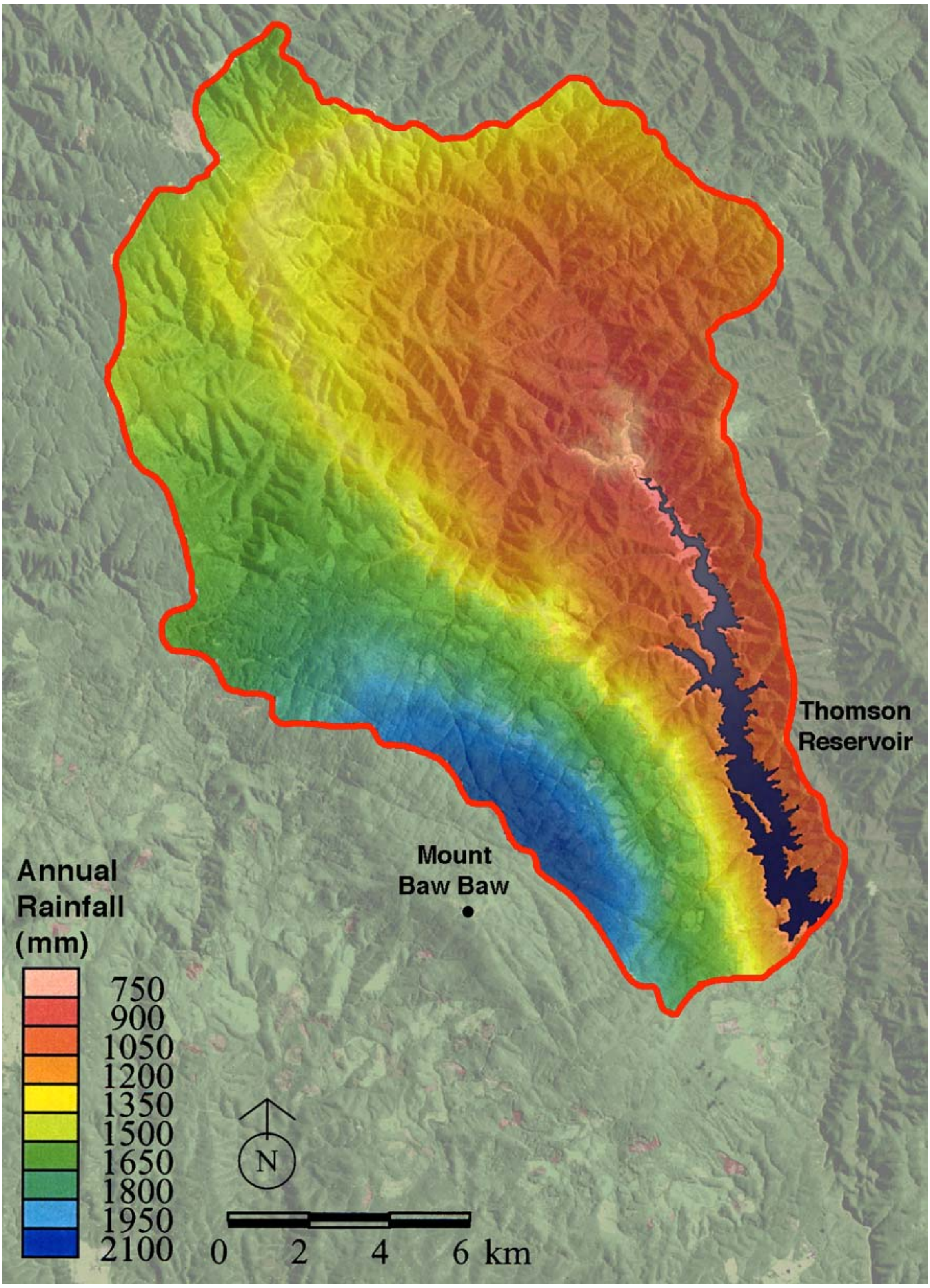
The Thomson Reservoir is situated along the eastern escarpments of Mount Baw Baw and carries approximately 60 percent of Melbourne's water storage capacity (Howe et al 2005). It is surrounded by 48,700 hectares of forested catchment that includes the northern and eastern slopes of Mount Baw Baw, the southern slopes of Mount Matlock on the Great Dividing Range and the western slopes of the Aberfeldy Range. The Thomson is the largest of four major water supply catchments for Melbourne, with the others being Maroondah, Upper Yarra and O'Shannassy. All are located within the Central Highlands of Victoria (Howe et al 2005). The Thomson is a major water supply catchment upon which logging is permitted. The forest industry considers the Mountain Ash, Alpine Ash and Shining Gum forests within the catchment as highly valuable for timber and pulp and targets these for logging. These forests cover 33.5 percent of the Thomson Catchment (Alaouze 2004) and occur within the high rainfall areas, mostly along the escarpments of Mount Baw Baw. When regenerating after logging, these species have been observed to double their use of water through having a higher Leaf Area Index (LAI) (Peel et al 2000, Vertessy et al 1998). The Strategy Directions Report stated that if logging were to be phased out of the Thomson Catchment by 2020, it is estimated that it will provide an additional volume of water in the order of 20,000ML (Water Resources Strategy Committee 2002). This chapter provides an overview of the issues concerning logging in the Thomson Catchment and implications for future management. These are covered in the following sections:

- Annual Rainfall within the Thomson Catchment (Section 10.2)
- Forests and Water Use (Section 10.3)
- Predicting Impacts on Water Yield within the Thomson Catchment (Section 10.4)
- Logging within the Thomson Catchment (Section 10.5)
- Global Warming and the Thomson (Section 10.6)
- Implications for Future Management (Section 10.7)

This chapter reveals significant problems with past and continued logging within the Thomson Catchment. **It reveals that logging Ash Forests results in the greatest water yield loss for any forest type in the catchment. 67 percent of the Ash forest area within the Thomson Catchment has been or will be logged. This exceeds the minimum of 20 percent for changes in the water yield to be detected.**

10.2 Water sourced from the Thomson Catchment

The highest rainfall area of the Thomson Catchment is along the top of the Baw Baw Plateau along the southwest boundary with an annual mean precipitation of 2475mm. Snow Gum Woodland *(Eucalyptus Pauciflora)* and alpine heathland are the dominant vegetation communities within this area (Peel et al 2000). These occur primarily within the Baw Baw National Park. The next highest area falls along the north and east escarpments of Mount Baw Baw below the plateau. These areas were found to receive a mean annual precipitation of up to 2220mm around the Upper Thomson River to around 1933mm along the 887m contour between Rocky Knob and South Cascade Creek along the eastern escarpments of Mount Baw Baw (Peel et al 2000). Alpine Ash *(Eucalyptus delegatensis),* Mountain Ash *(Eucalyptus regnans)* and Shining Gum *(Eucalyptus nitens)* are the dominant overstorey species for this area. The north and east of the catchment receive much less annual rainfall of around 1184mm. The majority of the reservoirs' yield is sourced from Mount Baw Baw and its associated escarpments. Refer to Map 10.2.1.



Map 10.2.1 Map of mean annual precipitation (synthetic) (in mm) for the Thomson Catchment based on 1962 precipitation data (Source – Peel et al 2000)

Figure 10.2.1 The Thomson Reservoir

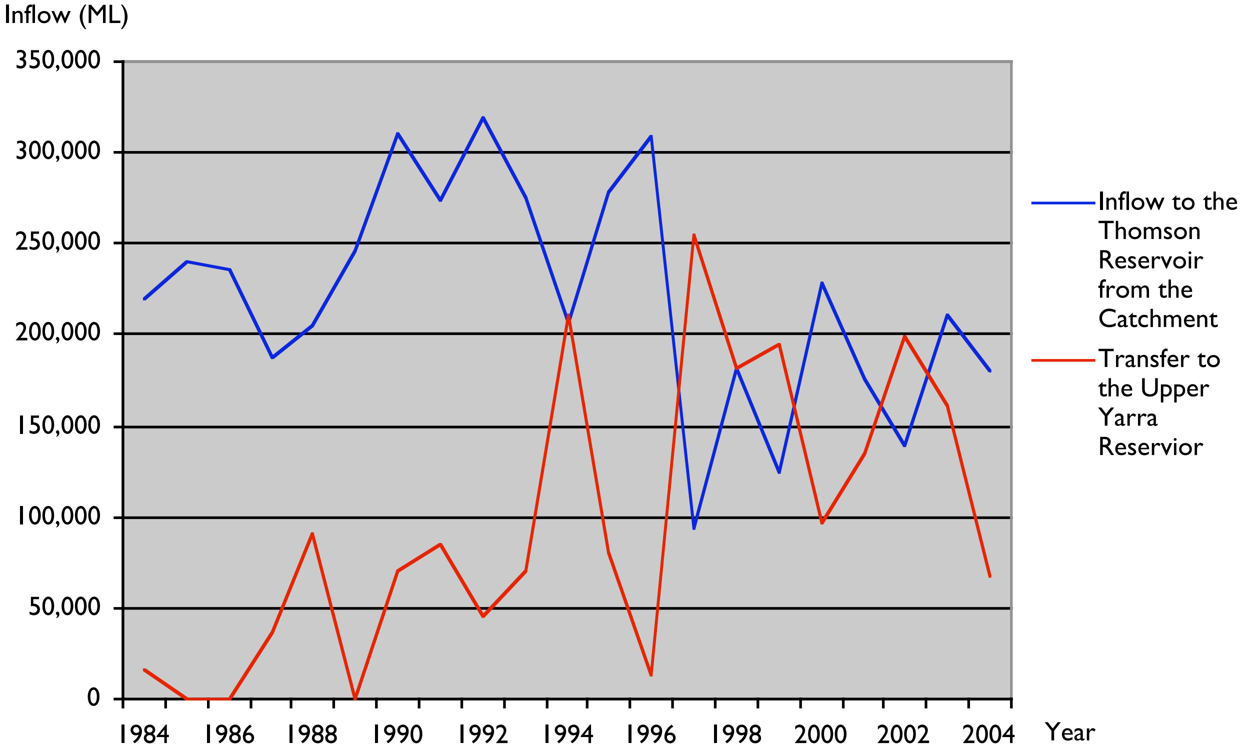


Figure 10.2.2 Thomson Reservoir inflow and transfer to the Upper Yarra Reservoir (Based on figures sourced from Melbourne Water).

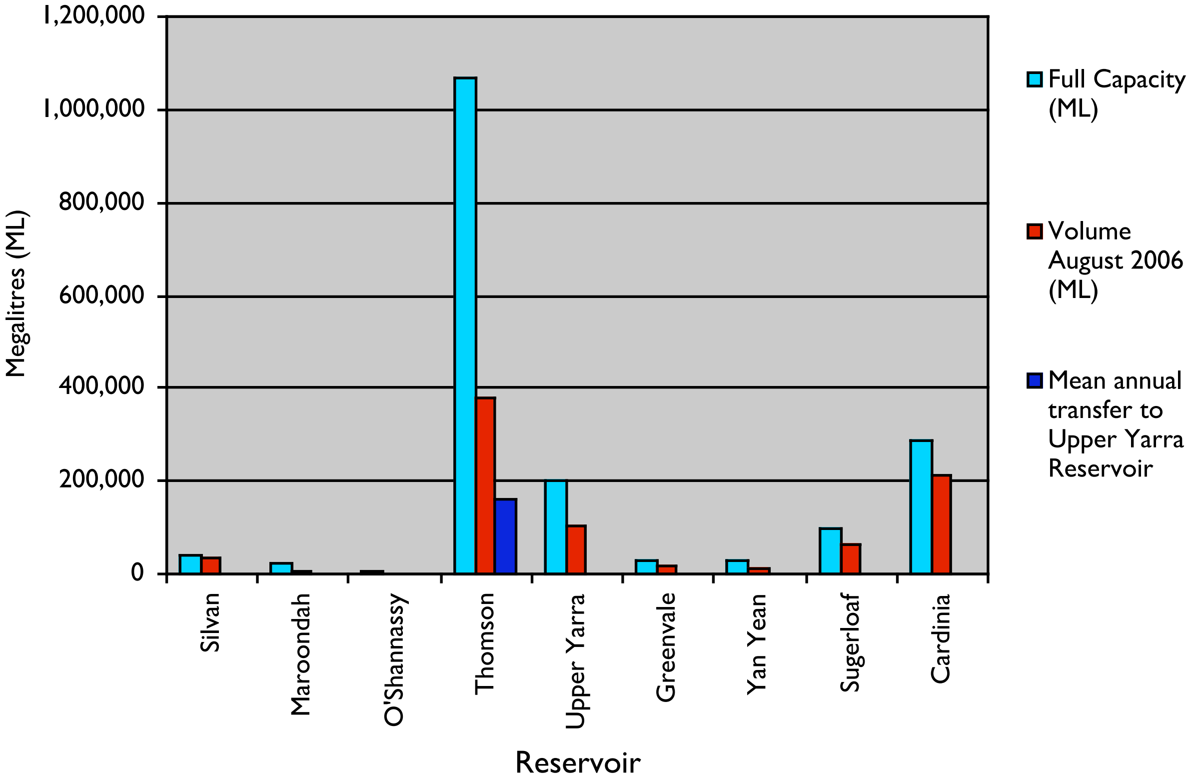


Figure 10.2.3 Graph showing capacity of Melbourne's Water Storage and volume as of 25.08.2006 (www.melbournewater.com.au - accessed 25.08.06).

From its catchment, the Thomson Reservoir has received a historical inflow between a high of 319,000 ML in 1992 and a low of 93,500 ML in 1997 (Melbourne Water Fact Sheet). The Thomson can hold 1,068,000 Megalitres (ML) or 60 percent of Melbourne's total water storage capacity. As of the end of August 2006, the Thomson was holding 379,353 ML or 46 percent of the total current supply (www.melbournewater.com.au - accessed 25.08.06). As the Thomson is the highest reservoir above sea level in the Melbourne Water Supply system, water is gravity fed through an underground tunnel to the Upper Yarra Reservoir, which then feeds into Melbourne's domestic water supply (refer to figure 10.2.5). Since the mid to late 1990's, the transfer of water to the Upper Yarra Reservoir has increased up to 254,500 ML. Between 1997 and 2004, a period of reduced rainfall, the mean average transfer has been in the order of 161,000 ML. This is over 80 percent of the Upper Yarra Reservoir's full holding capacity. Figure 10.2.3 reveals that the transferral from the Thomson makes a significant contribution to Melbourne'

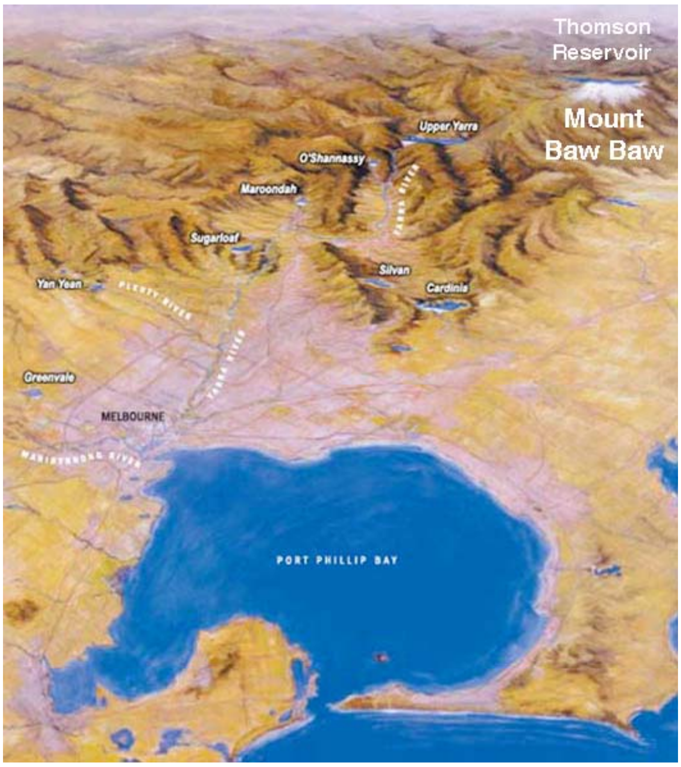


Figure 10.2.4 Location of water from the Reservoirs supplying Melbourne (Melbourne Water 2006)

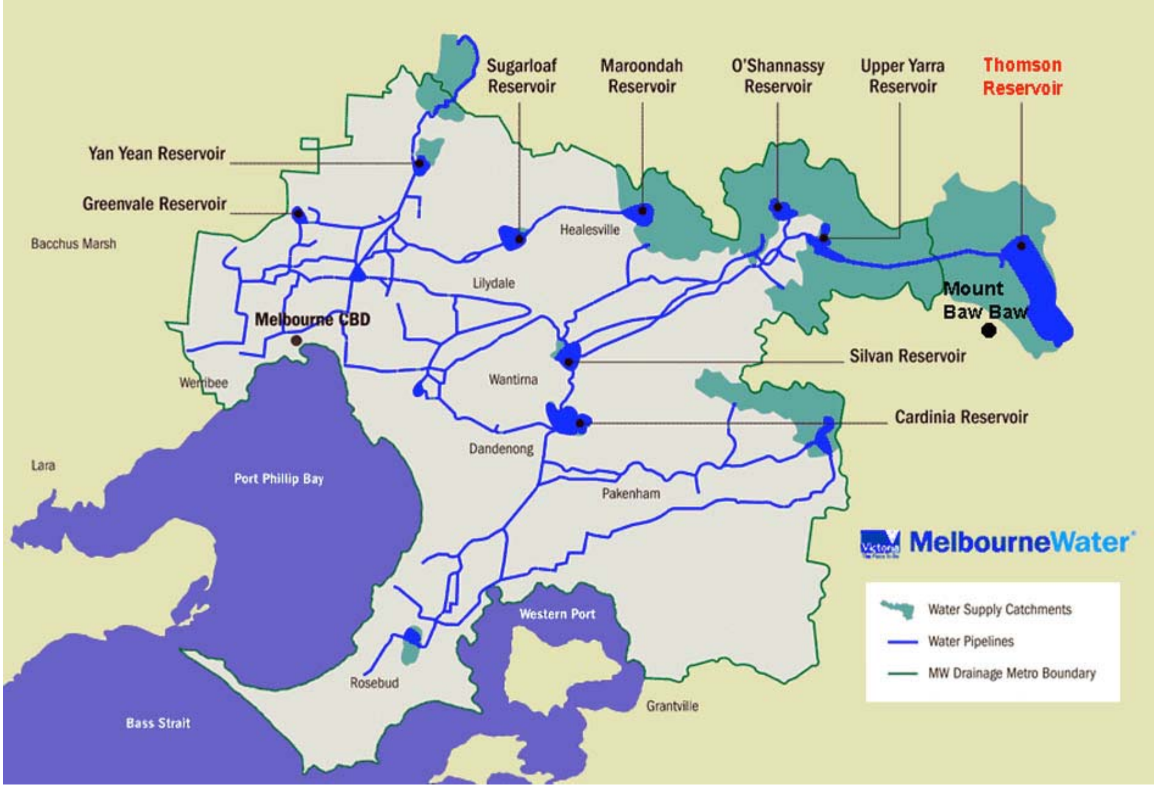


Figure 10.2.5 Distribution of water from the Reservoirs supplying Melbourne (Melbourne Water 2006)

10.3 Forests and Water Use

Our investigation of logging in Thomson Catchment refers to the application of the Macaque Model used in Peel et al (2000). Macaque is a large scale, long term, physically based water balance model that predicts the water yield of forested catchments subject to land cover change (Watson et al 1997). The Macaque Model was developed and tested using data from Maroondah (Peel et al 2000). An overview of the Maroondah data along with an introductory on the causes of water yield reduction is provided below.

10.3.1 Logging trials in the Maroondah Catchment

During the early 1950's, the then Melbourne and Metropolitan Board of Works (MMBW) initiated an experimental hydrological programme designed to test the effects of various forestry treatments on long-term water yield (Watson et al 1999). A number of small experiments were set up in the Mountain Ash forests of the Maroondah Catchments in the Central Highlands of Victoria. Some of the experimental plots contained old growth forest and some regrowth forest following the 1939 fires. A variety of silvicultural regimes, such as clearfelling, patch cutting, artificial thinning and planting at different stocking densities were applied throughout the 1970's and 1980's. The treated plots were then compared to untreated plots to measure differences (Watson et al 1999, Watson 1999).

The experiments were located at Coranderrk and North Maroondah. The Coranderrk experiment consisted of three small catchments that drained southwards into Coranderrk Creek below the water supply weir. The Catchments were named Picaninny (52.8ha), Blue Jacket (64.8ha) and Slip (62.3ha) and each contained a small gauging weir (Watson et al 1999). The North Maroondah experiments consisted of 15 small experimental catchments divided into five groups based on the type of experimental treatments applied. These groups were Monda (4 catchments), Ettercon (4 catchments), Myrtle (2 catchments), Black Spur (4 Catchments) and Crotty Creek (1 catchment).

The Picaninny catchment of the Coranderrk group was 78 percent clearfelled in the summer of 1971/72 and the Slip catchment was the control. The pre-treatment period was 42 months. The effect of this logging experiment on water yield is shown in Figure 10.3.1.1.

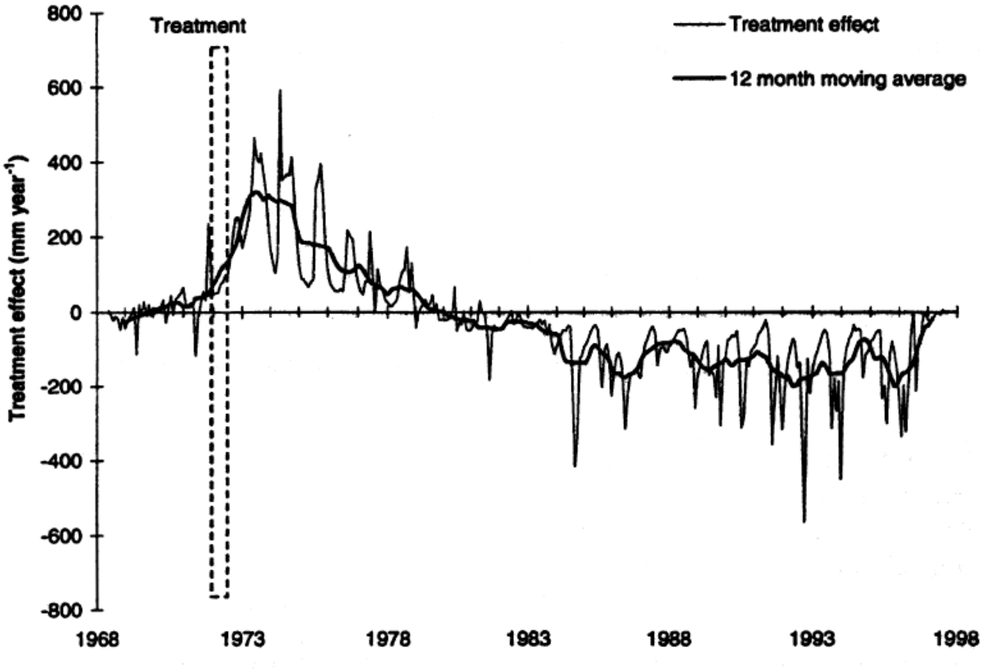


Figure 10.3.1.1 Logging effects on monthly stream flow at Picaninny (Watson et al 1999).

The results from the Picaninny logging experiment showed distinct increase in yield flow almost immediately following treatment, followed by a steady decline over the next 10 years to a low point that persisted for another 10 years when it apparently recovered. However, Watson et al (1999) was uncertain of the cause of the increase.

In the North Maroondah Catchment, the Myrtle Group consisted of 'Myrtle 2' being 74% clearfelled in the summer of 1984/85 with 'Myrtle 1' being the control catchment. The effects of this treatment are detailed in Figure 10.3.1.2.

In the post-treatment period, a significant increase in water yield runoff was observed for the first 2-3 years after treatment. Following this initial increase, the water yield then declined for a further 10 years where water yield increased following the regrowth becoming infected with Psyllids (Watson et al 1999).

From these trials, Watson et al (1999) concluded that the experiments showed a statistically significant medium term reduction in stream flow from the logged catchments.

Watson (1999) noted that Kuczera formed the 'Kuczera Curve' is used by Forest Management with regard to planning the location of new logging coupes within the Thomson catchment.
The Kuczera curve is based on an analysis of long term hydrographs from a number of affected water supply catchments in the period spanning from the 1939 Wildfires and is currently the best description of the effects of the 1939 fires, and of the effects of complete forest regeneration in general (Watson 1999). The curve is used to predict the effects of logging. However, the same curve is used for all Ash type forests regardless of other environmental influences on water yield such as precipitation and radiation. Precipitation has a range of well over 1000 mm within Mountain Ash forests, and radiation varies greatly between north and south facing slopes. **Watson (1999) states that current forest management is limited by inaccuracy in water yield prediction resulting from the assumption of spatial invariance of the yield/age relationship.**

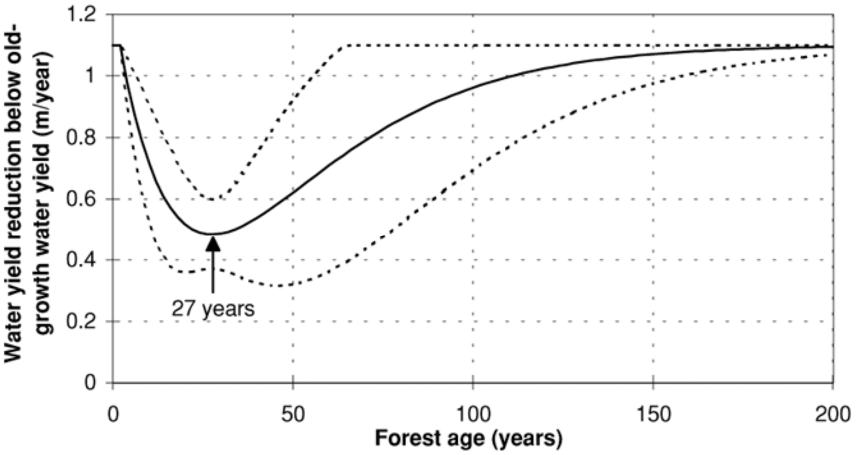


Figure 10.3.1.2 The "Kuczera Curve' as used to estimate water yield loss in Ash Forests (Watson 1999)

10.3.2 Causes of Water Yield Reduction in Regenerating Forests

In the Mountain Ash forests of south-east Australia, forest age is a major determinant of catchment runoff rate. It is now well documented that regrowth Mountain Ash Forest yields significantly less runoff than old-growth Mountain Ash. A great deal has been revealed about the hydro-ecological functioning of Mountain Ash forests through investigations on root development, stand structure, tree water relations and nutrient cycling (Watson 1999).

Watson (1999) states that the Leaf Area Index (LAI) is a major determinant of a number of hydrologic processes in forests. Vertessy et al (1998) states that the LAI controls the amount of plant transpiration and rainfall interception. Younger stands of Mountain Ash contain a higher Leaf Area Index (LAI) per unit of area and this is the key to the greater evapotranspiration difference between mountain ash stands of different ages.

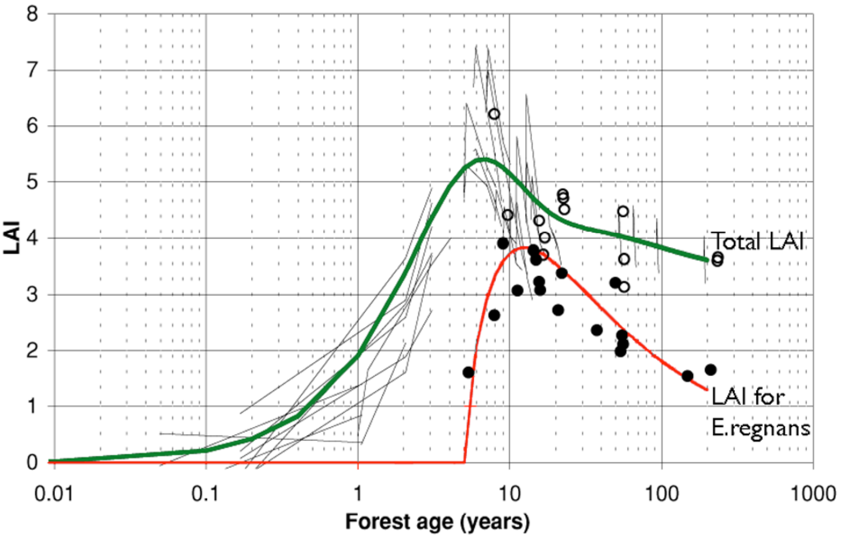


Figure 10.3.2.1 Leaf Area Index (LAI) following disturbance for a Mountain Ash Forest (Watson 1999)

Vertessy et al (1998) noted that the LAI of a mountain ash forest increases to a value of 4.0 at the age of 15 years and then decreases to about 1.3 at age 235 years, resulting in a threefold difference. The other Ash type species, that being Shining Gum *E. nitens*, and Alpine Ash *E. delegatensis*, appear to exhibit similar downward trends in LAI with age. In absolute terms Shining Gum is similar to Mountain Ash whilst Alpine Ash exhibits slightly lower total LAI in keeping with its preference for higher, colder sites. As expected, the drier, 'mixed species' forest type exhibits still lower LAI, with insufficient data to reveal any age trend. Finally, E. sieberi, which occupies the driest sites, exhibits the lowest LAI of the eucalypt forest types (Watson 1999).

The amount of water used by Mountain Ash Forests of different ages was studied and noted by Vertessy et al (1998). Here, the area of a trees' sapwood and the rate of water that passes through it is measured. For a stand of Mountain Ash, the volume of water passing through the sapwood did not vary greatly between the ages and was found to be a mean average of 11.6cm per hour for the six warmest months of the year. However, the total area of sapwood area greatly varied between the age classes. For a forest stand of 15 years, the total area of sapwood conducting water was measured at 10.6sq.m per hectare. At age 240 years, the sapwood area decreased to 3.6sq.m per hectare. As Vertessy et al (1998) assumed the sap velocity to be constant across the age classes, this threefold difference in sapwood area for Mountain Ash Forest overstorey translated into a threefold increase in transpiration for younger stands of Mountain Ash Forest.

The LAI for the understorey also increases with forest age. It was noted by Vertessy et al (1998) that the LAI increased from 0.1 in a 6 year old stand to 3.0 in an old growth stand. However, understorey trees were found to transpire significantly less on a per unit leaf area than the overstorey trees.

With regard to soil/litter evaporation, the study by Vertessy et al (1998) compared water yield loss between regrowth and old mountain ash stands. The study found that in an 11-year-old stand (with 15m tall mountain ash trees closely spaced at 2625 trees per hectare), with very little understorey vegetation, resulted in a mean daily soil and litter evapotranspiration rate of 0.36mm per day. For a 235 year old (80m tall mountain ash stand with a spacing of 50 trees per hectare), the Soil/Litter evapotranspiration decreased to 0.28mm per day. It is estimated that soil/litter evaporation accounts for 10-11% of annual evaporation from a mountain ash forest.

Further water yield losses are attributable to rainfall interception. This is where rainfall, landing on the leaves and stems of trees evaporates. The referenced study found that the rainfall interception rate peaked at 25% when the mountain ash forest was at the age of 35 years and declines slowly to about 15% by the age of 235 years. For a forest of a mean rainfall of 1800mm, stands aged 30 years intercept 190mm more rainfall than old growth forest aged 240 years.

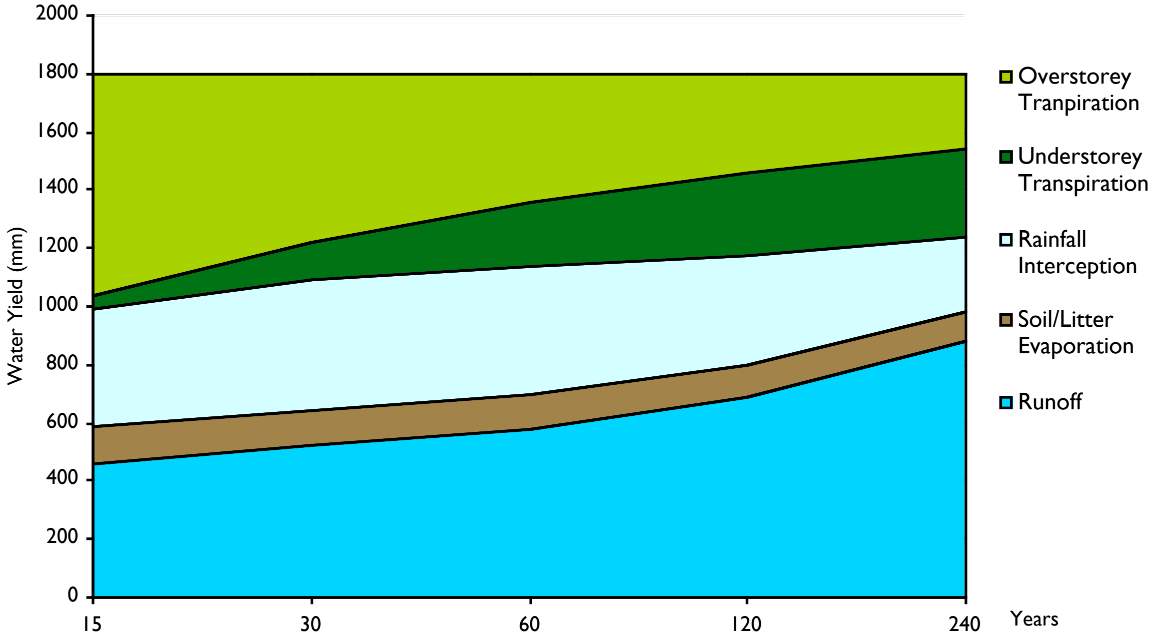


Figure 10.3.2.1 Water balance quantity estimates for 5 different age classes in Mountain Ash Forest showing increasing stream runoff with increasing forest age (Vertessy et al 1998)

Vertessy et al (1998) noted that water yield changes were difficult to detect if less than 20 percent of the catchment is disturbed. However, if disturbance is concentrated within a high rainfall area, these impacts may become obvious. For example, Vertessy et al (1998) notes that more than half of the Maroondah Catchment is Mountain Ash, yet it yields about 80 percent of water runoff because it is situated in the wettest areas. As the Forest Industry considers Ash Forest valuable for timber and pulp, it concentrates on species occurring in high rainfall areas. This is the case with logging in the Thomson Catchment.

10.4 Predicting impacts on Water Yield in the Thomson Catchment

Peel et al (2000) detailed a series of tests and predictions within the Thomson Catchment. Using the 'Macaque Model', Peel et al (2000) aimed to demonstrate the utility for management and planning within the Thomson Catchment.

As part of the study, Peel et al (2000) identified the Leaf Area Index (LAI) for a number of prominent tree species occurring with in the catchment along with their age classes. Together with taking account of the aspect of mountain slopes, altitude and mean annual precipitation patterns across the catchment, Peel et al (2000) processed the data to ascertain the changes in water yield following disturbance to the forest.

This section provides an overview of the simulated impacts that disturbance has on the forests within the Thomson Catchment. As Peel et al (2000) noted, different tree species vary with their LAI and water uptake. Map 10.4.1 details their distribution across the catchment. Table 10.4.1 lists the respective maximum and long term LAI of the primary species as detailed by Peel et al (2000). Table 10.4.2 lists five widespread species occurring within the high rainfall areas of the catchment with respect impacts that has on water yield. This is referenced from Figures 10.4.1, 10.4.2, 10.4.3, 10.4.4 and 10.4.5 where simulated changes to Water Yield following disturbance are plotted against time.

These figures were to provide an indication and were examples of the range of water yield responses to disturbance for the different species across the Thomson Catchment using the Macaque Model (Peel et al 2000).

Forest Type	**Maximum LAI**	**Long-term LAI**
Mountain Ash *Eucalyptus regnans*	6.0	3.5
Alpine Ash *Eucalyptus delegatensis*	5.7	3.2
Shining Gum *Eucalyptus nitens*	6.0	3.5
Messmate *Eucalyptus obliqua*	3.5	3.5
Silvertop Ash *Eucalyptus sieberi*	2.937	2.397
Snow Gum *Eucalyptus pauciflora*	2.5	2.5
Myrtle Beech *Nothofagus cunninghamii*	4.5	4.5
Silver Wattle *Acacia dealbata*	3.907	3.907

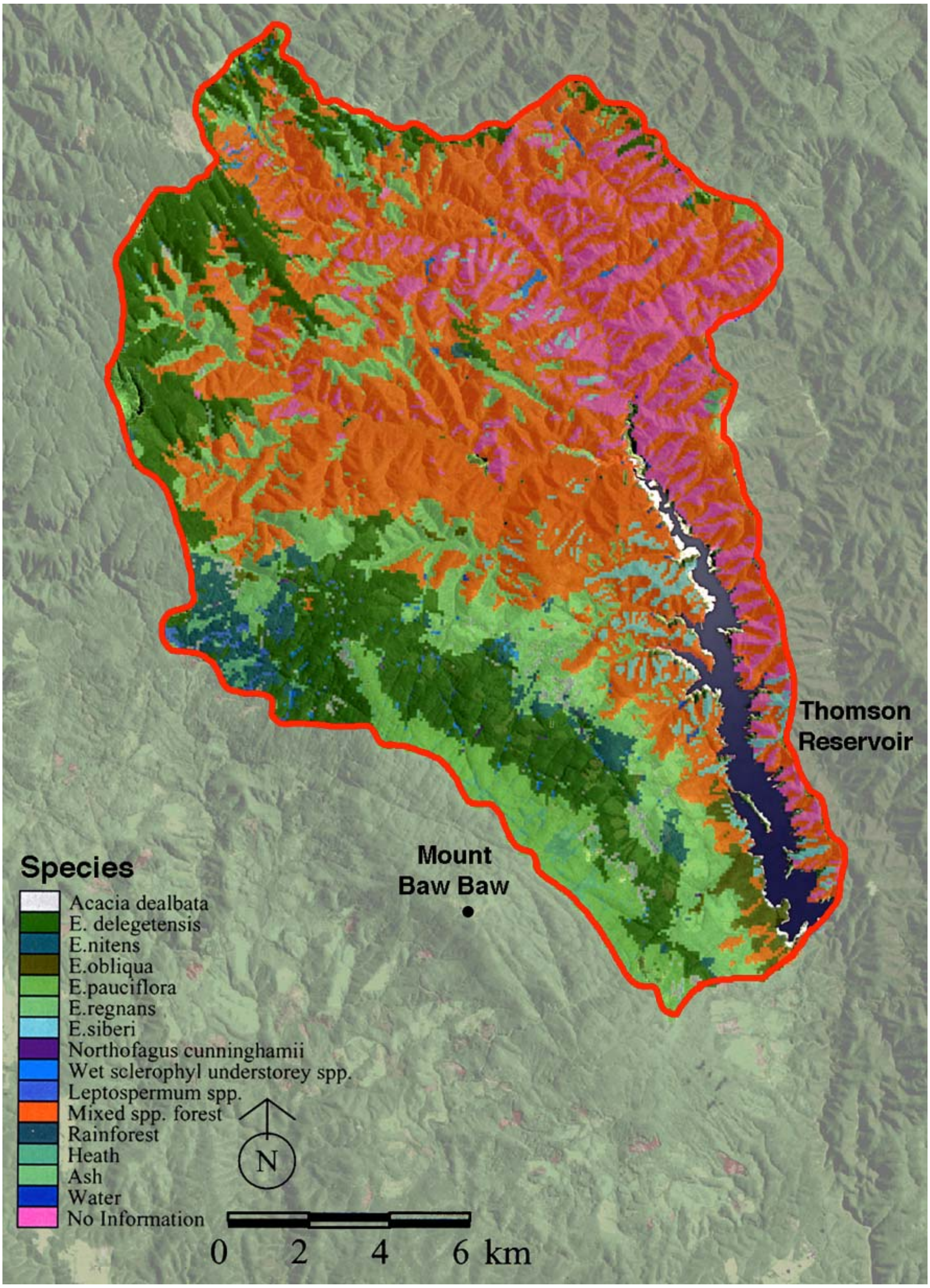
Table 10.4.1 Long term trends in Leaf Area Index (LAI) and maximum leaf conductance for the forest types present at the Thomson (Source – Peel et al 2000)

Forest Type	Total Forest Area (ha)	Percentage of Thomson Catchment Area	Forest available for Logging (ha)	Percentage of that Forest Type available for logging	Maximum Potential Water Yield Runoff per year (ML)	Percentage of Maximum Total Water Yield
Ash Forest	16,613	34.8%	11,133	67%	197,694.7	63.9%
Mixed Species	20,106	42.1%	10,333	51.4%	46,243.8	14.9%
Mixed	4,863	10.1%	0	0%	9,239.7	3%
Alpine	1,917	4%	0	0%	19,170	6.2%
Scrub	2,095	4.4%	0	0%	24,930.5	8%
Water	2,124	4.4%	0	0%	11,682	3.8%
Total	**47,718**	**100%**	**21,466**	**44.9%**	**308,960.7**	**100%**

Table 10.4.2 Area breakdown of the Thomson Catchment by Species (Read Sturgess 1994)

Forest	Species	Area of Species (ha)	% of total Catchment Area	Annual Rainfall (mm)	Old Growth Yield (mm)	Regrowth Yield (mm)	Difference in Yield (mm)
Alpine	Snow Gum	3,386	7%	2475	1546	1309	237
Ash	Mountain Ash	5,283	11%	1933	692	0	**692**
	Alpine Ash	9,193	19%	2220	1125	386	**739**
	Shining Gum	1,320	3%	2234	1036	359	**677**
Mixed	Messmate	20,106	42%	1184	238	46	192

Table 10.4.3 Table detailing simulated impacts of water yields following the logging an old-growth forest and replacing it with a regrowth stand in the Thomson Catchment (Source – Peel et al 2000, Read Sturgess 1992, Read Sturgess 1994)



Map 10.4.1 Thomson Catchment detailing species distribution across the Thomson Catchment (Source – Peel et al 2000)

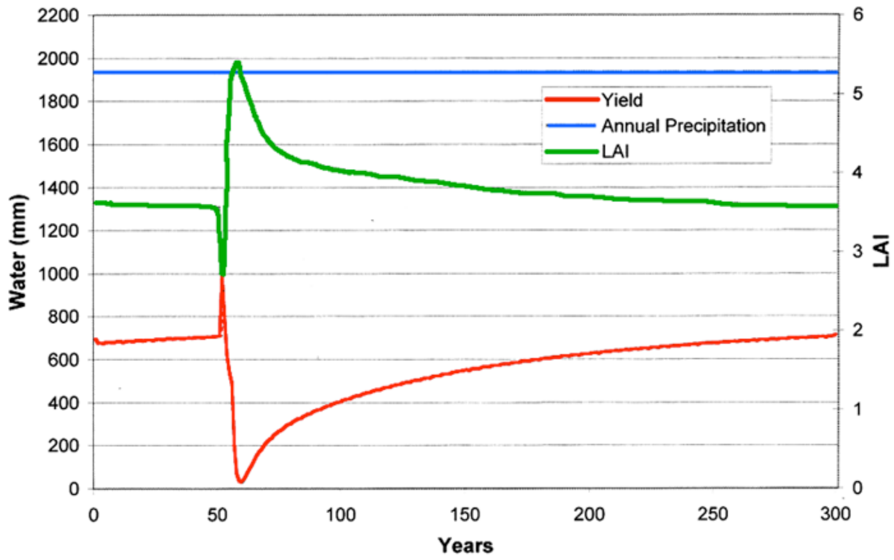


Figure 10.4.1 Results for a Mountain Ash Forest using a synthetic climate with a time series on annual water yield, annual precipitation and LAI (Source – Peel et al 2000)

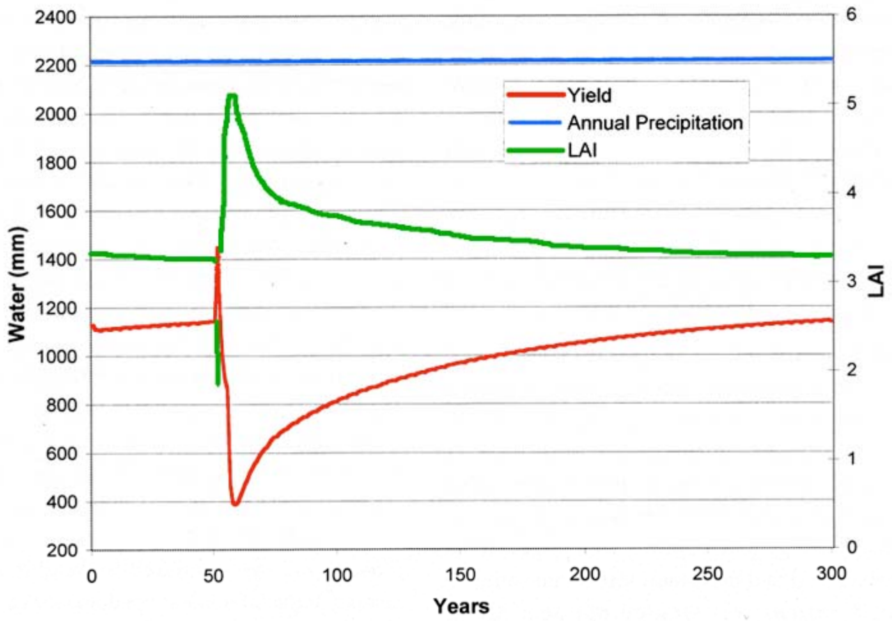


Figure 10.4.2 Results for an Alpine Ash Forest using a synthetic climate with a time series on annual water yield, annual precipitation and LAI (Source – Peel et al 2000)

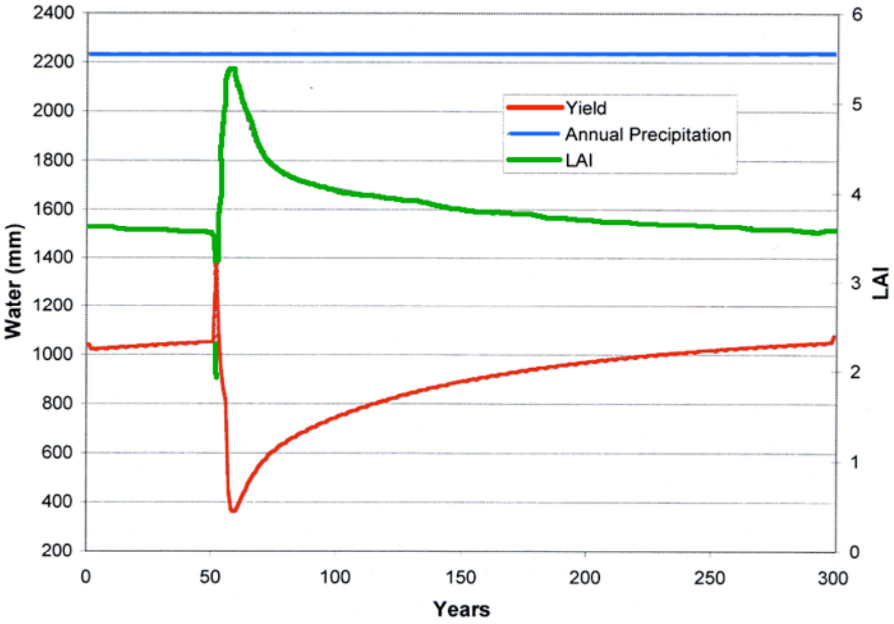


Figure 10.4.3 Results for a Shining Gum Forest using a synthetic climate with a time series on annual water yield, annual precipitation and LAI (Source – Peel et al 2000)

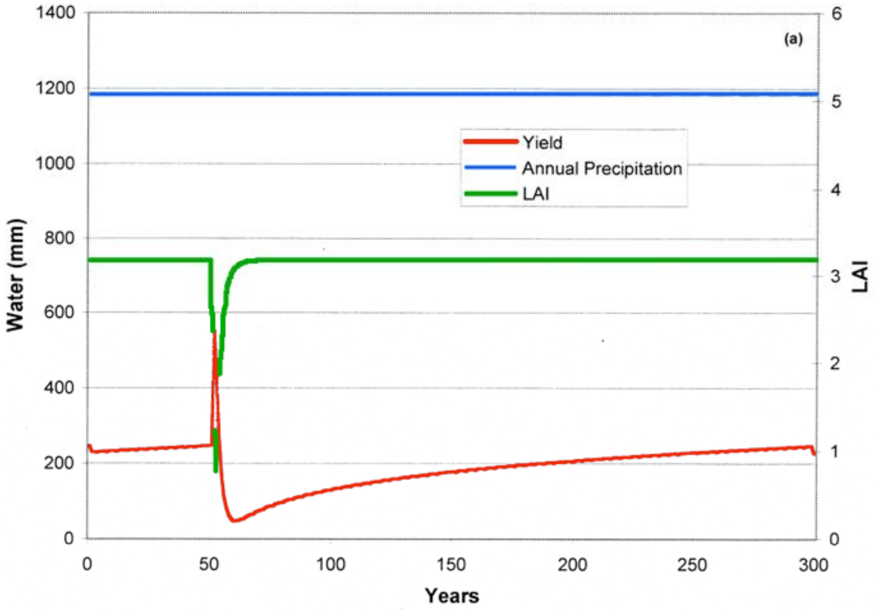


Figure 10.4.4 Results for a Mixed Species (include. Messmate) Forest using a synthetic climate with a time series on annual water yield, annual precipitation and LAI (Source – Peel et al 2000)

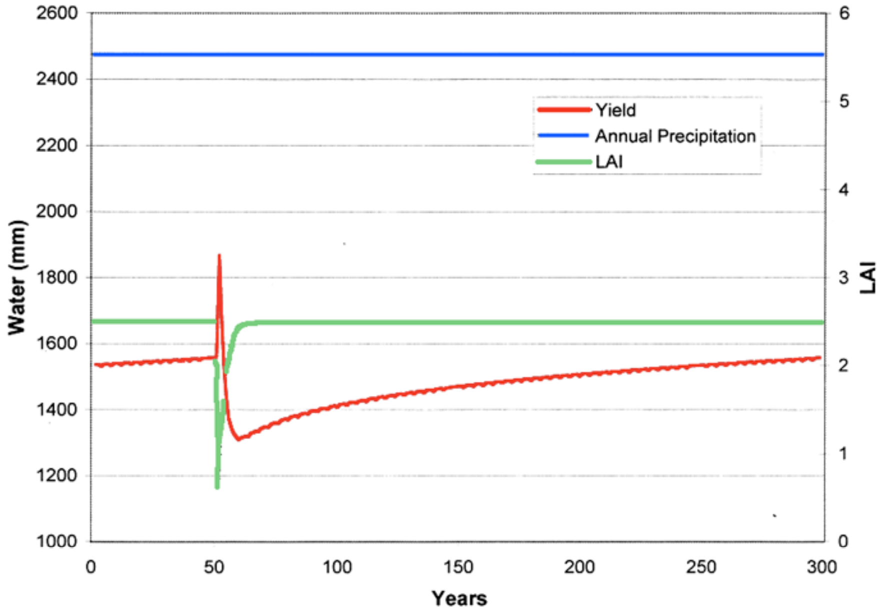


Figure 10.4.5 Results for Snow Gum using a synthetic climate with a time series on annual water yield, annual precipitation and LAI (Source – Peel et al 2000)

In Figure 10.4.6, Peel et al (2000) plotted the simulated water yield impact against the Mean Annual Precipitation (MAP) and provided the approximate prediction of the zone of maximum water yield reduction. It recognised that disturbance to Mountain Ash (E.regnans), Shining Gum (E.nitens) and Alpine Ash (E.delegatensis) resulted in the greatest reduction in water yield for the Thomson Catchment.

These simulations revealed that Mountain Ash, Alpine Ash and Shining Gum Forests have the greatest yield reductions following disturbance of the forest types in the Thomson Catchment. All these fall under the generic term 'Ash Forest' (Ref Figure 10.4.6).

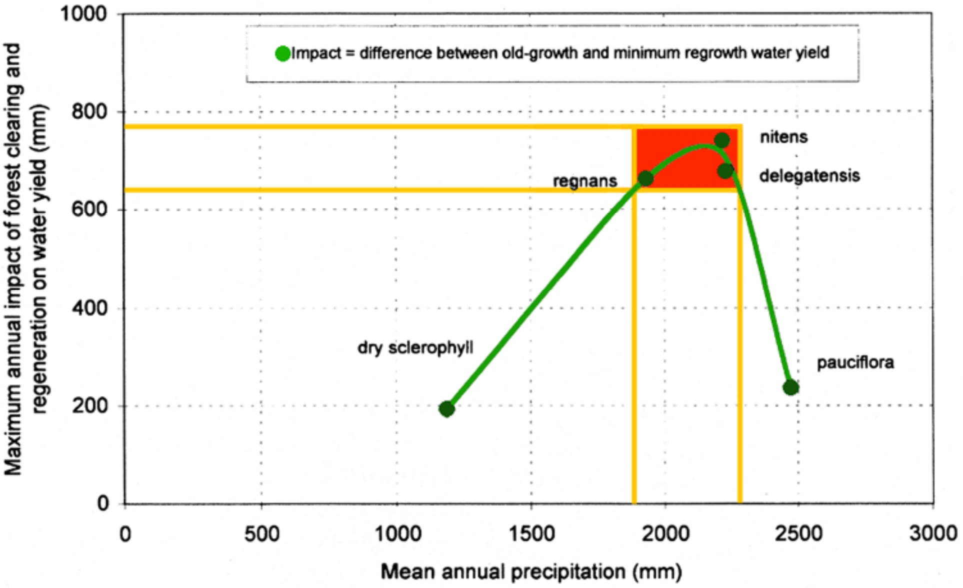


Figure 10.4.6 Macaque model suggests that maximum annual impact of clearfell logging and regeneration on water yields peaks at 2200mm Mean Annual Precipitation (MAP) on the ecotone between E.regnans (Mountain Ash), E.nitens (Shining Gum) and E.delegatensis (Alpine Ash) Forest (Source – Peel et al 2000)

Figure 10.5.1 Logging within the 'Ash Forests' of the Thomson Catchment with the Thomson Reservoir in the Background

10.5 Logging within the Thomson Catchment

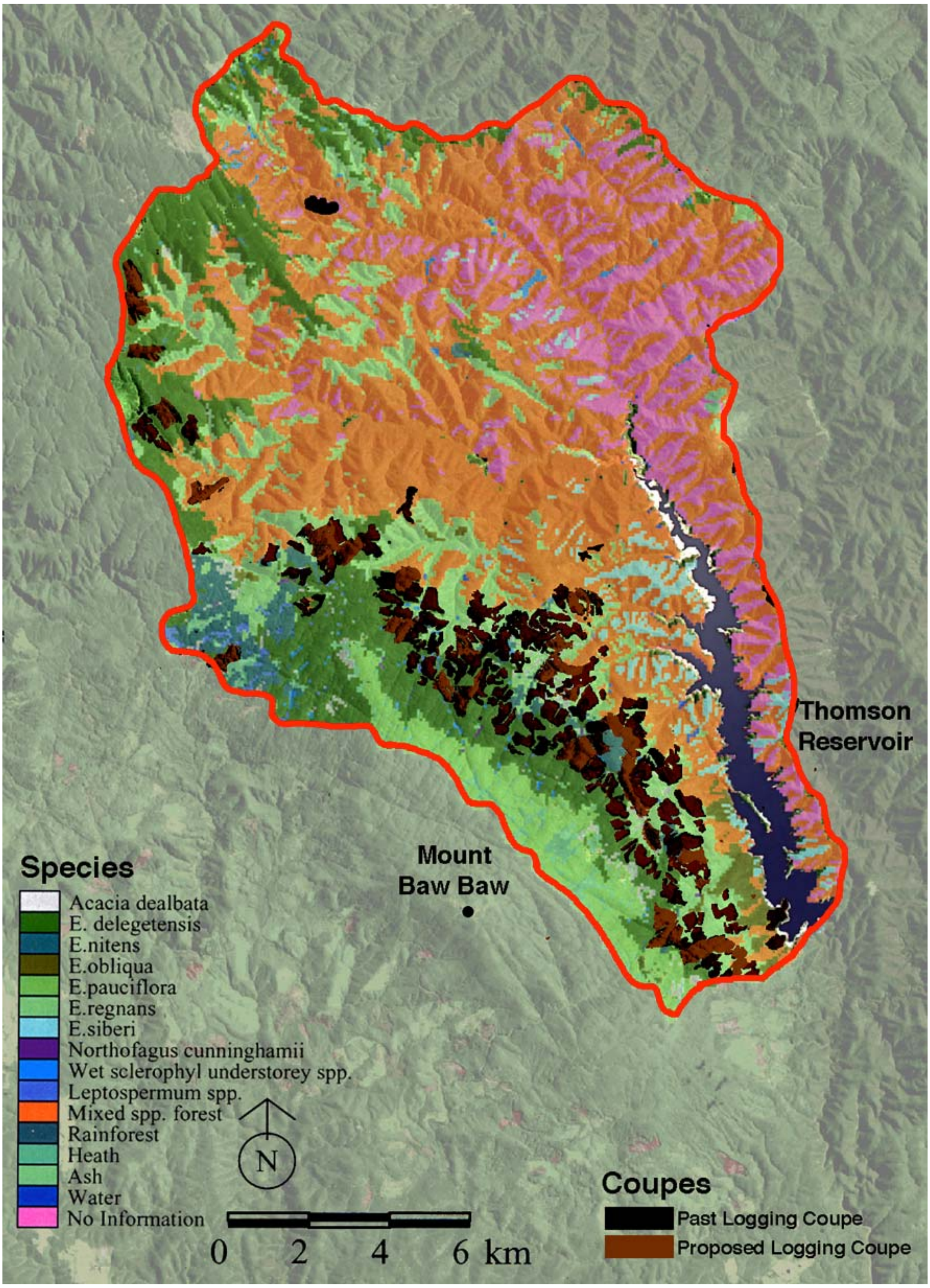
The Thomson Catchment is the only one of the four 'major' water catchments for Melbourne that is open to logging. Current forest prescriptions do not allow the area logged for any one year to exceed 150 hectares within the catchment (DSE 2006). The significant majority of the logging has focused on the 'Ash Forests' as Table 10.5.1 details below.

Table 10.5.1 Annual area cut within the Thomson Catchment (Source – DSE 2006)

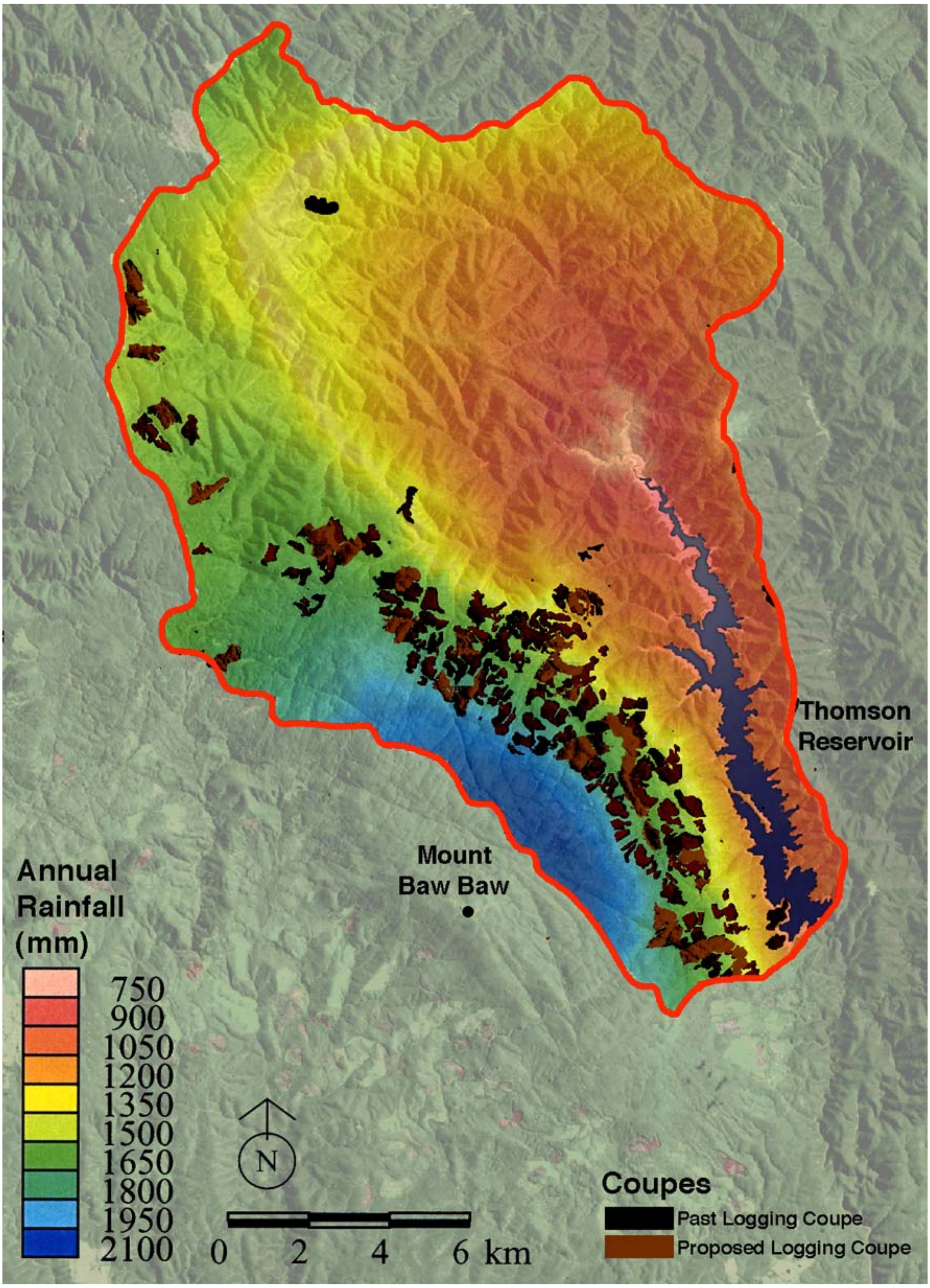
Season Ending June 30	**Ash (ha)**	**Mixed Species (ha)**	**Other Species (ha)**	**Total Hectares**	**Percent of Ash to Total**
1988	29	8	0	37	78%
1989	155	0	4	158	98%
1990	255	7	3	266	96%
1991	202	4	0	207	97%
1992	93	0	0	93	100%
1993	108	0	0	108	100%
1994	212	24	3	238	89%
1995	226	19	5	250	90%
1996	157	15	6	178	88%
1997	148	11	3	162	91%
1998	148	4	2	154	96%
1999	43	15	1	58	74%
2000	94	5	2	101	93%
2001	101	10	0	111	91%
2002	96	15	0	111	86%
2003	85	24	1	110	77%
2004	117	8	0	125	94%
2005	118	4	0	122	97%
Total	**2387**	**173**	**30**	**2589**	**92%**
Average	**132.6**	**9.61**	**1.67**	**143.8**	**92%**

As detailed in Table 10.5.1, an average of 92 percent of forest cut is Ash. These forests cover only 34.8 percent of the catchment (Read Sturgess 1994), however, they yield over 60 percent of the Thomson Reservoirs' water supply (refer to Map 10.5.1). Map 10.5.2 further reveals that logging is concentrated along this area where the high rainfall bands encircle the escarpments of Mount Baw Baw.

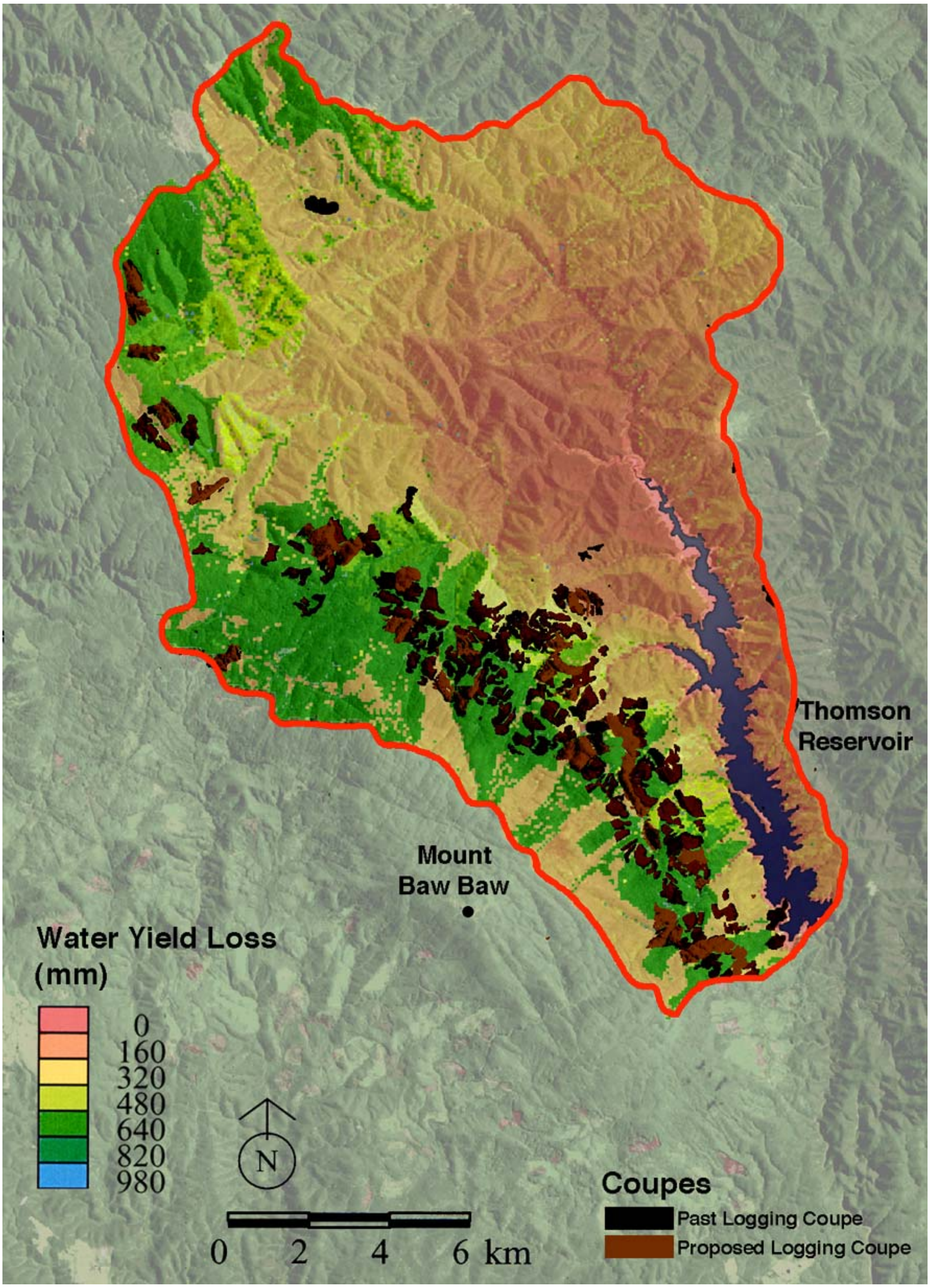
Note - The logging history on the maps date back to 1980. This was to coincide with the commencement of construction of the dam wall in 1976 and its completion in 1983 (Melbourne Water 2005).



Map 10.5.1 Past and proposed logging coupes concentrating on Ash Forest within the Thomson Catchment



Map 10.5.2 Past and current logging coupes occurring within areas of high rainfall within the Thomson Catchment



Map 10.5.3 Simulated maximum annual water yield reductions from vegetation disturbance with past and current logging coupes occurring within areas of high water yield impact (Based on – Peel et al 2000)

Peel et al (2000) details the maximum impact of vegetation disturbance on water yield calculated by subtracting post-disturbance minimum annual water yield from pre-disturbance average annual yield. This forms the base for Map 10.5.3. As detailed in Section 10.4, the greatest impact was found to occur within the ash forest. Map 10.5.1 details this area occurring mid slope along the escarpment of Mount Baw Baw. **Map 10.5.3 reveals that the significant majority of past and proposed logging occur within the vegetation zone where the impact and reduction on water yield is the greatest.**

With Ash Forest covering 33.5 percent of the Thomson Catchment (Alaouze 2004), the Ash forest cover approximately equates to 16,000 hectares with 11,000 hectares available for logging (Alaouze 2004). Table 10.5.1 notes that 2387 hectares of Ash Forest have been logged within the catchment since 1988 (DSE 2006). This equates to 15 percent of the total Ash Forest over an 18-year period. As the mean average area of Ash forest logged is 133 hectares per year, 11,000 hectares will be logged over an 83-year period. Vertessy et al (1998) notes that **for changes in water yield be detected on a catchment scale, at least 20% of the catchment has to experience disturbance. The area of high water yielding Ash Forest experiencing disturbance through logging is 67%. This is over 3 times the minimum threshold.** As the regenerating Ash forests reach a merchantable age, they will be logged again and the rotation will be repeated (according to Davies et al (1993), this can be as short as 50 years). This permanently holds the Ash Forests in a 'high water use' stage.

This finding is in contrast to the statement provided by the National Association of Forest Industries (NAFI) in its *'Submission to the Senate Rural and Regional Affairs and Transport Committee Inquiry into Rural Water Resource Usage'*, upon where is it stated that:

> *The Thomson Catchment covers an area of 48,700 hectares, with the forest industry harvesting ash timber from an area of less than 150 hectares per annum. At the present time, approximately 90 hectares or 0.18% of the catchment is harvested each year, producing 27,000 cubic metres of high value timber each year from the catchment. Over an 80-year rotation period, less than 20% of the catchment would be utilised for timber production. As is the case with plantations, the CRC Catchment Hydrology notes that "water yield changes are difficult to detect if less than 20% of the catchment is treated" by the harvesting of timber* (NAFI 2003).

In its submission, NAFI (2003) does not recognise that rainfall is variable across the catchment. As found by Peel et al (2000), drier forest types can a yield little to no water runoff and stream flow through these forests is depended on higher elevation forest where rainfall is greater.

10.6 Global Warming and the Thomson Catchment

In 2005, Melbourne Water published a study titled *'Implications of Potential Climate Change for Melbourne's Water Resources'* (Howe et al 2005). In its introduction, this report quotes the Water Resources Strategy for the Melbourne Area Committee finding that:

> *…..the increasing body of scientific evidence that gives a collective picture of a warming world and other climate changes and the potential of significant implications for our water resources systems. The Committee recommended that Melbourne Water and the retail water companies continue ongoing, active evaluation of climate change impacts on water supply and demand measures* (Howe et al 2005).

The report found identified major risk areas for water supply being:

- Reduced water supply due to decreased stream flows
- Increased risk of bushfires in catchment areas with associated risk of decreased stream flow

- Reduced environmental condition of streams with associated implications for water harvesting in regulated and unregulated streams

As part of its recommendations for catchments and recommendations, the report requests that:

- **Forested catchments are managed to minimise the water yield impacts from disturbances such as bushfires or logging**

- Evaporation reduction or rainfall enhancement measures are implemented

10.7 Implications for Future Management

The Committee for the Strategy Directions Report recognise that there are long term benefits from a water yield perspective of the gradual phasing out of existing logging from within Melbourne's water supply catchments (Water Resources Strategy Committee 2002). The report states that:

> *As an indication of the potential volumes of water involved, the gradual phasing out of logging in the Thomson catchment by 2020 could provide an estimated additional average annual volume of water of 20,000 ML in 2050* (Victorian Government 2005)

Creedy et al (2001) also demonstrated that the decision not to log the Thomson more than doubles its net present value when compared to the current management policy that allows logging to continue. Creedy et al (2001), from their economic analysis, found that:

> ***….given the Thomson Catchment is already an established forest, its net present value is maximised by taking advantage of the high water yield and carbon stock, rather than forgoing these to earn the profits from its timber resource.***

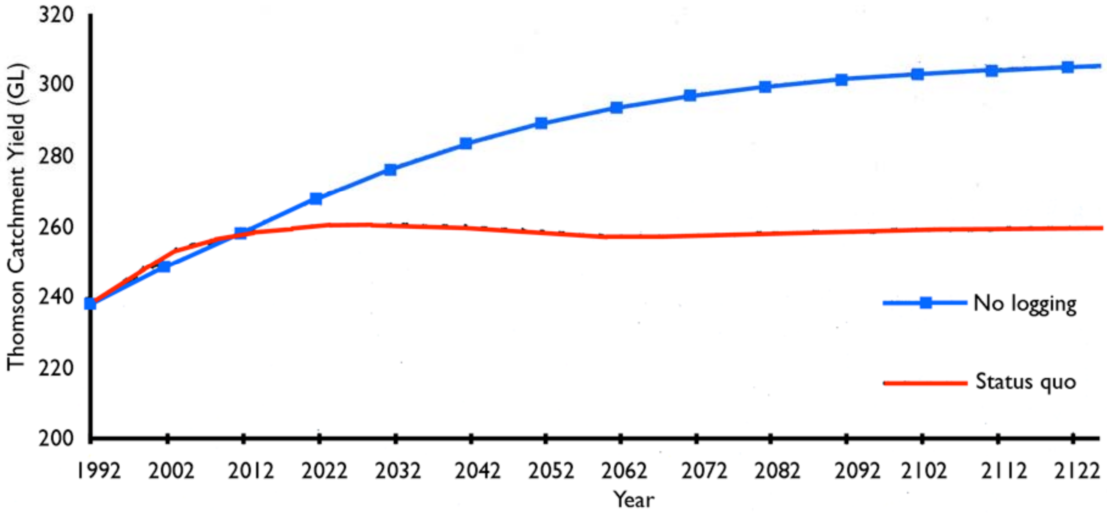


Figure 10.7.1 Predicted Yield analysis comparing a 'No Logging' scenario to one where current logging practices are maintained indefinitely (Source – Read Sturgess 1994).

With simulated evidence showing that logging is having an impact in water yield within the Thomson, along with risks identified by Melbourne Water with regard to Global Warming, it is recommended that a comprehensive impact study be made on the Thomson. All logging must cease whilst the investigation is underway to minimise any further potential degradation. The study must be conducted in an independent and transparent manner.

Key References

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LOGGING AND WATER

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THE AUSTRALIA INSTITUTE

LOGGING AND WATER

A study of the effects of logging regimes on water catchment hydrology and soil stability on the eastern seaboard of Australia

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The report

This report considers the impacts of logging in forests on the quantity and quality of water available for users. It considers the impacts of:

- the silvicultural regimes, yield control and scheduling systems used;
- the on-site logging technology and the conduct of operations; and
- the infrastructure of roads required to extract the wood from the forests.

It also considers the economic implications of the effect of logging on water yields and water quality and the lessons for policy makers.

This study is concerned with use of the forested catchments of the eastern seaboard of Australia and is not concerned with urban areas, dryland catchments, agricultural areas, the Murray-Darling Basin.

Impacts of logging

The great variability of Australian rainfall and the occasional occurrence of bushfires poses particular problems for the study of hydrological impacts. Occasional, unpredictable peak rainfall events can outweigh or mask the effects of alternative catchment treatments.

Studies reviewed in this report show that the method of harvesting can greatly influence soil disturbance. Landslips on steep slopes with deep soils can be caused by road cuts and road drainage. Such events have occurred in Australia. In Australia up to 25 per cent of a logging coupe can be covered by snig tracks and landings and this indicates a need for scientifically developed standards for the amount of allowable soil compaction. Overseas and local studies show the major impact that poor roading and harvesting practices can have on stream water quality particularly in steep country with unstable or erodible soils. Erosion mitigation measures can minimise, but not prevent, erosion and the supply of sediment to streams. The amount of compaction can be reduced by limiting traffic and increasing soil organic matter especially in sandy soils.

Streamflow is the residue of rainfall after allowing for evaporation from vegetation, changes in soil storage from year to year and deep drainage to aquifers. Forest management operations can interfere with these processes by:

- changing the type of vegetative cover on a catchment. Experimental results show that these changes can affect evapotranspiration and therefore streamflow;
- changing the soil properties. The ability of the soil to both absorb and store moisture infiltration can affect the proportion of rainfall delivered. Forest

operations which compact the soil can reduce both infiltration and storage capacities.

Following clear felling in both ash and mixed species forests, Nandakumar and Mein estimate that for every 10 per cent of a catchment cleared, a 33 mm increase in runoff can be expected. Flows reach a peak 2 to 3 years after clearing and then decline which, in the case of the Melbourne Water experimental catchments, meant a return to pre-treatment levels in some 5 to 8 years. For ash-type catchments subject to clear-felling and regeneration, water yield continued to decline below pre-treatment levels. In one experimental catchment, water yield declined to 50 per cent of its pre-treatment level. This finding is compatible to the yield changes reported by Kuczera after wildfire.

Forest management issues

The potential for forest operations to affect water yield and quality, soil and a wide range of environmental values has been reflected in regulations which, over the last twenty years have become increasingly detailed. Where water production is important, they specify that forests are to be managed by appropriate techniques, such as thinning and long rotations. Water quality is protected by limitations on the proportion of a catchment which can be logged in any one year and the specification of appropriate roading and logging practices. Detailed requirements are elaborated for each forest region.

All the Eastern seaboard States have codes of logging practice or regulations in place aimed at protecting forest values including water yield and quality. The Victorian and Tasmanian codes are particularly comprehensive. Currently the Victorian code is being renewed and revised. A review of the perceptions of the Code of Forest Practice held by workers, contractors and supervisors revealed that most timber workers accept the need for codes of practice but that compliance is in practice not as good as it is perceived. Better training for workers is needed, particularly as the pressure to keep up the supply of timber results in logging during inappropriate weather and soil conditions.

If the comprehensive codes of practice now specified were applied at a high standard in all public and private forests, the impacts on water quality would be greatly reduced. The key matters are:

- better road planning, design and maintenance;
- exclusion of 4WD vehicles from roads unsuited to heavy use;
- better use of buffer and filter strips;
- prohibition of logging when soil moisture content is high;
- better logging site rehabilitation;
- better training of supervisors and operators; and

- better designed logging and roading equipment.

Economic impacts

In the past, the abundance of water on the eastern seaboard has meant that the water used up as a result of forest growth has not been valued. As other uses emerge which can compete with forest use -- including urban consumption, irrigation, fisheries, recreational activities and natural systems -- then the value of water in alternative uses increases. The question now being asked is whether use of water in forest growth is the most efficient way of using the resource or should it be allocated to other uses. The concept of 'efficiency' needs to be interpreted to include long-term sustainability.

The hydrological evidence reviewed in this report indicates that current logging regimes in the native forests of eastern Australia can result in a decline in water yields. Other things being equal, an increase in rotation lengths reduces the volume of logs taken out of a forest over time but increases the run-off due to a decline in evapotranspiration.

The major economic study of forests and water was carried out by Read Sturgess for Melbourne Water. The study evaluated economically a range of management options involving different mixes of wood and water production from the Thomson River catchment. The study deals only with timber values and the value of water for Melbourne consumers. Moreover, the results of the study pertain only to the Thomson catchment and should not be extrapolated to other catchments which may have different forest cover, soils, hydrological characteristics and uses. The results of the Thomson catchment are heavily dependent on the prevalence of ash-type forests in the Thomson catchment and the fact that this catchment is very important to the water supply of a large city.

Apart from the hydrological data on which the study was based, key variables in the study included the pricing of water and of logs, and the discount rate employed. The study concluded that among the options considered, the existing management of the Thomson catchment (based on an 80-year rotation) is the most inefficient. The most economic silvicultural options are either a very long rotation (200 years) or a complete end to logging. The conclusion is that, using the estimated prices for timber and water, the loss of timber as the rotation is lengthened is more than compensated for by the increased water yields. If other values were taken into account, in particular ecological values, it is likely that the results would favour long rotations or no logging options more strongly. However, the Read-Sturgess method of calculating the value of water has been challenged by subsequent authors.

Conclusions

The very substantial differences between catchments in terms of their hydrological characteristics, patterns of land use and array of water users makes it clear that the analysis of forest use and management in relation to water must proceed on a regional scale at which the details can be evaluated properly. The integrated catchment management process now being adopted by most States and the Comprehensive Regional Assessment process being undertaken jointly by the Commonwealth and States, are being carried out at the relevant scale. However, it is far from clear that all important catchments will be included in the former process within the foreseeable future or that water will be considered at all in the Comprehensive Regional Assessments.

In relation to water quantity, it is clear that in some regions water has to be allocated between tree and other crops, and between primary, secondary and domestic use, but the effect of tree crops on water yield is known for only a few sites.

In relation to water quality, it is clear that the most important issues relate to the standard of forest management practice. The major obstacles in some locations are the continued pressure of governments to reduce field staff, lack of training, the unwillingness of industrial companies holding resource rights to pay adequately for high quality work, and the need to upgrade much of the old roading infrastructure.

The broad conclusion of this report is that existing assessment processes, including those being developed for the Comprehensive Regional Assessments, do not adequately deal with the potential impacts of logging on water yields and water quality. Conflicts over access to water on the eastern seaboard are likely to become a much more pervasive problem in the next decades as water-intensive activities expand on the coastal strip. If the issue is taken up now there is an opportunity to develop the data bases, methods of analysis and institutions that will help to resolve conflicts before they become entrenched.

1. INTRODUCTION

1.1 Concern and context

Water, its quantity, exceptional variability from year to year, and variable quality, is an evolutionary determinant of Australia's ecology and a major determinant of agriculture, settlement, and economic development. In turn, development has substantially modified the catchments for agricultural, industrial and urban use and created many now well-known problems.

Although the total annual runoff per person in Australia is far higher than in many developed countries, more than half the runoff is in northern Australia with a low level of development. Moreover, Australia's rainfall is highly variable with long drought sequences being experienced and occasional heavy rainfall events resulting in flooding. As the population is highly urbanised with a high level of water consumption, large water storages have to be constructed to cope with the variability. Even so, there is significant stress on water resources to supply the largest capital cities.

On the eastern seaboard, the catchments comprise a mix of forest, farmland and urban land uses and they supply water for domestic, industrial and agricultural users. The forested parts are the least modified ones left, but they too are subject to continuing change through deforestation, road construction, weed invasion, logging, mining and bush fires, for example. They are particularly important as the source of water supplies to the majority of the population and this will undoubtedly increase as the population increases. The concern underlying this paper is that the use and management of the forests may become a more important, but not yet fully recognised issue for some of the rapidly growing coastal regions, perhaps even for the whole belt between Sydney and Brisbane and part of the belt between Melbourne and Sydney. This paper examines how the forested catchments are being modified by logging, what implications this has for future water use, the economic consequences for water users and what policies governments should adopt.

The study is being conducted at a time when the Commonwealth and State governments are embarking on a process of regional assessments and agreements which will determine how the forested catchments will be modified in future. Under the 1992 *National Forest Policy Statement*, the Commonwealth and the States are committed to negotiating regional forest agreements based on a process of comprehensive regional assessments. The process is expected to be completed over the next three years. The agreements are intended to provide a representative reserve system for conservation and resource security for large-scale industrial developments - such as continued woodchip exports or new large export pulp mills - based on forests and plantations outside the reserve system. Hence, the decisions that are made over the next three years will shape forest use and management with consequences for water users well into the next century. The process is being driven primarily by concerns for biodiversity, heritage and wilderness values while a number of other values, such as water, recreation and employment appear to be receiving little attention at present.

1.2 Integrated catchment management

Although issues of riparian rights to divert the natural flow of water have an ancient history, the problems of land degradation and salinity in Australia have led State governments to realise the need to integrate the management of catchments across land-use and property boundaries. They have established organisations to advance an integrated approach over whole catchments, usually in collaboration with local land care groups.

The integrated catchment management approach provides the conceptual model for estimating the physical and economic effects of changes and decisions on water users. For each group of users, the quantity and quality of their water is determined by the interaction between the hydrological characteristics of the catchments, the mix of land uses, the way in which each type of use is managed, and whatever dams and treatment works are installed.

The management of forests and the construction of dams have to be considered over very long time periods; typically 100-200 years for the ecologically sustainable management of native forests, and 30-50 years for the amortisation of investments in infrastructure. With occasional refurbishment, Australian dams seem to last a long time. In Victoria, for example, the Yan Yean dam, built in 1860, and the Silvan and Maroondah dams, built in 1928, are still in use. Considering such long-term futures requires that the needs of future as well as present users be recognised.

There are thus four inter-related areas which public policy has to integrate for the long-term management of catchments:

- the area allocated to each type of land use;
- the way in which each type is managed;
- the investment in infrastructure; and
- the allocation of water and the distribution of costs and benefits between types of user.

1.3 Forest decisions that affect water

The headwaters of catchments are of particular importance and are often covered in forests, or in need of reforestation. Logging, the subject of this paper, needs to be seen in the context of other changes to the forests which affect water. The three greatest are deforestation, reforestation and bush fires. Deforestation is still a significant process on private land and one which requires further monitoring and control (Resource Assessment Commission 1992, v.1, p.129-30). Reforestation may be directed to the rehabilitation of land which should not have been cleared, to commercial wood production, or to some combination of both. Reforestation is being encouraged by several public programmes and plantations are being expanded by both public and private investment. Major bush fires have significant effects on water quality and quantity, especially in Victoria's forests of fire-sensitive mountain and alpine ash. Public policies on access, fire protection and control can influence, but never eliminate or predict them. Seasonal climatic variations, particularly droughts affect forests but, as they are long-lived systems, to much lesser extent than agricultural land uses. Changes to climatic patterns as a result of global warming are a further source of uncertainty but are not considered in this report. Deficiencies in the scientific knowledge about the effects of logging create further uncertainty.

Forests and plantations have many uses and values and require a wide range of management activities for their protection and regulation: one hundred activities are listed for managing the Otway forests in Victoria, for example (Dargavel and others 1995). Outside the conservation reserve system, logging is a major activity, but several others, such as road construction, utility easements, mining, gravel extraction, recreational and rally driving in cross-country vehicles or motor cycles affect the quality and quantity of water available to users. Camping is particularly important in relation to bacterial contamination because people like stream-side sites, but authorities find it difficult to manage them. Reforestation for commercial wood production obviously leads to logging when the tree crops are ready for harvesting, and there are some connections between logging and bush fire incidence and control.

The conduct and control of logging operations, and the decisions readily available to governments, vary between the privately-owned and public forests. The issues of privatisation or public acquisition, which could affect water users, are considered to be beyond the scope of this report, although it should be noted that most of the public plantations, covering three-quarters of a million hectares, have already been corporatised and may well be privatised. Similarly, the uneven allocation of resource rights between logging firms and processing firms is considered beyond the scope of this report, although it should be noted that the present system does nothing to reward high standards or long-term responsibility.

This report considers four types of decisions which can be made about forests in relation to logging which affect the quantity and quality of water available for users. They are:

- the balance between the area of public forests in the conservation reserve system and the area outside the reserve system open to multiple use management which includes wood production;

and for the forests outside the conservation reserve system:

- the silvicultural regimes, yield control and scheduling systems to be adopted;
- the on-site logging technology and the conduct of operations; and
- the infrastructure of roads required to extract the wood from the forests.

Many other decisions about the use and management of the non-forested parts of catchments, and about the regulation and distribution of water have substantial effects on users but are not analysed in this report. However, they form the context within which the economic analysis of the effects of logging have to be seen.

2. FORESTED CATCHMENTS OF THE EASTERN SEABOARD

2.1 Introduction

This discussion paper is concerned with use of the forested catchments of the eastern seaboard of Australia and is not concerned with urban areas, dryland catchments, agricultural areas, the Murray-Darling Basin or the forested catchments in Western Australia with their particular problems of mining and salinity. Tropical areas are not included, partly because their characteristics are so different from the major areas studied, and partly because there is so little known about their hydrology. The Australian standard definitions and boundaries are used in this paper which focuses primarily on the South-east Coast Drainage Division which lies east of the Great Divide, running from the Queensland border round to the south-east of South Australia. Its contains 39 River Basins and includes both Sydney and Melbourne(Map 1). The study also draws on some relevant scientific research from outside the Division.

The term ‘forested catchments’ is used in this paper to refer to those catchments in which the use and management of native forests and forest plantations is important to the provision of water to other users. Some catchments on the eastern seaboard have been so deforested that only residual patches of forest remain. At the other extreme, are a small number of catchments which are still mostly forested but have very few water users, although they may have more in future. In between these extremes are the great majority of catchments which have some forest, other forms of land cover, and many users.

2.2 Characteristics of South-east Coast Division

Surprisingly in view of the importance of water, no national review of resources and their use has been conducted since 1985 (Department of Primary Industries and Energy 1987). However, the characteristics of the South-east Division relative to Australia as a whole are still relevant (Table 1). The Division has slightly over one-half of Australia’s population but uses only 17 per cent of the water. This anomaly occurs because irrigation uses only 40 per cent of water used in the region, compared to 70 per cent in Australia. Domestic (30%), industrial (15%) and commercial (9%) uses account for slightly over half the water used in the Division.

Although urban and industrial uses amount to only 0.8 per cent of the country’s runoff, much of the unused resource is in northern Australia. In the South-east Division urban and industrial use amounts to 3.2 per cent of the runoff, or 8.3 per cent of the resource of fresh and marginal quality water that could possibly be diverted by dams and reticulation systems. In this aggregate view of the Division, no absolute shortage of water appears likely for a considerable while. For example, total usage could roughly double before an ecologically critical level of say 30 per cent diversion was reached, and even then urban usage could double again at the expense of irrigation and other land uses including wood production.

Map 1. South-east Coast Division
Source: DPIE 1987

The relationship between water resources and use varies considerably between water regions within the Division (Table 2). The Coffs Harbour region has a high rainfall and several important river basins whose resources are little used. The Snowy-Shoalhaven and East Gippsland regions are in a similar situation. By contrast the Melbourne and Sydney regions are consuming a high proportion of their major divertible resources. The economic consequences of alternative forest use and management strategies for the various sorts of users are quite different in the two situations. There is considerable variation between catchments within regions Comprehensive Regional Assessment and integrated catchment management processes need to assess the specific water resource, catchment management and water use factors for each river basin.

Table 1 Water resource and use

Characteristic	Units	South-east Coast Division		Australia	SE Coast Div. as proportion of Australia
Area	square km	273,000		7, 680,000	4%
Population	millions				
Urban		7.820	96%	14.1	55%
Rural		0.359	4%	1.28	28%
Total		8.180	100%	15.4	53%
Mean annual water use	000's Ml				
Urban and industrial					
Domestic		747	30%	1,790	42%
Industrial		385	15%	790	49%
Commercial		228	9%	481	47%
Sub-total		*1,360*	*54%*	*3,060*	*44%*
Irrigation					
Pasture		711	28%	5,180	14%
Crops		137	5%	3,550	4%
Horticulture		176	7%	1,510	12%
Sub-total		*1,020*	*40%*	*10,200*	*10%*
Rural					
Stock		120	5%	1134	11%
Other		24	1%	206	12%
Sub-total		*144*	*6%*	*1,340*	*11%*
Total		2,530	100%	14,600	17%
Surface water resource	000's Ml				
Mean annual runoff		41,900		397,000	11%
Divertible resource					
Fresh		14,700		98,100	15%
Marginal		236		865	27%
Brackish		113		1,040	11%
Saline		16		188	9%
Total		15,100		100,000	15%
Developed resource		4,280		21,500	20%
Groundwater resource	000's Ml				
Divertible resource					
Fresh		760		4,860	16%
Marginal		699		6,880	10%
Brackish		353		1,830	19%
Saline		50		836	6%
Total		1,860		14,400	13%
Proportion of resource (surface + groundwater) **being used**		15%		13%	

Source: DPIE 1987

Table 2 Utilisation of fresh and marginal major divertible resources in the South-east Division

Region		Total resource (000's Ml)	Total consumed (000's Ml)	Proportion of resource consumed
I	Millicent Coast	548	299	55%
C	Sydney	1,050	496	47%
F	Melbourne	810	348	43%
E	Gippsland	2,580	543	21%
H	Hamilton	470	84	18%
B	Hunter	1,170	202	17%
G	Otway	468	68	14%
D	Snowy-Shoalhaven	3,510	141	4%
A	Coffs Harbour	5,710	97	2%
Total		16,316	2,277	14%

Source: DPIE 1987

2.3 Upper Shoalhaven Valley

The general water supply and land use interaction was illustrated in an intensive study of the upper one-third of the Shoalhaven River Basin which was conducted in light of a proposal to construct a large dam at Welcome Reef to supply domestic and industrial water to Sydney (Costin, Greenaway and Wright 1984). The study drew on detailed land classification and hydrological research conducted by CSIRO since the 1960s and focused on the effects of land use and management on the quantity of water that would be available.

In 1980, one-half of the Upper Shoalhaven Valley was forested (42 per cent eucalypt forest, 9 per cent semi-cleared forest, 4 per cent pine plantation), one-third was covered in improved pasture, one-tenth in native pasture and only a very small area (2 per cent) was cropped. There was considerable scope for both pasture improvement and pine plantations and it was thought that the semi-cleared forest and native pasture could well disappear by the end of the century if then current trends continued. The effect of these trends on decreasing the water yields was the prime concern of the study. However, changes to the eucalypt forest due to logging, a major concern of this report, were not considered.

The study was conducted in considerable detail. The valley's 8 sub-catchments were sub-divided by slope, hydrologic soil types and land use (classified by vegetation). The intentions of land-owners and their possible options were obtained and the effects of alternative uses of the land on future water yields were simulated using water runoff models for dry, average and wet years. The water yields were found to vary according to rainfall and various soil characteristics, and to a lesser extent to land slope, surface roughness, the extent of vegetation cover and its capacity to intercept and store water. Deep permeable soils were found to be relatively low yielding, but were not very sensitive to changes in how they were used; shallow soils were high yielding and also relatively insensitive; while areas of moderately deep topsoils were fairly high yielding but most sensitive to changes in land use. Evapotranspiration indices were estimated for each type of vegetation on each hydrologic soil type. Although differences in evapotranspiration due to vegetation differed considerably between soil types, each type showed the same ranking from native pasture (least), to improved pasture, to eucalypt forest, to pine plantation (greatest). The application of these and other factors through the water run-off models demonstrated the very considerable differences which could be expected in the different sub-catchments.

While much of the data and models used in the Upper Shoalhaven could now be updated, the study displays a number of features or general principles which can inform the conduct of studies of other forested catchments:

- The hydrology of catchments varies greatly according to topography, geology, soil, vegetation and other factors. Hence, detailed surveys are required before land use and management effects can be estimated reliably.
- The type of land use significantly alters the amount of water which can be harvested. Less water can be harvested from eucalypt forest areas than from grassland, but for each general form of vegetative cover, less water can be harvested the more intense the production.
- These responses vary between wet and dry years.
- Their import for other users depends on whether the water resource is limiting and the extent to which it is stored and distributed.

3. LOGGING REGIMES

3.1 Introduction

In this section, the four concepts -- natural resource regimes, silvicultural systems, logging systems and transport systems -- which make up the very broad scope of the term ‘logging regimes’ adopted for this paper are defined. The nature of forest landscapes is then described. In the final part of the section, the major logging regimes used in Australian forests are described.

3.2 Natural resource regimes

The concept of ‘natural resource regimes’ (Young 1981, 1982) provides the basic structure for examining how natural resources are used and regulated. It stresses that each regime has to be seen as a set of three types of relationships:

- *The degree to which resources are devolved by the state into private ownership or are retained and managed by the state.* In Australia, three-quarters of the forest land has been kept in state ownership and state agencies are responsible for its protection and management.

- *The structure of regulations and administrative practices by which the use of the resource is controlled.* In Australia, a mass of licences and agreements serve to allocate the forest resource to processing companies, while various policies and acts of parliaments specify how the resource should be managed. The interpretation of these policies by long-established forest services has frequently been questioned.
- *The degree to which compliance is enforced.* There has been increased resort to the courts to resolve forest contests. The degree of compliance with regulations by logging contractors and farmers can have a significant effect on water quality, as discussed later in this report.

3.3 Silvicultural systems

A 'silvicultural system' refers to the set of protection, tending, harvesting, regeneration and other operations which determine how the stands (patches of reasonably uniform forest, typically 2-50 hectares) are managed (Troup 1952; Jacobs 1955: 183-249). Separate systems are prescribed for each sort of stand and purpose, and many variations are possible within each system. Those used in the study area include systems for uneven-aged forests such as:

- an individual tree selection system in which only a few large trees in each hectare are removed; and
- a group selection system in which small gaps of 50-100 metres width are created;

and systems for even-aged forests such as:

- a clear-felling system in mature eucalypt forest for woodchip and some sawlog production combined with a thinning system in part of the subsequent regrowth;
- a pine plantation system involving 2 or 3 thinning operations prior to clear-felling and, for the sake of illustration; and
- a small-scale coppicing system in which trees are cut every 5 years or so for eucalyptus oil distillation.

The intensity and frequency with which logging occurs varies both between and within systems. Intensity refers to the proportion of a stand and hence the quantity per hectare removed in an operation. Frequency refers to the time interval between operations and hence the number of operations which occur in a stand each century.

The uneven-aged individual tree or small group selection systems now specified in many state forests on the north coast of New South Wales commonly remove about one-tenth to one-fifth of each stand, returning on a cutting cycle of 30-40 years. Ideally, the quantity cut is related to the growth potential of each stand so that the process can continue indefinitely Adequate regeneration is often difficult to obtain in these systems. On most private forests logging occurs as unmanaged 'high-grading' in which the largest merchantable trees are cut whenever sufficient have grown to be sold. A few owners take a more managed approach. Most of the readily accessible public and private forests on the east coast have been selectively logged at some time in the past, even if only lightly for the premium sawlogs. The less accessible forests which have never been logged are the main focus for the well-known environmental controversies.

Even-aged systems of clear-felling are preferred for most eucalypt forests because they enable regeneration to be obtained more successfully and certainly than selection systems do. However, most forests on the east coast, especially those which have been cut selectively for sawlogs in the past, now contain far more pulpwood than sawlogs and can only be clear-felled in regions where there is a domestic or export market for the pulpwood. Some of the very high quality mountain forests are an exception to this general situation. The critical parameter of even-aged systems is the age specified for the final felling or 'rotation'; it can be 5 years for coppice crops of eucalypt leaves, 20 years for eucalypt pulpwood plantations, 30-35 years for pine plantations growing sawlogs and pulpwood, and 80-180 years for eucalypt forests. The pine plantations are well established with some areas now in their second rotation. However, most of the eucalypt forests are in the 'conversion period' during which the first rotation under systematic management is being started.

The case of the state forests in the south-east of New South Wales supplying the Eden woodchip mill illustrates some of the relevant factors (Dargavel 1995). When the Eden mill was proposed in the late 1960s, the native forests there were of little economic value for the production of sawlogs, and the more accessible ones on the coast had been logged over selectively but not in a systematically managed way. Regeneration in the cut-over areas was patchy. It was decided to fell the forests over a 40 year conversion period with the expectation that if woodchip exports continued after that time, part of the forest would be managed on a 30-40 year clear felling system just for pulpwood, and part would be managed on an 80 year or longer system which would produce pulpwood from thinnings and sawlogs and pulpwood from clear felling. Now that slightly over half the conversion period has passed it is apparent that the systems need to be re-thought because the planned frequency of logging would not meet the objective of ecological sustainability; rather than 40 years between clear-felling operations, something of the order of 120-180 years would now be thought necessary. It has also been found that only about one-quarter to one-third of the stands will be able to be thinned due to poor stand conditions, steep slopes or obstructions left on the ground from the original logging.

Planned rotation lengths are likely to be extended for ecological reasons throughout the eucalypt forests of the eastern seaboard and will have an obvious effect on logging frequency. For example, rotation length was found to be one of the important influences to be considered in developing strategies for the preservation of Leadbeater's Possum in Victorian ash forests (Lindenmayer and Possingham 1995), and stand age is a major determinant of habitat quality and species abundance in the Otways as in most forests (Brinkman 1990).

Plantations are managed far more intensively and logged more frequenly than native forests. Pine plantations are typically managed with 3 or 4 thinning operations before clear felling at a 35 year rotation age. Improved tree breeding and higher levels of weedicide and fertiliser treatment are likely to reduce this age appreciably. There are few eucalypt plantations in the region, the largest being in Gippsland and near Coffs

Harbour. If more are to be planted, it is likely that they will be managed on 15-20 year rotations for the production of pulpwood only.

3.4 Logging systems

A 'logging system' refers to the organisation and technology used in timber production from the forest stands to the transport system. It requires operations of:

- planning and preparing the site,
- felling the trees,
- processing the tree lengths into logs,
- extracting the logs to the transport system, and
- sorting and loading the logs for transport to the mills.

Logging systems vary according to the size of trees, type of forest, type of logs, topography, silvicultural system, and equipment employed. Over the last few years, logging on public land has been subject to increasingly detailed planning and codes of forest practice. Many of the items in the codes relate to measures needed to protection water quality. Operations on public land are supervised to obtain compliance. Some codes and regulations apply to private land..

Planning and preparing the site

This is a critical step in most eucalypt forests involving detailed inspection, locating access roads and sites for log 'landings' where the logs are to be prepared and loaded, and in sensitive areas extraction routes through the stand and even sometimes marking the direction each tree is to be felled. Strips along streams and other areas not to be logged are marked out. Map 3 shows how a compartment is divided into coupes (an area to be cut in one operation), the log landings located, and the reserve areas and strips planned. In pine plantations on flat country very little more than identifying the rows or trees to be cut may be required.

Felling

Prescriptions and codes of practice warn against felling trees so that their heads fall into creeks or filter strips of riparian vegetation. The heads and branches are normally cut off at the stump.

Processing to logs and extraction from stump to transport system

In eucalypt forests, the felled trees may be either debarked, cut into log lengths at the stump, and the logs extracted to the landings; or more commonly now the stem is extracted to the landing where it is debarked and cut into logs. The logs or stems are mostly extracted by dragging, or 'snigging' them behind a crawler or rubber-tyred tractor. This disturbs the soil so that the resulting snig tracks have to be 'barred' to prevent erosion. Skyline (overhead wire rope) systems can be used instead of tractors in very steep country, but they are uncommon. The landings are major areas of disturbance, bark accumulation and soil compaction. The bark has to be dispersed or burnt and the landings ripped after logging has finished. Early thinning operations in pine plantations and some regrowth stands are now often carried out by harvesting machines which fell and process the stems into logs. Some machines which delimb the trees are able to move forward on the branches, thus reducing soil compaction.

3.5 Transport systems

Road haulage is now the only means of transporting logs from the forest landings to the mills. Several categories of roads are used:

- Short 'spur' roads lead from the landings to a forest road. These are usually temporary tracks which are opened before logging and left to revegetate naturally, sometimes assisted by ripping afterwards. Creek crossing culverts are installed where necessary, but drainage culverts are rarely installed. They are rarely surfaced although wet patches may be gravelled or stoned. Logging is usually closed in very wet weather to prevent erosion.
- Forest roads lead from each forest block to the public road network. They are drained with culverts and surfaced with gravel or stone. They are closed to trucks, and sometimes all traffic during very wet weather to prevent damage.
- The public road network leading to and through the forest is made up of roads of different standards. Local authorities can close some roads during winter.

The forest roads were extended progressively with a major road-building programmes undertaken during the 1930s and during the 1950s-1960s spurred by the intense post-war demand for timber and the need to improve fire-fighting access to remote forest areas. Some of the primary forest roads were carefully surveyed and designed by engineers, but most of the secondary forest roads were built incrementally, either by local forestry staff or by sawmilling companies; some followed the routes first opened by wooden tramways. Since the 1960s, larger log trucks have come into use, the amount being carted each year over some roads has increased substantially. Many of the existing roads do not meet current standards. The ready availability of bulldozers and the need for better fire-fighting access led to a proliferation of fire trails in the 1950s and 1960s, often on very steep grades without heed for water quality. With the popularity of 4WD travel they now carry far more traffic, but with little maintenance, they often act as sediment sources during rain. Many need to be closed or relocated.

3.6 Major logging regimes

The various silvicultural, logging and transport systems used in the resource regimes described earlier are summarised in Table 3.

Table 3.Major logging regimes

Logging regime	Resource regimes	Silvicultural systems	Logging system	Transport system
State eucalypt forests				
Selective sawmill logging	Small sawmills (short-term licences), Large sawmills (long-term licences)	Individual tree selection and small group selection. State regeneration	Manual felling, tractor snigging. Some operations also produce pulp logs as by-product	Truck haulage on spur, forest and public roads to sawmills.
Integrated	Integrated concession (long-term agreements or licences)	Clear-felling and some thinning. State regeneration	Manual felling, tractor snigging, logs sorted on landings	Truck haulage on spur, forest and public roads to woodchip, pulp or sawmills
Private eucalypt forests				
Selective sawmill logging	Log sales. Natural regeneration	Unmanaged high grading	Manual felling, tractor snigging.	Truck haulage on spur and public roads to sawmills.
Integrated	Log sales. Natural regeneration or reforestation	Clear-felling	Manual felling, tractor snigging, logs sorted on landings	Truck haulage on spur and public roads to woodchip mills or pulp mills, and sawmills
Public and private plantations				
Plantation	Large mills Log sales	Multiple thinnings followed by clear-felling	Various harvesting and extraction machines. Mechanical felling for early thinnings	Truck haulage on plantation and public roads to mills

4. EFFECTS OF LOGGING ON HYDROLOGY AND SOILS

This section examines the potential effects of forest operations in native forests on water catchment values and soil stability. It first outlines what is meant by forest hydrology and examines data collection and analysis procedures. Research results are outlined for the eastern States and the implications of this research drawn out. Gaps in current research and future requirements are outlined. This section draws on a number of recent reviews, describes the main outcomes and updates them with more recent results.

It is important to bear in mind that the great variability of Australian rainfall and the occasional occurrence of bushfires poses particular problems hydrology. Occasional, unpredictable peak rainfall events can far outweigh or mask the effects of alternative catchment treatments. This is particularly so for water quality and soil erosion, and significantly limits the ability to produce statistically significant research results. The problem is compounded by bushfires which drastically alter the vegetative cover. Particular combinations of events, such as flooding rain immediately after a severe bushfire, can lead to far more severe effects than either alone. Such variability makes much of the mean data reported in the literature meaningless for many purposes. Variability is being increasingly recognised and is changing the way in which Australian hydrology is being studied.

The variability of Australian rainfall also results in far larger water storages having to be built to even out the effect of 2-3 years of drought than is the case in more equable climes. The high cost of the large dams required can have a significant economic bearing on how forests in some regions are managed as there are significant advantages if construction can be delayed a few years (see Section 6). However, it should be noted that generally the effects due to changes in land use or management are minor, and are difficult to detect, when compared to the 60-70 per cent inter-year variability in stream flow.

4.1 Forest hydrology

Forest hydrology can be defined as the science which examines the interaction between forest cover and the hydrological processes operating in a catchment. It examines the effects of natural changes to vegetation cover and changes due to human actions. Forest hydrology studies range from the scale of large catchments to detailed process studies. They are normally done by interdisciplinary teams with engineering, hydrology, forest management and plant physiology skills. Forest soils store water and nutrients and changes to the condition of the soil can be detrimental to plant growth. Therefore forest hydrology studies also require a good understanding of soil physics and structure.

McCulloch and Robinson (1993) provide a history of the development of forest hydrology. Catchment experiments in the European Alps at the turn of the century were followed by large scale experiments in the United States. For example, at Coweeta approximately 60 years of data have been collected on the interaction between catchment condition and streamflow. Although these and other experimental studies had an early emphasis on streamflow, from the 1950s onwards water quality and hydrologic processes were increasingly studied.

Catchment experiments began to be established in Australia from the 1950s (Costin and Slatyer 1967). By the 1970s a range of catchment experiments and other forest studies had been established in all States. Not all of these are still operational but long term experiments are still in progress in Western Australia, Victoria and New South Wales. Doeg and Koehn (1990) identified 36 past, present and proposed Australian studies. They have influenced catchment management policies. For example research in Western Australia on forest clearing and streamflow salinity has been instrumental in the development of restrictions on land clearing; Melbourne Water research into the effects of forest harvesting has influenced aspects of the Victorian Code of Forest Practices for Timber Production and in New South Wales forest hydrology research results are taken up in the environmental assessment of potential harvesting effects.

Data collection and analysis

Collecting hydrologic data is costly because instrumentation has to be bought and maintained, sites have to be monitored, results of accidental damage and vandalism repaired and analysis is labour intensive. Despite manufacturers' claims, instrumentation never operates in a totally trouble free mode, lightning strikes, temperature and humidity place a strain on the equipment, and inquisitive animals chew through cables. For example, the 17 experimental catchments managed by Melbourne Water require 2-3 person years per annum for routine data collection and maintenance and about 2-3 person years for routine data processing. Water quality sample analysis costs at least $50 per sample. Analysis of the processed data for research reports can take another 1-2 person years or greater if special process studies are undertaken. These labour requirements result in a wages bill alone of about $200,000 to $300,000 per annum. These costs need to be considered when the detailed monitoring of all catchments subject to forest harvesting operations are advocated. It would be a better use of resources to monitor some regional scale catchments and to improve code of practice requirements and compliance generally.

Recent developments in instrumentation have facilitated continuous monitoring. For example data loggers allow streamflow data to be stored in a form ready for analysis. Sensors for measuring parameters such as total dissolved solids, pH, and turbidity can be linked to data loggers which interrogate the sensors and record the results. However, routine calibration of the sensors can be required more often than is claimed by the manufacturers. Recent New Zealand and Australian developments have enabled transpiration flows to be monitored on a continuous basis. A further convenience is that researchers now have access to off the shelf commercial equipment. The main areas where measurements can require a high degree of specialist knowledge are those which measure atmospheric characteristics and soil moisture flows as distinct from changes in soil moisture content.

Experimental approaches to determining land use effects

According to McCulloch and Robinson (1993) researchers working at the turn of the century made direct comparisons of catchment streamflow and vegetation and ascribed catchment differences in streamflow to, for example, vegetative cover. This early app-roach took no account of differences in catchment characteristics such as geology, aspect etc. Later researchers used a larger number of catchments to determine average catchment behaviour. Single catchment studies offer an improvement on this approach in that a catchment after a period of monitoring is subjected to an experimental treatment.

Whereas this approach removes the problem of differing catchment characteristics it does not remove the problem of climatic variability. This led to the development of the control catchment approach in which characteristics, such as streamflow, are monitored for a pre-treatment period of at least five years in at least two similar catchments. One catchment is then kept as a control and the other given an experimental treatment. The untreated or control catchment predicts within certain statistical error bands the streamflow from the treated catchment as if it were still in a pre-treatment condition. Actual streamflows from the treated catchment are measured and if they differ statistically from the predicted flows treatment may be judged to have had an effect. Provided the pre-treatment calibration periods covers a long enough period the effects of climate, except for extreme events, are largely removed.

More recently pre-treatment catchment streamflows have been calibrated against daily rainfall and temperature in what is known as the climatic index approach. (Langford et al 1978). Due to the expense and time consuming nature of catchment experimentation hydrologists since the 1960s have been attempting to hasten the techniques of predicting the effect of catchment treatment on streamflow and streamflow quality. Continuous attempts were, and are being made to develop mathematical models which use the input of climatic and catchment characteristics to predict the effect of land use change on streamflows and other values. However these models still require calibration using the results of process experimentation, catchment experiments and detailed measurements of catchment characteristics if the results are to be used with confidence.

Some recent Australian research using these models is encouraging. For example the problems inherent in modelling approaches and the encouraging results obtained from a terrain analysis based model (TOPOG) are described by Vertessy and others (1993). Bonell (1993) made a strong call for further field experimentation particularly in hill slope hydrology in order to improve the performance of physical models. Lacey (1993) provides a detailed review of the interaction between forest activities, soil erosion and soil deformation. He points out that soil strength (resistance to deformation) reduces moisture content increases. He also points out that soil disturbance can expose more erodible subsoil to erosion forces. However, careful operational planning and the right choice of machines can reduce these impacts. Compacted soils can be rehabilitated by fertilisation and deep ripping. High standards of road design, construction and maintenance are required to prevent erosion and the degradation of water quality. While Lacey considers that properly implemented Codes of Practice can prevent these, he calls for more research into the effects of compaction on tree growth and into the ultimate fate of erosion products.

4.2 Effects of logging on soils

The impact of forest operations, such as roading, timber harvesting and site preparation, varies according to the percentage of a catchment subject to an operation, the fragility of the soils, the climate, the nature of the operation and equipment used, and the manner in which they are carried out.

Effects on forest soils

Langford and O'Shaughnessy (1977) review studies which showed that the method of harvesting can greatly influence soil disturbance. Severe soil disturbance can vary from 5 per cent of a harvested area after helicopter logging to over 70 per cent from conventional tractor logging. Skyline systems can the reduce impacts of conventional logging to about 15 per cent.

Research in the Pacific North West showed that landslips on steep slopes with deep soils can be caused by road cuts and road drainage. Such events have occurred in Victoria and Tasmania. Rab (1992) reviewed a range of Australian studies. Rab concludes that 25 per cent of a logging coupe can be covered by snig tracks and landings. He considered that scientifically developed standards for the amount of allowable soil compaction are required. The amount of compaction can be reduced by limiting traffic and increasing soil organic matter especially in sandy soils. Where compaction occurs it can be at least partially alleviated by deep ripping and cultivation. Using mechanical methods to dispose of logging slash can reduce the loss of organic matter resulting from burning.

The mapping of readily compactable or erodible soils using a geographic information system (GIS) can enable special precautions to be taken. Systems are needed to develop an index which would indicate the times to avoid traffic on wet soils as some soil types are especially prone to compaction when wet. Constantini (pers. com. 1994) found that for coastal sandy clay loam soils that the depth of compaction on tracks used by rubber tyred skidders increased from 10 cm in dry soil to 20 cm in wet soil. Constantini also found that rutting depths may not always be a direct indication of damage. When rutting depths doubled from 15 cm to 35 cm the area of compaction more than doubled increasing from 10 per cent to 46 per cent.

Rab also points out the need to limit soil compaction as compaction effects can last from 25 to 100 years, while removal of topsoil and compaction can severely limit plant growth. The amount of compaction can be reduced by limiting the number of snig tracks as compaction can occur after a relatively few passes. The use of slope limits has the potential to decrease soil impacts as most unwanted effects increase with slope. Bonell (1993) reported that, for some soils, compaction caused by forest use can disrupt sub-surface macro-pores resulting in an increase in overland flow during storm events.

Effects of regeneration and fuel reduction burning on soils and water quality

There have been several useful Australian studies. Ronan (1985) used plot studies to investigate the processes involved in sediment production and runoff. The plots were subjected to varying intensities of fuel reduction burning. Ronan postulated that for the gradational red loams on the site most soil movement consisted of a creep process with water flow consisting of a transient process from rainfall input to infiltration. Unit area yields of runoff and silt production in the undisturbed state were low at 1 per cent of rainfall and 75 kg/hectare/annum respectively. Higher yields occurred during the warmer and drier summer months. Following burning, runoff and silt production doubled but recovered within four years. Initially low ion concentrations increased by 100 per cent to 300 per cent but returned to normal within three months.

Immediately north of these plots an intense wildfire burnt over 5000 hectares of largely mixed species forest including the headwaters of several large catchments. All the understorey including the wet gully vegetation was burnt. Water quality sampling commenced immediately and the results compared to historic data. Storm-flow peak concentration of most ions increased by two to five times while base-flow levels doubled. Levels of most parameters returned to normal within 12 months. The changes to water quality were not a concern from a water supply viewpoint. The fact that little deterioration occurred can be put down to the generally low levels of rainfall intensity, stable soils and gentle slopes. Ronan recommended that long term damage to soil structure by repeated burning could be minimised by using low intensity fire, long burning cycles and burning when the surface soil is moist. Talsma and Hallam (1982) reported similar results for a low intensity fuel reduction burn in high altitude dray and wet sclerophyll forest. Water quality was not affected by the burn. They attributed this to the predominance of sub-surface flow and the lack of surface flow.

These results are a contrast to these reported from Leitch and others (1983) who reported on the severe erosion caused by a thunderstorm on a duplex soil six days after a severe wildfire. Debris flows of ash and surface soil resulted with soil and ash losses of about 22 tonnes/hectare which can be put down to high soil hydrophobicity, a steep slope and the high rainfall intensities which occurred in this severe event. Similar results were reported by Brown (1972) who found that massive increase in sediment loads resulted from a wildfire in two Snowy Mountain catchments. Rapid decreases in sediment yield resulted from vegetative recovery. In general, the effects of wildfire on water and soil are determined primarily by soil type, the severity of the fire and the post-fire weather.

4.3 Effects of logging on stream water quality

Physical water quality

Overseas and local studies as reported in Langford and O'Shaughnessy (1977) show the major impact that poor roading and harvesting practices can have on stream water quality particularly in steep country with unstable or erodible soils. They also show that the introduction of good practice prescriptions can markedly reduce these impacts.

More recent research undertaken in the Melbourne Water Catchments reported in O'Shaughnessy and Jayasuriya (1991) has demonstrated the potential impact of roads. Good practice roading and harvesting treatments were applied to two 50 hectare catchments located in the Coranderrk Experimental Area. One catchment had two stream crossings located in shallow gullies and the other had four stream crossings located in steeper gullies. The impact on suspended solids readings and bed load measured in the weirs was greater and more persistent in the catchment with more stream crossings.

This was considered to be caused by the increased stream disturbance at the time of road construction and the greater impact of road drainage into the streams. These results need to be considered in an operational perspective. Ronan and others (1982) applied the results to the 16,000 hectare Maroondah Catchment where it was estimated that some 5,600 hectare were hypothetically suitable for the application of clear felling and regeneration treatments. They reported that, if the impacts of good practice roading as measured at Coranderrk were assumed to be persistent and were applied to the whole catchment over an 80 year rotation, the sediment input would increase by 15 per cent (or 49 kg/hectare/annum). Although this level of increase would be difficult to detect it still has some potential for concern in catchments where the water is chlorinated without prior filtration.

The importance of roads was illustrated by two subsequent Melbourne Water studies. In one study Haydon and others (1991) reported on the varying erosion rates from an earthen road subjected to 12 years of low and high use and maintenance. Total sediment yields varied from 52 to 89 tonnes per hectare per annum of road surface depending on vehicle use and road maintenance. These levels are much higher than the estimated long term accumulation of sediment in the Maroondah Dam of 0.3 tonnes hectare/per annum.

In the other study of roading effects (Grayson and others 1993) a 28 hectare catchment covered in mountain ash (*Eucalyptus regnans*) old growth was given a harvesting and regeneration treatment in the summer of 1984/85. Long term streamflow and water quality records comprising both grab samples and automatic stormflow samples were available from 1981 to 1991 for both the treated catchment and a nearby control catchment. The logging treatment was carried out under a strict code of practice which limited operations to the summer months, imposed stoppages during wet conditions and required a minimum 20 m buffer around streams and swampy areas. None of the temporary logging roads within the catchment crossed the stream. At the end of the operations all roads and tracks were drained. While relatively small increases were detected in base-flow turbidity, iron, and suspended solids, they were small in absolute terms and of similar magnitude to the measurement error. This seminal study shows the importance of roads and the benefits of good management practice.

The series of Melbourne Water papers reviewed dealt with catchment experiments on land systems with very stable soil subject to a high quality roading and harvesting practice. On more erodible soils the results of a combination of roading and harvesting can have much greater impacts on water quality parameters as is shown by studies reported in Doeg and Koehn (1990). Studies reported in Doeg and Koehn also show that if wildfire occurs at the same time as forest harvesting water quality degrade can be accentuated.

Cornish (1993) and Harper and Lacey (in press 1995) have reviewed the extensive literature based on research conducted for over 20 years in the Yambulla catchments near Eden in New South Wales. They reported quite widespread movement of erodible granite soil after a combination of wildfire and/or logging. Although the movement was extensive, the soil was largely redistributed locally on the site. Concentrations and total loads of suspended sediment increased but recovered after *either* fire *or* logging in three years, or after *both* fire *and* logging in five years. Although operations were generally undertaken according to good practice, one poorly located and inadequately drained road contributed a large proportion of the sediment deposited in drainage lines by large rainfall events. The rapid decay of the impact of logging/fire can be put down to a combination of the application of good harvesting practice and rapid vegetation recovery. Cornish (1992) reported on changes to water quality caused by roading (at relatively low intensity with good practice) and logging in a high altitude, wet sclerophyll forest near Eden in NSW. The area was monitored for two years prior to logging and it was found that there only relatively minor (but statistically significant) changes to the physical water quality in the two years after logging. He concluded that erosion mitigation measures had minimised, but not prevented, erosion and the supply of sediment to streams.

Both overseas and Australian research confirm that for roading and harvesting operations avoidance of direct stream disturbance and the prevention of turbid water inflows will provide a high level of protection. Borg and others (1988) found that in Western Australia reducing river and stream buffers from 200 m to 100 m and 100 m to 50 m had no impact on water course and stream water quality. Barling and Moore (1992) reviewed the functions of buffer strips and the actual processes which occur in buffer strips. They point out that more research is needed to develop the knowledge for sound recommendations.

4.4 Effects on total dissolved solids and bacterial water quality

The review by Doeg and Koehn (1990) showed that the impacts of forest harvesting and regeneration can be variable with some studies reporting increased ionic concentrations and others a decrease. Even where there is a decrease in concentration the total export can increase due to increased flows. Langford and O'Shaughnessy (1980) provided the results of timber harvesting and roading in the Coranderrk Catchment and these results could be considered to be typical of these likely in the higher quality eucalypt forest growing on deep soils. The average concentration of total dissolved solids varied very little with streamflow and ranged from 50 mg/l in Blue Jacket Catchment to 80 mg/l in the Coranderrk Catchment. The relative proportions of cations and anions were the same as the rainfall with the addition of silica and bicarbonate from the bedrock.

Following clear felling of the Picaninny Catchment the increased streamflow caused a flush of dissolved solids with an average increase in total dissolved solids of 10 mg/l. Concentrations fell as streamflows returned to pre-treatment levels. There was no discernible effect on dissolved material concentrations from the selective cut in the Blue Jacket Catchment. There was a temporary increase in nitrate export from the Picaninny Catchment. No change could be detected in stream temperature, dissolved oxygen, biochemical oxygen demand, pH, and phosphate concentrations. Soil disturbance caused an increase in 22 bacterial plate counts for Picaninny Catchment but no changes could be detected in the levels of bacteria which are used as indications of faecal pollution.

4.5 Impacts of changes in water quality

Domestic water supply systems

The impacts of changes in the quality of water provided for domestic use depend on the quality of the water coming out of the catchment and the way it is stored and treated before it is supplied. At present, many country towns do not have filtration and disinfecting facilities. In Victoria, for example, only 66 of 347 country towns had full treatment facilities, and 149 had no disinfection facilities. Some have only 'run-of-stream' water supply systems, where streams are diverted to supply without detention in storage and are therefore particularly be susceptible to changes in water quality (Langford and O'Shaughnessy 1977). This is often critical because the average turbidity of many forested streams is naturally about the maximum turbidity level set by the 1987 National Health and Medical Research Council Standards (5 Nephelometric Turbidity Units) for domestic consumption.

By contrast large reservoirs generally have a major capacity to improve turbidity levels in stored water. However occasionally high turbidity readings can occur in the outflow. Given that their purification ability may not always be effective, there are major benefits in keeping inflow turbidities into major storages as low as possible.

Impact on stream biota

Forest roading and harvesting operations have the potential to affect stream habitat values and therefore stream biodiversity in the following manner:

- Removal of stream bank vegetation thus affecting stream temperatures and reducing leaf fall;
- Introduction of increased bed load and suspended material thus affecting macro-invertebrate habitat and numbers, fish, spawning habitat and fish/prey interactions;
- The introduction or removal of debris in the stream thus affecting stream dynamics;
- Pollution of streams through oil spills, inappropriate choice and use of herbicides and pesticides;
- Change in stream access to vertebrates;
- Changes in flow regimes through accidental diversion of streams and in some cases major changes in vegetative cover.

Doeg and Koehn point out that studies to quantify the effects on biota of forest operations are difficult due to the problems of determining what was the natural variation in populations prior to any disturbance. The studies are necessarily long term and can be technically difficult.

Some studies have not monitored the impact of actual forest operations but instead have artificially manipulated the environment. Doeg and Koehn found that no Australian studies had examined and reported on the impact of forest operations on fish populations using methods which lead to absolute confidence in the results. Since their review, Davies and Nelson (1994) have reported on a Tasmanian study which used 45 matched sites. One site of each pair was located upstream of a harvesting operation and the other downstream. The treatments involved conventional and cable logging operations with stream buffer widths varying from 0 to 50 metres. They found that, below a width of 30 metres, buffer width had a significant impact on stream sediment algal growth, water temperature, and the volume of snags. There were also decreases in macro invertebrates and brown trout abundance. Coupe slope, soil erodibility and time since logging (1-5 years) had no effect. Above a buffer width of 30 metres the impacts of logging were not significant.

Overseas studies have reported detrimental affects on fish populations of decreases on stream vegetative cover. Other overseas studies have shown that fish populations can be reduced by activities which increase water temperature and increase silt loadings. American research has shown that macro-invertebrate density reduced with the increasing age of the riparian cover but increased with increased shading. Sediment inflows can reduce invertebrate numbers. Buffer strips have been found to reduce the effects of logging. Some studies show a recovery after disturbance which can vary from a few years to over 10 years. Australian studies have shown qualitative effects on stream fauna due to forest operations but the study reported in from Davies and Nelson is the most definitive to date.

Another Australian study of interest is that by Doeg and Milledge (1990). It shows that many invertebrate taxa increased their rate of drift when suspended sediment concentrations rose above 133 mg/l from a background of 25 mg/l. Such studies are needed in order to develop effective suspended sediment criteria for the protection of aquatic ecosystems. Doeg and Koehn consider that Australian studies into the effects of logging on water quality parameters and stream habitat need to be wider in scope, have a better statistical basis and a longer period of record. Nutrients, temperature, the role of bed load sediment, vertebrates other than fish, and aquatic microphytes all need more study. If the causes of regional differences in experimental results can be understood the results will be transferable.

4.6 Environmental standards and monitoring

The *National Forest Policy Statement,* finalised in 1992 and finally agreed to by all States and the Commonwealth in April 1995, contains a commitment that consistent nation-wide base line environmental standards will be established for forest use and management. They will be endorsed by Governments and met through Codes of Practice. To this end a draft report for comment has been prepared by the Technical Working Group on Forest Use and Management and issued in late July 1995 by the Joint Australia and New Zealand Environment and Conservation Council / Ministerial Council on Forestry, Fisheries, and Agriculture, National Forest Policy Implementation Sub Committee (JANIS).

The report deals with soils, water, flora and fauna and pests and diseases. A critical review of the document is beyond the scope of this report preliminary comments can be made. The section on soils is soundly based and it is agreed that monitoring should be undertaken on a case study basis rather than for all the forest estate. However, the intensity of sampling required to detect a 10 per cent change in the parameters described would make routine monitoring expensive. The section on water requires a detailed review and comment in regard to the protection of those potable water sources which are given only minimal detention and treatment and the management of water yield especially where potential declines could be caused by afforestation and/or conversion of old growth forest to a regrowth condition.

The question of monitoring needs careful evaluation. Olive and Rieger (1988) show that sediment sources and transport systems need to be understood in the light of natural variability and the effects of extreme events. The costs of sampling and analysis are such that consideration should be given to sampling representative regional catchments for say a 5 to 10 year period. The results need to be linked to catchment events so that management practices can be improved where necessary. Some of the standards need to be made more practicable. For example, the Australian and New Zealand Conservation Council (ANZECC 1992) developed some water quality guidelines. They set the standard to be less than 10 per cent change in seasonal mean concentrations, but it is doubtful if anything less than 15 per cent could be detected. Their standard of 0 faecal coliforms per 100 ml is unrealistic given that forest streams can have high readings due to wildlife.

4.7 Effects of forest change on streamflow

Recent and not so recent reviews have discussed the interaction between forest change and streamflow characteristics for the Australian context and the outcome of these reviews along with recent research will be discussed. This review will have an empirical thrust rather than one dealing with the fundamentals of the hydrological cycle. At its simplest, on a year to year basis, streamflow is the residue of rainfall after allowing for evaporation from vegetation, changes in soil storage from year to year and deep drainage to aquifers. Logging can interfere with these processes by changing vegetative cover, hence affecting evapotranspiration and therefore streamflow, and can compact the soil which can reduce its ability to absorb and store water and hence the proportion of rainfall delivered as base and storm flows.

Changes in forest cover

The outcomes of reviews such as those by Bosch and Hewlett (1982), Cornish (1989), and Nandakumar and Mein (1993) are provided as useful background. Figures 1 (from Cornish) and 2 (from Nandakumar and Mein) show that streamflows from forested eucalypt catchment only become appreciable above rainfalls of 800 mm per annum and greater. The actual streamflows vary according to the location and aspect of the catchment but on average increase with rainfall, elevation, and shelter from radiation. For example the lower altitude mixed species forests of the Melbourne Catchment area yield about 200 mm per annum while the undisturbed upland old growth ash type forests yield over 1000 mm per annum.

Figure 1 shows the impact of higher forest evapotranspiration on water yield compared to pasture. For example for an average annual rainfall of 1000 mm streamflows from forest are 50 per cent less than those from pasture. For higher rainfalls the difference in percentage terms is less at 33 per cent. These differences show the effect of permanently converting forest to pasture and conversely show the effect of afforestation of pasture. Cornish predicts that streamflows from pasture sites with average annual rainfalls of about 1000 mm can be expected to decline by 200 mm, or over a 50 per cent, after afforestation with radiata pine (*Pinus radiata*). These potential declines raise planning issues for local regions where pasture streamflows may be regulated for local irrigation use.

Figure 1 Evapotranspiration and rainfall for fully forested catchments. The black circles show radiata pine plantations in South Australia (from Cornish 1989)

Figure 2 Annual catchment loss vs. rainfall for eucalypt catchments (from Nandakumar and Mein 1993).

Effects of wildfire on annual streamflow

Both Langford (1974) and Kuczera (1985) investigated the effects of the 1939 wildfire in the Melbourne Water catchments. This wildfire burnt at an intense level through several large catchments supplying water to Melbourne. The fire resulted in the death and regeneration of over 45,000 hectare of ash type forest and the destruction of the canopy along with limited tree death of large areas of mixed species forests. Analysis showed that the known declines in catchment yield could be explained by assuming that water yield from the mixed species forest stayed constant while that from the ash type declined to about 50 per cent of pre-fire flows, reaching a minimum some 30 years after the fire.

Kuczera used streamflow data from a wide range of operational catchments with ash type forests burnt in the 1939 wildfire. He showed that for every 1 per cent of catchment converted from old growth to regrowth a decline of 6 mm in water yield could be expected some 30 years later. Predicted effects were then modelled (Figure 3). For the mixed species foothill forests, Langford (1974), Kuczera (1985), and Read Sturgess (1992) assumed that any yield changes in mixed are temporary due to the rapid recovery of forest canopy and the persistence of the mature rooting system. Hence, they were able to adopt the concept of there being no long-term yield changes.

Figure 3 Water yield and stand age in ash type forests (from Kuczera 1993)

Effect of forest harvesting and regeneration on streamflow

From a hydrological perspective (but not from an ecological one) the impact of harvesting and regeneration in the ash type forests is comparable to the impact of wildfire. For the mixed species forests of the eastern seaboard harvesting until recently was selective with only minor modifications to the forest canopy. Since the 1970s clear felling operations, used in the integrated logging regime, have resulted in extensive openings of the canopy, although a much reduced upper canopy of seed or habitat trees generally remains. Felling is followed by large scale natural or artificial regeneration.

Following clear felling in both ash and mixed species forests, Nandakumar and Mein estimate that for every 10 per cent of a catchment cleared, a 33 mm increase in runoff can be expected. Flows reach a peak 2 to 3 years after clearing and then decline which, in the case of the Melbourne Water, meant a return to pre-treatment levels in some 5 to 8 years. For these ash type catchments, water yield continued to decline below pre-treatment levels (as shown in Figure 3). In the case of Piccaninny catchment, which had 80 per cent of its forest cover clear-felled and regenerated, water yield declined to 50 per cent of its pre-treatment level. This finding is compatible to the yield changes reported by Kuczera after wildfire. The temporary increase in yield following experimental clearing and regeneration has been incorporated into the Kuczera model (Figure 3) for recent modelling studies (such as the Read Sturgess 1992 study).

Cornish (1993) reported clear felling and regeneration experiments in moist old growth eucalypt forests in the central coastal ranges of New South Wales. Immediately after logging, water yields increased in a similar manner to these reported by Nandakumar and Mein. Streamflows then decreased at a rate proportional to proportional to the density of the regrowth and reached pre-treatment level in about 4 to 6 years. In a catchment with the highest density of regrowth, water yields five years after treatment had dropped significantly lower than the pre-treatment level by about 200 mm representing an approximate 30 per cent reduction in pre-treatment streamflow. This work is important because it shows effects similar to those in the Victorian ash forests.

Unfortunately there are no recent long term catchment experiment results available for mixed species forests on the eastern seaboard which might indicate effects of clear felling and regeneration on streamflow. Although, a number of experiments have been established the results have not been analysed due to staff and funding shortages. However, Cornish (1993) and Harper and Lacey (1995) have reviewed the extensive literature dealing with the results of fire and timber harvesting on streamflow in five small sub-catchments of the Wallagaraugh River known as the Yambulla Catchments (quality effects are noted elsewhere in this report). These catchments have a granite bedrock with relatively shallow, erodible soils. After fire and logging, separately or in combination, large increases in the annual flows occurred but largely returned to pre-treatment levels within 4 to 8 years. Return to pre-treatment levels was slowest where catchments were both burnt and logged. Peak and storm flows increased by 2 to 10 times, with the increases being larger where the catchments were both burnt and logged. As the vegetation recovered, the flows returned to normal within four years. Harper and Lacey concluded that most of the impacts fell within the natural fluctuations of the Yambulla catchments and that any excessive results were of short duration.

A recent study (O'Shaughnessy and others 1995) shows, for a central Victorian mixed species catchment (The Lerderderg), that logging 16 per cent of its area between 1985 and 1994 had no statistically detectable effect on long term water yield, which has been stable for the entire period 1960 to 1995.

Clearly, research work into the problems of water yield from the drier mixed species forests of the eastern seaboard requires an increase in research resources and active support and direction by government.

Effect of forest thinning on streamflow

O'Shaughnessy and Jayasuriya (1991) described the effects of various forms of thinning in the ash type forests. Reductions of 50 per cent in the basal area of stands about 40 years of age lead, in the case of a uniform thinning, to streamflow increases of about 30 per cent which lasted for about 15 years. In the case of a similar reduction in basal area due to strip thinning a similar streamflow increase occurred but indications are that the increases will be more persistent. Overall it appears that changes in streamflow occur in the spring-summer period when evapotranspiration is highest and rainfall reaches its seasonal maximum. While a 50 per cent reduction in basal area due to thinning leads to a decline in final timber production, Benyon (O'Shaughnessy and others 1993) found that in economic terms this is more than off set at discount rates of 2 per cent or greater by the value of obtaining an intermediate timber return with a further bonus compensation due to the value of the increased streamflows.

4.8 Mechanisms operating to change streamflows

When streamflow changes occur they are mainly due to changes in evapotranspiration caused by changes in canopy leaf area which in the ash type forest are reflected in the area of sapwood. Jayasuriya and others (1993) describe the processes operating in mountain ash in terms of relatively uniform sap-flow velocity independent of age but a variation in the amount sapwood per hectare. This reaches a peak early in the life of a stand and then steadily declines. The combination of sap-flow velocity and sapwood area allows transpiration volumes to be determined. Increased evapotranspiration during the spring/summer period due to the high leaf area of regrowth leads to a greater proportion of winter rainfall being needed to replenish the soil store thus delaying and reducing the amount of spring and summer rain converted to streamflow. Conversely the much lower leaf area/sapwood area of old growth ash type forest leads to reduced transpiration rates and higher streamflows. For any one forest stand, the total water use is a combination of its rainfall inception and transpiration characteristics. Both vary with the type of stand and change with time.

Seasonal distribution

Nandakumar and Mein examined the seasonability of changes in streamflow following forest treatment. They concluded that the greatest proportion of the annual increase appeared in winter and spring while the bulk of yield decreases occurred in spring and summer. For the Corranderrk Catchment inspection of raw data indicates flow declines are greatest during spring and summer.

O'Shaughnessy and Jayasuriya (1994) found that the higher percentage flow increases following uniform thinning appeared in the January-April period. Haydon (O'Shaughnessy and others 1993) found that both the highest absolute increase in flow and percentage increase occurred in the October/March period. In summary, for temperate climates it appears that changes in streamflow from the ash type forests are greatest during spring and summer. Similarly, Cornish (pers. comm.) considers that, for the central NSW coast, the greatest relative changes in yield occur during August, the driest month.

5. FOREST USE AND MANAGEMENT

The management of forests outside the conservation reserve system involves the recognition, assessment and balancing of all the uses, values and functions which they provide. The full decision-making problem is formidable. Although valiant attempts have been made to place economic values on matters such as species survival, scenery and wilderness, they have not found a place in planning practice. However, water and timber are commodities to which commensurate market values can be attached, as discussed in the next section of this report. This section describes advanced planning operational planning, and operational practice.

5.1 Advanced planning systems

The decision-making problem can be described first in relation to wood production. There are two types of decision which have to be made: the silvicultural system to be applied to each stand in the forest has to be prescribed, and the total yield of the forest, or 'allowable cut', has to be set at a level that is sustainable. The problem is difficult because forests are made up of a great many stands, the decisions have to be made simultaneously, and for a planning period long enough to ensure that sustainability criteria can be met. Computer-based modelling has enabled this to be done since the 1970s. The models provide schedules showing, for the prescribed silvicultural systems, which logging operation should be conducted in which patch of forest in each future period in order to meet the overall supply commitments.

Advanced planning systems were developed from this approach in order to model forests with multiple uses and values. They were first applied in Australia in a pilot project conducted in the Otway Ranges in Victoria (see Brinkman 1990; Dargavel and others 1995; McKenney 1990; McKenney and Common 1989; and the references to the extensive documentation these contain). There was sufficient quantitative information to be able to model wood production, water yield, habitat change, budget requirements and employment. A planning period of 100 years was used, made up of 10 periods each of 10 years.

The Otway model provided interesting results in relation to water. Some but not all of the catchments were important in providing water supplies to Colac and Geelong and the ash forests there have a marked response of stand age to water yield, hence it was important to ensure that logging in the forest did not unduly diminish the water yield. The model was constrained to ensure that this could not happen and showed that by carefully distributing the logging between the various catchments throughout the planning period, both timber and water yields could be sustained in an even manner. Such models can provide important economic insights (from the marginal values attached to constraints). More importantly, they provide the most thorough means of conducting an economic analysis of the trade-offs over time between water and timber production (especially in the face of the many other values and constraints which apply). The reason for this originates in the great diversity of stand conditions in a forest and the number of silvicultural alternatives available for each. For example, a forest might reasonably be modelled with say 1000 stands for each of which there might be say 20 alternative silvicultural options for varying the frequency and intensity of logging operations. Theoretically, there could be 20,000 different ways of scheduling the operations in the forest as a whole; in practice there are fewer but still several thousand from which to select. The remarkable maleability of the decision-making problem comes from the ability to juggle wood yields, and their consequent effects on water yields in future years, between stands over a long periods of time. This means that economic analyses of the effects of land use or management changes often need to examine values attributable to long-term changes in the system as a whole. Analyses of simple trade-offs between water and timber production may lead to erroneous estimates. The importance of this for determining public policy is not as widely appreciated as it should be.

5.2 Operational planning

The manner in which logging operations are planned has a significant effect on their impact on water quality and other values. Operational planning is guided not only by the long-term plans, but also by the raft of legislation, policies, and regulations that apply to the forest sector including those from State water and soil conservation authorities. Having digested all these, operational plans are made for 1 to 3 year periods. Critical features are:

- specification and siting of any new forest roads,
- the siting of feeder roads, landings and dump sites,
- the identification of the trees or stands suitable for logging and the particular silvicultural regime to be applied,
- the recognition of areas to be excluded from logging, or require special treatment on account of their soils, slopes, habitat, wildlife corridors, amenity and other reasons,
- the distribution of coupes across the landscape, and
- their landscape design.

Having been planned, the design has to be laid out in the forest (Map 3) and the loggers and other relevant authorities advised. This involves substantial documentation and field work. Operational plans are also made for fire protection, recreation, plantation establishment, vermin and noxious weed control for example, all of which have effects on water.

Map 3 Example of layout of logging coupes in an operational plan

5.3 Operational practice

The potential for forest operations to affect water yield and quality, soil and a wide range of environmental values has been reflected in regulations which, over the last twenty years have become increasingly detailed. In Victoria, for example, the results of the Melbourne Water research were amongst information used in the formulation of the Government's *Timber Industry Strategy* (1986) and the Department of Conservation Forests and Lands' *Code of Forest Practices for Timber Production* (1987). These policies require the general protection of water values. Where water production is important, they specify that forests are be managed by appropriate techniques, such as thinning and long rotations. Water quality is protected by limitations on the proportion of a catchment which can be logged in any one year and the specification of appropriate roading and logging practices. Detailed requirements are elaborated for each forest region.

Codes of forest practices

All the Eastern seaboard States have codes of logging practice or regulations in place aimed at protecting forest values including water yield and quality. The Victorian and Tasmanian codes are particularly comprehensive. Currently the Victorian code is being renewed and revised. O'Shaughnessy (1995) conducted a review of the perceptions of the Code of Forest Practice held by workers, contractors and supervisors. Its major findings were:

- the overwhelming proportion of timber industry workers accept the benefits and need for codes of practices;
- compliance is perceived to be good, which is not always the case;
- better training for workers and instructors is needed;
- the pressure to keep up the supply of timber results in logging during inappropriate weather and soil conditions;
- loggers need to be paid enough to cover the costs of good practice;
- specialised contractors with the right equipment should be used to clean up coupes and maintain roads;
- fair and efficient mechanisms are needed to penalise non-complying operators;
- low maintenance road drainage systems are needed; and
- more research is needed into the prescriptions for buffer strips and their use for multiple benefits Bren (1995).

If the comprehensive codes of practice now specified were applied at a high standard in all public and private forests, the impacts on water yield and quality would be greatly reduced. They need to be applied retrospectively to old works, especially roads, to bring them up to standard. The key matters are:

- Road planning, design, and maintenance aimed at preventing the direct entry of road drainage into streams.
- Many fire trails being used by 4WD vehicles for recreation and with little maintenance need to be closed or relocated.
- The adoption and protection of buffer and filter strips wide enough to prevent overland drainage from logging areas directly entering stream courses.
- The prohibition of logging when soil moisture content is high.
- Adequate logging site rehabilitation including the ripping of landings and the drainage of snig tracks.
- Good management of herbicides, pesticides and fertilisation applications. This requires avoidance of non-target areas, the use of adequate buffers, control of droplet size and keeping a strict watch on excessive wind speeds.

6. ECONOMIC IMPACTS OF CHANGES IN WATER YIELDS

6.1 Water as a multiple-use resource

Competing demands for water in the Australian inland rivers have driven home the fact that water has alternative uses. There is now a substantial body of research into the economic consequences of the allocation of water among various uses. However, with the exceptions of the Hunter and Nepean-Hawkesbury Rivers, for the most part, on the eastern seaboard there has not been great competition for the water that flows down streams and rivers to the sea. There are signs that this will change as demands for limited water supplies intensify.

The principal uses of coastal water resources are to support:

- domestic and industrial consumption;
- irrigation for crops and livestock production;
- fisheries;
- recreational activities;
- hydroelectricity production;
- natural systems; and
- cultural, scientific and educational purposes.

Domestic and industrial consumption

Water use for these purposes is growing at rates of around 2 per cent per annum and would continue to grow at this rate in the absence of water conservation measures, which are expected to become more widespread. However, the switch from rate-based to user charging by metropolitan water authorities does appear to have reduced increases in domestic and industrial water consumption. For example, Sydney Water shifted to a pricing system based on user charges, eliminating cross-subsidisation from industrial to domestic users, but at the same time introduced demand reduction measures. About half of the domestic water consumed is used for gardens. While demand for water for use inside houses is not very responsive to price increases, demand for water for outside purposes (gardens and car washing) is price sensitive, especially in the longer term as households have the opportunity to switch to native gardens.

There are very large investment costs associated with providing water storage for urban water supply, so that decrease in stream flow may mean that greater or earlier investments in dams become necessary. Similarly, increased siltation of streams due to upstream economic activities may require dredging of dams or construction of new ones before they are due. These both impose costs on urban water consumers. Sediment from logging activities can increase the cost of municipal water treatment. Holmes (1988) found that the cost per thousand tonnes of sediment is between $10.84 and $27.95.

Irrigation for crops and livestock

On the eastern seaboard agricultural irrigation includes dairy cattle, sugar cane and horticulture. Declines in streamflow may have a significant impact on the volume of water available for irrigation. For example, it has been reported that dairy farmers require 1000 litres of water for every litre of milk produced.

Fisheries

Fisheries are used by both recreational and commercial fishers. In some areas it includes aquaculture. Changes in water quality and quantity affect the ability of rivers to sustain fish populations.

Recreation

The types of water-based recreation in a catchment depend on the type of river. Narrow, fast-flowing upland rivers characterised by rapids and clear, clean water are preferred for rafting, bushwalking and picnicking, while wide, slower-flowing and turbid lowland rivers are preferred for power boating, skiing, house-boating and camping. Both types of rivers are used for swimming, fishing and canoeing.

In many parts of the eastern seaboard, tourism based on nature recreation is emerging as an important industry sustaining regional growth. Hansen and Hallam (1991) found that the cost to recreational users and tourist industries of declines in water quantity and quality could be substantial in some catchments. Loomis (1987) calculated marginal values of in-stream water flows for recreation to be in the range from $11 to $22 per megalitre. Brown and Daniel (1991) found that in-stream flow is an import-ant factor in public perceptions of scenic beauty.

Hydroelectricity production

The Snowy River has been diverted as part of the supply for the Snowy Mountains hydroelectric scheme. Beyond this, there is almost no hydroelectricity generation in the eastern seaboard area under study as the river systems on the coast are mostly unsuitable. However, it may be noted that in other regions where hydroelectricity is generated any decrease in streamflow will have a direct bearing on the amount of energy generated. Bearing in mind that hydroelectric energy is especially valuable because it can be generated at times of peak usage, the value of this foregone energy is the opportunity cost of generating electricity at peak times by other means.

Natural systems

Continued healthy functioning of a water course is often measured by its assimilative capacity. Australian river systems are unique in the world for the high levels of variability in flows due to seasonal factors and droughts. Activities that cause inputs such as silt and pesticides to exceed the capacity of rivers to assimilate them or which lead to larger fluctuations in water flows may disturb the ecological quality of water courses. Blue-green algae blooms on the Hawkesbury-Nepean are a case in point. While such disturbances may not have any direct or indirect economic costs, it is likely that they are nevertheless considered by most people to be impacts to be avoided even if it means some loss to the economy. An analogy might be drawn with the natural values of Coronation Hill in Kakadu National Park which was threatened with disturbance from mining. Australians expressed a strong desire to preserve the hill even though $500 million of gold and other minerals would be forgone (Imber, Stevenson and Wilks 1991).

6.2 Scarcity and the value of water

Introductory economics textbooks often use the 'diamond-water paradox' to illustrate the idea of utility. Adam Smith pointed out in the 1760s that while water, which is essential to life and has many uses, sells at a very low price, diamonds, which have limited usefulness, sell at a very high price. This puzzle - that why something that is enormously useful has a very low value while something that is not very useful has a very high value - was resolved by understanding the relationship between abundance of a resource and its price. When water is in abundant supply, as it has been in most parts of the eastern seaboard, people use as much as they want to. An extra litre of water does not add much to their level of satisfaction, so the price they are willing to pay for it is small. Diamonds, on the other hand, are very scarce and each extra diamond makes a substantial addition to the value of the stock of diamonds. People are thus willing to pay more for them.

There are signs that the demand for water in more catchments on the eastern seaboard from various users is beginning to approach the supply and that therefore water will become more and more scarce. As various users begin to compete for water resources the price of water is likely to rise. According to economic theory, water should be allocated to the users who are willing to pay most for it, and they will be the users who benefit most from its use, although this fails to take account of equity and sustainability conditions. Scarcity will mean that some users will miss out, or will gain access to less water than they might want. Allocation of water to one use means that it has an 'opportunity cost', and that is the foregone output of water users who missed out.

In the past, the abundance of water on the eastern seaboard has meant that the water used up as a result of forest operations has not been valued. As other users emerge who can make use of the water used up in forest operations then that water has a value. Thus forest operations use water as an 'input to production' and the question is now being asked is this: given that there are alternative users of water that flows out of forests, is the use of water in forest operations the most efficient way of using the water or should it be allocated to other uses? The concept of 'efficiency' needs to be interpreted to include long-term sustainability.

On the big inland rivers, where the availability of water and quality of water has been a contentious issue for some time, systems have developed to allocate and regulate it. On the eastern seaboard, water licenses have usually been required, although they have not always been based on volume. Little is known about the effects of changed water conditions due to licensed water extraction on downstream water users.

Logs-water production possibilities

The hydrological evidence reviewed in this report indicates that current logging regimes in the native forests of eastern Australia result in a decline in water yields. Other things being equal, an increase in rotations reduces the volume of logs taken out of a forest over time but increases the run-off due to a decline in evapotranspiration. In catchments used to supply urban centres, this means that there is less water flowing into dams that provide water to cities and towns for drinking, washing, cleaning, watering gardens and industrial uses. We can represent this trade-off between the volume of logs and the water yield from a catchment by a 'logs-water production possibilities frontier' (Greig n.d.). Figure 4 shows a hypothetical production possibilities frontier for a catchment. As the volume of logs increases along the horizontal axis (due to shorter and shorter rotations) the water yield from the catchment declines.

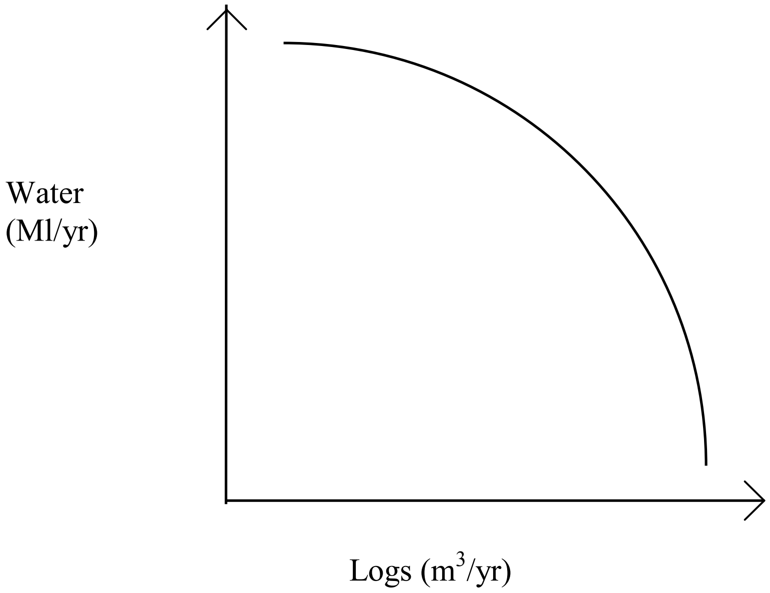

Figure 4 Logs-water production possibilities frontier

In practice, the story is more complex because rotation length is only one of the factors affecting the volume of logs and the yield of water. Others include the prevalence of thinning and various other silvicultural practices. In addition, the log volume-water yield relationship varies according to the type of forest and location of the catchment.

The curve in Figure 4 shows possible combinations of logs and water yields. It is the ability to manage forests according to a great many silvicultural options (section 3.3) produce different combinations of logs and water. The economic optimum combination depends on the relative prices of logs and water. Determining the prices of logs and water thus becomes very important to the efficient allocation of water to tree growing rather than other uses.

6.3 Pricing of water

The actual prices of logs and water are determined in large measure by administrative measures rather than by market pressures. In the case of logs, prices are set as royalties determined partly by the costs of forest management (usually weighted from area to area by production and processing costs), partly by historical precedent and political pressure, and partly by market prices obtained in auctions of non-licence parcels of logs. Water prices have also been determined by costs of collection and distribution and social priorities rather than opportunity costs, although this is changing. While pricing by means other than markets may be appropriate in practice, this raises difficulties in the measurement of the values of logs and water.

On the eastern seaboard water is not bought and sold in markets, putting prices on water in its different uses needs to be done indirectly and may involve technical complexities. In the case of water used for town and city water from the tap does have a price, but this price will be higher than the value of water in the streams of catchments because there are costs associated with getting the water from the catchment to the urban user. In this situation, three methods are available to estimate the value of water for urban consumption so that it can be compared with its alternative use in growing trees.

The constant residual price approach

This method requires first an estimate of the true willingness to pay per kilolitre by urban users (actual prices are administered prices and do not necessarily reflect true economic values). To arrive at a price for water 'in the stream' it is necessary to subtract the costs of water distribution (disinfection, pumping and augmentations to storage) from the final volumetric charges paid by urban consumers.

Variable price approach

The above approach does not take account of the responsiveness of demand for water to changes in price, but estimates the price for the current level of demand. Estimation of the responsiveness of demand to price changes into the future allows a better estimation of the value of water in different uses. However, accurate estimation of demand curves is difficult.

The opportunity cost approach

Growing populations in the cities and towns will require investments in augmentation of water storage capacity -- increasing the capacity of existing dams, building new dams, and river diversions. If stream flows are reduced as a result of logging then it will be necessary for these capital works to be undertaken sooner than they otherwise would. This imposes an economic cost on urban water users. The opportunity cost of using water to support log harvesting is the cost of bringing forward these investments in headworks.

Conversely, additional water obtained by not logging the forests is valued at the extra cost of capital works required to augment the supply of water. This extra cost arises from the need to bring forward capital works as a result of reduced stream flow after logging. Increased stream flows as a result of longer rotations would allow authorities, such as Melbourne Water, to delay building more dams or other expenditures on augmenting headworks. The approach attempts to find whether the least cost way of augmenting future capacity is by reducing logging intensity or by investing in additional capital outlays. This method deals with total costs and does not need to calculate a unit price for water.

The opportunity cost method can be also used to estimate the value of water to other types of water users. For example, dairy farmers require water to irrigate pastures for their cattle. If logging reduces streamflow to the point where farmers cannot get enough water then the milk productivity of their cattle will decline. Although this is especially likely during droughts, the impacts of forest use on yield are less during droughts than in other years. The value of water can then be estimated by the lost output of the farms. A similar procedure may be used to estimate the value of water to water-based tourism industry and fisheries. However, in these cases it is very difficult to isolate the impact of changes in streamflow and water quality on output.

6.4 Economic studies of the impact of logging on water

There are very few studies in Australia (or elsewhere) of the economic impact of logging on other users. A prescient and interesting precursor was carried by P. J. Greig in 1981 examining water-timber trade-offs in another Victorian catchment. The outstanding study was undertaken by Read Sturgess and Associates for Melbourne Water. It examined options for the use of the Thomson catchment (Read Sturgess 1992). That study was revised by Read Sturgess and Tasman Economic Research in 1994 but its report has not been publicly released. The only other study of direct relevance is by Costin, Greenaway and Wright (1984) although that study is much more notable for its hydrology than for its economics and is not reviewed in this section.

Greig's study

Greig (n.d.) set out to estimate the optimal production of logs and water from the Maroondah catchment that supplies some of Melbourne's water. The catchment had never been logged at the time of the study because of the perceived scarcity of high quality water and its value for nature conservation. Hydrological data suggested that the effect of harvesting and regeneration in a mountain ash forest would be first an increase in average streamflow and then, after 5 to 6 years, to a decrease which would persist for many decades. The average streamflow after logging was expected to fall by around 13%.

Greig valued logs at their royalty rates ($10.65 per cubic metre), despite acknowledgment that these rates were set by administrative decree and probably underestimated the true economic value of logs. The unit value of water was estimated by the marginal cost of augmenting yield (the estimate was $79 per megalitre). These costs would include increased costs of storage and distribution.

Greig considered various options involving different rotations and thinning practices. The results of the analysis showed that logging using 60-year rotation generated slightly higher revenues than the no-logging (status quo) option, while logging with a 150-year rotation showed revenues a little higher still. However, the option with highest return was one involving a thinning without regeneration. In this case, 50% of the forest is cleared and turned over to scrub (i.e. deforested). This option not only generates a once-only log volume but actually increases the water yield (by 6%). Recognising the problems with such a conclusion, Greig abandons the strict economic approach and rules out this last option as 'infeasible'. He develops a further option with a 60-year rotation with thinning at 30 years and concludes that this is the best one. A dubious discussion of other impacts of the various options does not lead to any modification of this conclusion.

Read Sturgess Study 1

Melbourne Water was concerned about the potential loss of water as a result of logging in catchments which became part of the Melbourne system in the early 1980s. It commissioned Read Sturgess to evaluate economically a range of management options involving different mixes of wood and water production from the Thomson River catchment. It should be stressed that each forest management option has impacts on several types of forest value, including ecological values, non-timber forest products, non-urban water uses, and recreational values. The study deals only with timber values and the value of water for Melbourne consumers. Moreover, the results of the study pertain only to the Thomson catchment and should not be extrapolated to other catchments which may have different forest cover, soils, hydrological characteristics and `uses. The results for the Thomson catchment depend on (at least) three important factors:

- logging in ash-type forests appears to have a higher impact on water yields than in other forest types;
- the Thomson catchment provides a large proportion of the water supply of a major urban centre; and
- excess storage capacity in the Thomson means that increased water yields will be economically valuable because the water can be captured.

Previous hydrological work by Melbourne Water in similar, older catchments indicated that a reduction in timber harvesting would be very likely to increase the water yields from the Thomson catchment and thus the water supply to Melbourne. The study simulated the physical and economic implications of a range of silvicultural options and compared them with the status quo, that is, the existing harvesting plans for the Thomson catchment. The status quo is defined by an 80-year rotation in ash-type forests, the predominant forest type in the Thomson.

Two harvesting features were varied to give a range options for evaluation:

- the rotation -- varied from 40 years to 200 years and to no logging at all. Other things being equal, a longer rotation will reduce the volume of timber and increase the water yield; and
- the use of thinning, that is, removal of a proportion of the basal area after, say, 20 or 50 years, followed by clear felling. Not all parts of the area are suitable for thinning. Thinning can take the form of strip (or 'corridor')thinning involving the thinning by long thin corridors of perhaps 20 to 35 metres wide.

Table 4 Returns to silvicultural options in the Thomson Catchment (net present values in $ millions)

Option	*NPV ($M) relative to Status Quo (Base Case)*
No logging	147
40 year rotation	4
120 year rotation	45
200 year rotation	102
80 year rotation with thinning	19
200 year rotation with thinning	113
200 year rotation with strip thinning	169

Source: Read Sturgess (1992), Table 4.3

Estimates were made of wood yields and water yields for the eight silvicultural options thus generated for the 200 year period of the study. These volumes of wood and water were then valued using price estimates. The price of standing timber was estimated by relying on information from auction prices for timber harvesting licences. The base case prices for sawlogs ranged from $35 to $60 per cubic metre. The price of water 'in the stream' was estimated using the constant residual price approach described in the last section. The base case price for urban water was estimated at $530 per megalitre. Using a discount rate of 4%, the study calculated net present values for the silvicultural options and reported the difference between NPVs for the status quo and each other option. The results are reproduced in Table 4.

All of the options considered show improved returns over the status quo. In other words, among the options considered, the existing management of the Thomson catchment is the most inefficient. According to this analysis the best options are either a very long rotation (200 years) or a complete end to logging. The clear conclusion is that, using the estimated prices for timber and water, the loss of timber as the rotation is lengthened is more than compensated for by the increased water yields. If other values were taken into account, in particular ecological values, it is likely that the results would favour long rotations or no logging options even more strongly.

Read Sturgess Study 2

The 1992 Read Sturgess study was revised by Read Sturgess and Tasman Economic Research in 1994. The second study differed from the first by valuing water by the opportunity cost method and considering a wider range of silvicultural options. Although the report itself has not yet been publicly, press reports indicate the study generally confirmed the results found in the first study. However, both studies have been criticised by Ferguson (1995) for their methods of valuing water.

6.5 Some general principles of forest economics

The results of the Greig and the Read Sturgess studies illustrate some of the general principles of forest economics which should be applied to the economic analysis of other catchments.

Relative pricing. Finding the optimum economic mix of commodities which can be produced jointly from forests requires estimates of the economic values of timber and water (and other commodities and attributes where possible). It is their relative marginal values that are important. In some cases, such as the Thomson catchment, the need to augment water storage through expensive capital works at various points in the future can give water a very high value. Such data then must be combined with the silvicultural options (joint production possibilities, Figure 4) to find the best economic solution. However, there are environmental impacts of silvicultural options that are difficult to quantify, so that ultimately decisions require social and political judgements as well as economic analysis.

Silvicultural options The silvicultural options which affect water yield are those of rotation length and thinning (including a do-nothing option). When water is of far greater value than timber, then very long rotations will be preferred to short ones because (under ‘normal’ management) a far smaller proportion of a catchment will be covered with fast-growing regrowth.

Discount rate The choice of a discount rate is a critical but contentious issue. For long-term public works, a discount rate of 4 or 5 per cent is now generally advocated for evaluation; it is interpreted as a social rate of time preference and is derived from long-term bond or similar rates. However, its application to forest evaluation is more problematic. Higher discount rates favour short rotations and, it can be argued, are contrary to the interests of future generations when account is taken of the option and existence values of forests.

7. CONCLUSIONS: REGIONAL ASSESSMENT, PUBLIC POLICY AND RESEARCH

This report introduced the general concepts of logging and forest management in the forested catchments of the eastern seaboard and reviewed the available scientific literature concerning the effects of logging regimes on hydrology and soils. The preceding section reviewed the economic effects of changes in water yields due to forest management practices. This concluding section draws together these matters, considers how water issues should be considered in the Comprehensive Regional Assessment process and forest policy generally, including research.

7.1 Context and types of forest decisions

The very substantial differences between catchments in terms of their hydrological characteristics, pattern of land use and array of water users makes it clear that the analysis of forest use and management in relation to water must proceed on a regional scale at which the details can be evaluated properly. The integrated catchment management process now being adopted by most States and the Comprehensive

Regional Assessment process being undertaken jointly be the Commonwealth and States are occurring at the relevant scale. However, it is far from clear that all important catchments will be included in the former process within the foreseeable future or that water will be considered at all in the latter process.

The situation is complicated because the decisions and actions discussed in this report are of different types, some being far more amenable to public policy processes than others. Those related to water quantity appear more straightforward than those related to water quality.

In relation to water quantity, it is clear that in some regions - and in more as demand increases - water has to be allocated between tree and other crops, and between primary, secondary and domestic use. Tree and other crops grow on both public and private land and there are few examples as yet in Australia of integrated catchment management systems being able to effect such allocations efficiently or equitably. Moreover, the effect of tree crops on water yield is known for only a few sites.

In relation to water quality, it is clear that the most important issues relate to the standard of forest management practice. This, of course, also applies to agricultural practice. However, as three-quarters of the forests are in the public domain, the task of ensuring good practice is somewhat easier. The major obstacles are the continued pressure of governments to reduce field staff, the unwillingness of industrial companies holding resource rights to pay adequately for high quality work, and the need to upgrade much of the old roading infrastructure. A series of detailed matters relating to standards, training, equipment and so forth are contained in various places in this report.

7.2 Comprehensive Regional Assessments

The Comprehensive Regional Assessments leading to Regional Forest Agreements should involve evaluation of the range of uses of forests including comparison of impacts of various management regimes on users. Assessment of the impacts of management regimes on water users should be an important aspect of this in many forest areas. The assessment process needs to include the following stages.

- For each forest area being assessed it will be necessary, as far as possible, to match data on the forested area (area forested, forest types, silvicultural management, expected growth rates) with data on catchments. It should be noted that some water users are well outside of the catchment itself.
- All major water users from the catchment/forested area in question need to be identified along with the uses to which they put water and any rights or entitlements to water that they may have.
- For each user or class of users the assessment needs to assess the amount of water used, its approximate contribution to their economic and other activities and the likely impact on those activities of changes in its quantity and quality.
- In this context, it will also be necessary to make some projections of future demands for water from the various users. It will not be possible to make these assessments with a great deal of accuracy, but some order of magnitude estimates will be possible using rapid appraisal techniques.

- Finally, it will be necessary to assess the economic impacts of possible changes in water yields and water quality as a result of feasible silvicultural regimes and logging and roading systems. Approximate data on the impact of changes in water yields and quality on output or consumption need to be combined with price data.
- This assessment should also consider alternative sources of water (such as diverting irrigation water) and demand management (especially for urban water).

As a result of these analyses for each forest region, consideration of water impacts may lead to recommended changes in the silvicultural regimes chosen (including rotation lengths and thinning systems) and the logging and roading systems applied. The former are more relevant for issues of water yields while the latter are more relevant to water quality.

7.3 Implications for public policy

The broad conclusion of this paper is that existing assessment processes, including those being developed for the Comprehensive Regional Assessments, do not adequately deal with the potential impacts of logging on water yields and water quality. The National Forest Policy Statement gave inadequate attention to forest water issues. These issues cannot be resolved through information gathering, analysis and negotiation at central levels but must be resolved through detailed regional studies. There are however, a few areas -- such as catchments for major cities -- where the issues need to be developed in coordination with other major planning processes that extend beyond the boundaries of particular catchments.

There do appear to be a few catchments in the study area where conflict over limited water is already a serious issue. However, we expect that conflicts over access to water will become a much more extensive problem in the next century as more and more water-intensive activities develop on the eastern seaboard. Questions about the impact of logging on water supplies and water quality will be asked with increasing frequency and choices will need to be made about the optimal distribution of water resources across competing uses.

This emerging situation provides an opportunity to develop the data bases and methods of analysis that will help to head off conflicts before they become entrenched. It would be foolish to allow this resource-use issue to create yet another battleground over conservation and resource management.

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WOODCHIPPING OUR WATER

Victoria's Goulburn Broken Catchment

A case for reassessing the use of the catchment's wet montane forests. **May 2009**

WOODCHIPPING OUR WATER

A case for reassessing the use of Victoria's Goulburn Catchment's wet montane forests

May 2009

Acheron Valley near Black Spur looking east toward Mt Ritchie (C.Taylor 2008)

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Contents

Appendices

1 Introduction

This report, *Woodchipping Our Water*, assesses how the logging of mature forests in the Goulburn River catchment threatens the enormous water production and carbon sequestration potential of the region.

The Goulburn River is one of Australia's most important and degraded river systems. It supplies water to many regional towns and cities, including Shepparton, Bendigo and Ballarat. The Goulburn also supports Victoria's major irrigation industries and its flows are vital to the health of the Murray River system.

The report finds that if logging in the study area stopped tomorrow, an additional water yield of 3,807 gigalitres would be delivered into the Goulburn River over the next 100 years. This is more than six times Melbourne's annual average water use and around 165 times the amount of water the City of Bendigo uses in a single year. The economic value of this water would be $1.68 billion.

In addition, the carbon sequestration gains – the ability of mature forests to draw down carbon dioxide from the atmosphere – are immense. Stopping logging operations would enable 21,150 additional tonnes of carbon to be stored in the Goulburn's forests each year. That's the equivalent of taking 4,700[1] cars off our roads. This stored carbon could be worth $6.15 billion over the next 100 years.

The Australian Conservation Foundation (ACF) estimates that the financial assistance needed to support the ending of logging operations would be approximately $12 million.

Clearly, the Goulburn Broken Catchment offers far greater economic and environmental opportunities to Victoria than those that come from current timber extraction practices. In addition, the implementation of proactive management practices and a return to the forests' ecological maturity would restore ecosystem health, build resilience to climate change, strengthen the forests' potential to survive wildfire events and provide vital flows to the Goulburn River.

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[1] Average vehicle = 4.5 tonnes per year; http://www.environment.gov.au/settlements/challenge/members/greenhousetips.html

2 Geography

2.1 Victoria's eastern Central Highlands

Victoria's eastern Central Highlands extend to Seymour and Lake Eildon in the north, the Hume Freeway in the west and Baw Baw National Park and Moe in the east. The Great Dividing Range is the dominant feature, running east-west and dividing the north of the region from the south. The defining image of the Central Highlands forested catchments is the tall Mountain Ash, the tallest flowering plant in the world.

2.2 The study area – Goulburn Broken Catchment

The Goulburn Broken Catchment lies between the Murray and the forested catchments on the northern face of the Great Dividing Range. The catchment's state-owned public native forests are located within the sub catchments of the:

- Upper Goulburn River
- Snobs Creek
- Royston and Rubicon Rivers
- Acheron River
- Yea River

A rain-shadow effect[2] has created drier environments on the higher ridges of the divide, making mixed species forests and woodlands more common. However, there are ash-type forests within the upper riparian corridors and the highest rainfall zones, characterised by an over story canopy dominated by Mountain Ash (E. regnans), Alpine Ash (E. delegatensis) and Shining Gum (E. nitens).

View of Goulburn Valley looking north from Mt Torbreck C.Taylor 2008

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[2] When mountains block the passage of clouds, and therefore rain, casting a 'shadow' of dryness

3 Goulburn Broken Catchment – the study area

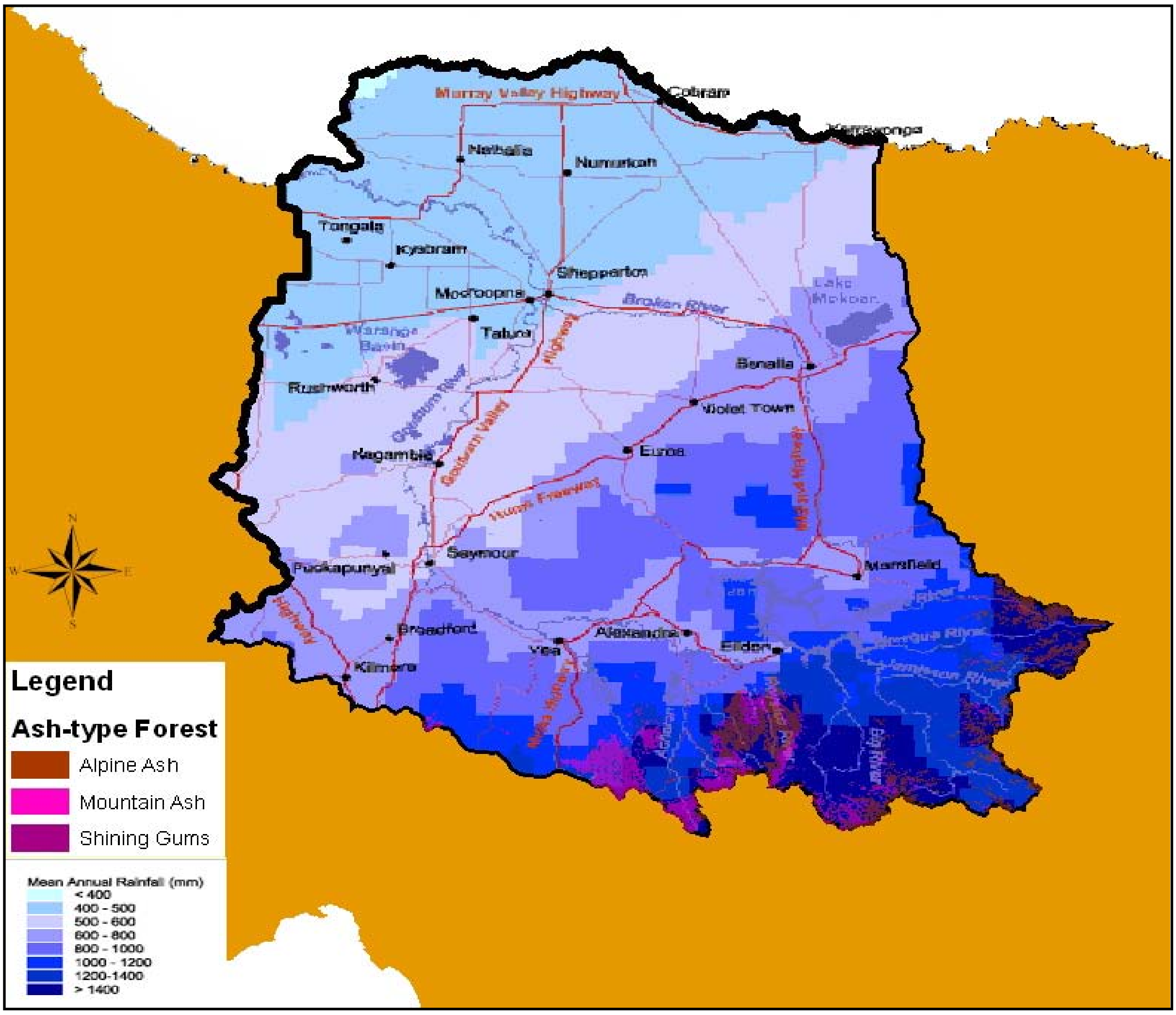

Fig 1: Goulburn Broken Catchment Management Area (GBCMA) Source: Victorian Resources online

Ash-type forests are considered to be ecologically mature when the eucalypt overstorey reaches an age of around 120 to 150 years. These trees form the major part of a multi-aged canopy that sits high above an understory composed of cool temperate rainforest species. Mature wet eucalypt forests may contain individual trees that reach 500 years of age before they decline and decompose, often assisted by fire.

4 Timber extraction

Timber is currently logged from public forests within the Goulburn Broken Catchment by the State government business enterprise, Vicforests. This logging is conducted under a Timber Allocation Order created by the Department of Sustainability & Environment and approved by the Minister.

Ash-type forests are logged using the ‘clearfelling’ technique, which sees virtually all standing trees removed from the area in the form of sawlogs and residual logs.

This logging is planned on an 80-year rotational basis, which allows for around 500 hectares of forest to be cut every year from an area of approximately 40,000 hectares. After clearfelling the vast quantity of wooden debris and other vegetation left behind, known as 'slash', is formed into rows which are allowed to dry through the ensuing summer. The following autumn the slash is burnt in intensely hot 'regeneration burns' in order to convert the remaining organic material into an ash bed. This creates optimum conditions for eucalypt seed germination following aerial distribution of the seeds.

Employing an 80-year growth cycle means the regrowth forests in the area don't achieve ecological maturity. Instead, they become more like plantations, which are converted into even aged monocultures with a simplified understory. Thinning operations currently proposed in the area's regenerated forests, similar to those conducted in plantations, will also add to this conversion and ecosystem impoverishment.

This practice results in the average forest age class being maintained at a point of maximum water demand, and denies the forest the opportunity to reach its full carbon sequestration potential.

4.1 Current extraction

Each year the Goulburn catchment's state forests produce approximately 50,000m^3 of sawlogs, sold to sawmills in the region, and approximately 135,000m^3 of residual logs. These are sent to Australian Paper in Gippsland or to Geelong to be wood chipped for export to the Japanese paper industry.

4.2 Alternative resource

Vast amounts of alternative hardwood timber are becoming available in Victoria due to the extensive expansion of the hardwood plantation industry. There is an enormous opportunity now for the wood product industry to make the transition from a reliance on hardwood native forest toward this emergent plantation base. Indeed given the global financial crisis and reduced Japanese demand for Australian woodchip, this may become necessary to underpin the security of the highly capitalised Victorian private plantation sector.

5 Impact of logging on water production

Victoria is currently in a water supply crisis, and on top of the current situation, three major factors threaten the future supply of our most precious resource:

- Increasing public demand in both rural and city regions,
- climate change, and
- land clearing and logging in water catchments.

Given these challenges, Victoria must improve its water conservation and efficiency. Alongside other measures, this means reviewing logging practices in the rain-soaked upper catchments that supply water to Melbourne and to the stressed catchments of the upper Murray. This report shows that mature forests return cleaner and larger volumes of water to river systems – around 12 megalitres per hectare per year – than re-growth[3] forests, therefore creating additional water for public use.

5.1 Ash forests water yield analysis

ACF commissioned consultants Practical Ecology to investigate and profile the hydrological performance of the wet mountain ash forests of the Upper Goulburn Broken catchments. Using Fred Watson's hydrology model, known as the 'Water Balance' model (Watson et al 1999), the study assessed water production yields for two scenarios in the catchment from the present day to 2150.

- Status quo – the projected water production from continued logging.
- Management change – the projected water production with no logging.

It is important to note that this report does not model projected decreases in rainfall caused by the impacts of global warming on Victoria's climate.

The study found that due to the regrowth effects of 1939 bushfire regeneration, water production will continue to increase in the catchment in the absence of extensive bushfire and regardless of management changes, by an additional 80,000 ML/year by 2035.

However, an immediate end to logging would see water yields increase even further beyond 2035. To be specific, an immediate end to logging would mean:

- 20,000 ML/year of additional water by 2050
- 36,000 ML/year of additional water by 2060
- 52,000 ML/year of additional water by 2070
- 67,000 ML/year of additional water by 2080
- 81,000 ML/year of additional water by 2090
- 94,000 ML/year of additional water by 2100
- 163,000 ML/year of additional water by 2150 [4]

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[3] Vertessy R, Watson F, O'Sullivan S, Davis S, Campbell R, Benyon R, Haydon S (1998), 'Predicting Water Yield from Mountain Ash Forest Catchments', Cooperative Research Centre for Catchment Hydrology

[4] See Appendix A – Water yield analysis of ash forests – Goulburn Broken Catchment (Practical Ecology 2008)

6 Timber extraction vs water production

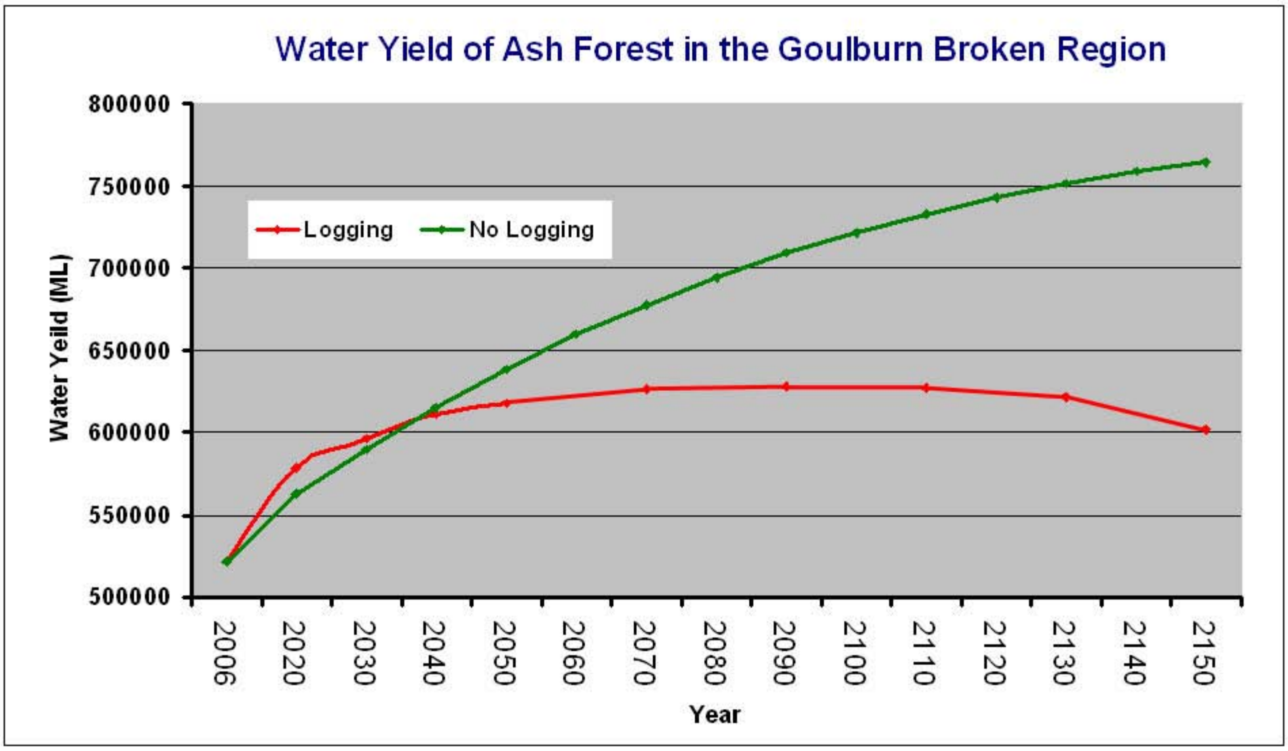

Fig 2: Water yield of ash forest in the Goulburn Broken region

The NPV analysis on water (based on data from the previous section) shows that the economic value of water saved by stopping logging is clearly greater than the economic value of timber logged.

While an immediate end to logging in the catchment will lead to decreased water yields in the short to medium term, it will have huge medium to long term water yield benefits. This makes it a sound investment, particularly in light of decreasing rainfall projections due to the effects of climate change.

As the forests regrow, eventually establishing a mature age profile (150+ years), water yields will increase drastically when compared to a continued logging regime (as shown in the previous section).

Modelling shows that if logging in the wet montane catchments ceased altogether, there would be an additional water yield of 3,807 GL delivered over the next 100 year period, with the gain rate continuing to increase beyond that time.

That's more than six times Melbourne's annual average water use.

Net present value analysis shows that the additional water yield delivered over the next 100 year period has a value of $1.68 billion.

In order to calculate the NPV of water over 100 years, a low discount rate of 2 per cent has been applied. This follows the example set by the world's most significant recent climate change modelling reports – Lord Nicholas Stern, author of the UK's Stern Review and Professor Garnaut, in Australia's Garnaut Review. In both of those reviews, a discount rate of close to zero was considered appropriate for the long term environmental impact of climate change (0.05 per cent in Garnaut the Review).[5]

This was due to both authors arguing that when considering long term impacts, the welfare of future generations should not be considered less valuable than those of us alive today. The impact of water availability and carbon emissions are of equal importance to all humans, whether today or in 50 years time. Due to the applicability of this theory to water yields over a century, we have followed the precedent of Stern and Garnaut in choosing a low discount rate. However, in order to remain conservative, we have chosen a slightly higher two per cent discount rate.

The potential to create more than one and a half billion dollars worth of additional water over the next 100 years clearly demonstrates the significant value of stopping logging in the wet catchments. When fully calculated to include the multiplier impacts across environmental flows and agricultural enterprises, this is likely to create additional tens of billions of dollars, as well as healthy and productive downstream riverine ecosystems.

In comparison, the NPV of timber harvested in the catchment over the same 100 year period is overwhelmed by the value of water (at the same discount rate).

The value of saw logs and residual timber extracted from the catchment over a 100 year cycle has a net present value of $811 million.[6]

This figure represents revenues from the sale of timber (stumpage), without any costs of harvesting or transport, and as such, well overstates the profit that can be derived from these forests. VicForest's recent annual reports would indicate that actual profit from these extraction activities is minimal. Furthermore, the appropriate discount rate for an investment by a government business enterprise to extract timber would be more appropriately upwards from 8 per cent. For comparison, we have used the same rate as the water NPV in this report.

It is clear the economic benefits derived from additional water yields, due to stopping logging in this catchment, are a significantly greater contribution to the economy than continued logging activity.[7]

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5 Garnaut, R. (2008), Garnaut Climate Change Review Final Report page 18.

6 Based on extraction of 50,000m3 of saw logs per annum at $100/m3, and 135,000m3 of residue at $10m3, and includes a 2.5% CPI per annum on timber values.

[7] See Appendix B – Water vs Wood Net Present Value Analysis (ACF)

7 Carbon and wet eucalypt forests

In August 2008 the Australian National University (ANU) released a report, *Green Carbon,* [8] which profiled long term research into the levels of carbon stored within Australian native eucalypt forests. The ANU describes the research and its application as:

> *"Green Carbon is the carbon stored in the plants and soil of natural ecosystems and is a vital part of the global carbon cycle. The report is the first in a series that examines the role of natural forests in the storage of carbon, the impacts of human land use activities, and the implications for climate change policy nationally and internationally. REDD ("reducing emissions from deforestation and degradation") is now part of the agenda for the "Bali Action Plan" being debated in the lead-up to the Copenhagen climate change conference in 2009."*
>
> *Currently, international rules are blind to the colour of carbon so that the green carbon in natural forests is not recognized, resulting in perverse outcomes including ongoing deforestation and forest degradation, and the conversion of extensive areas of land to industrial plantations. This report examines REDD policy from a green carbon scientific perspective."*[9]

In addition to increased water yields, ending logging in the area will provide further external benefits, including additional carbon sequestration and ecosystem services, such as habitat for insect eating animals and pollinators that benefit local farmers and water filtration. Most critical though, and potentially the most economically attractive, is carbon sequestration.

In *Green Carbon* the ANU estimates South-East Australian eucalypt forests can store a mean value of 640 tonnes of carbon per hectare. (It is worth noting that the report indicates this may be a conservative figure for the Goulburn Broken Catchment, where the highest carbon stocks were found – up to 1,500 tonnes of carbon per hectare in the ash forests of the Central Highlands.)

Much research now shows that older mature forests, particularly of mountain ash, have significant carbon storage capabilities which are well above that of young forests actively managed for logging.

---

[8] Brendan G. Mackey, Heather Keith, Sandra L. Berry and David B. Lindenmayer (2008). Green Carbon. The role of natural forests in carbon storage. Part 1. A green carbon account of Australia's south-eastern Eucalypt forests, and policy implications. http://epress.anu.edu.au/green_carbon_citation.html

[9] ibid

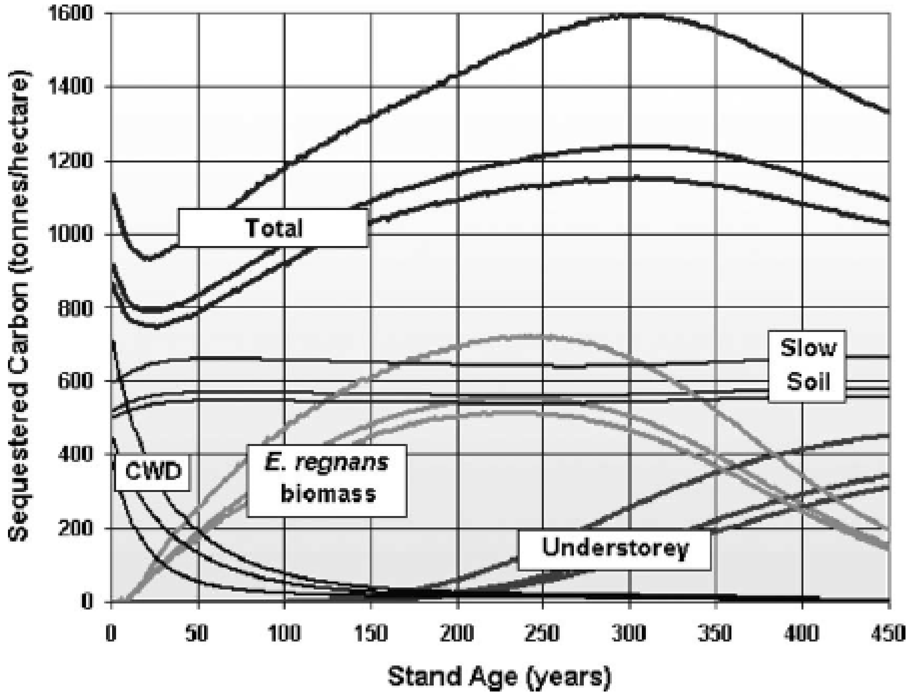

Fig 3: Forecasting landscape-level carbon sequestration using gridded spatially adjusted tree growth, from Dean, Roxburgh and Mackey (2004) *Forecasting landscape-level carbon sequestration using gridded spatially adjusted tree growth* in Forest Ecology and Management 194:109-129

This carbon stock does not reflect the annual sequestering ability of a forest, rather the total stock of carbon held in the timber and soil of the forest. A direct conversion to estimate the value of the carbon sequestering ability of these forests can be difficult to make. As a result, accurate calculations of carbon held and sequestered in native forests and subsequent values are too often ignored.

A great deal of research on this topic supports a strong position to protect the carbon storage capacity of these forests in light of the urgent need to reduce carbon emissions. Currently, there is no policy mechanism that allows for the trading of carbon in Australia's native forests and therefore no way of realising the potential value of carbon sequestered in the Goulburn Broken Catchment.

Nevertheless, as a proxy value for this carbon asset, an estimate of the value of these carbon stores is an absolute priority. These values may, under future policy scenarios, be realisable values, and despite their economic value, are critical for Australia's efforts to manage greenhouse gas emissions.

Based on data from the same research conducted for the ANU report (by Brendan Mackey), with an estimate of carbon sequestration of 12 tonnes of carbon per hectare per year (or, when converted to carbon dioxide, 43.2 tonnes of carbon dioxide equivalent per hectare per year), an NPV can be undertaken using shadow carbon prices as estimated by Federal Treasury modelling.[10]

Under a scenario where logging ceases in the Goulburn Broken Catchment, it is estimated, based on current logging patterns, that 500 hectares of logging would be avoided per annum.

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[10] Treasury (2008), Australia's Low Pollution Future, based on data under the low CPRS-5 scenario (5 per cent cuts by 2020)

In order to remain consistent with the water calculations in the previous section, there would be an additional carbon sequestration benefit from avoiding this logging upon which we can place a value. This is carbon sequestered above business as usual logging and needs to be valued and treated as an asset that it is.

Modelling shows that if logging stopped altogether in the wet mountain ash catchments the additional carbon yield delivered over the next 100 years would be valued at $6.15 billion.[11]

It is important to recognise that this value is merely the additional carbon sequestered above business as usual logging. It is critical that policymakers begin to account comprehensively for the carbon stocks and yields across the entire catchment. In this way, the significant value of carbon sequestered annually across the entire catchment could be recognised for the state asset that it is, and more accurately reflect the critical role of forests in greenhouse gas reductions.

8 Resilience to bushfire

Ecologically Mature Ash forest

Regrowth Ash forest (C.Taylor)

8.1 Mature wet ash forests compared with regrowth

Ecologically mature wet forests have a greater ability to tolerate and survive severe bushfire events when compared with their re-growth form, which are more easily destroyed by a 'crowning fire.' The great height of mature wet forests, coupled with wet understory and midstory species and low level of fine fuels, have been shown to reduce and lessen bushfire intensity once it has entered their domain. In *Australia Burning* (2003), ANU forest ecologist David Lindenmayer refers to the submission by ANU forestry lecturer Ross Florence, who

---

[11] See Appendix C - Analysis of the Value of Carbon sequestration potential (ACF)

made the following observations on fuel loads and forest disturbance in a submission to the New South Wales Bushfire Inquiry in 1994.

> *On fuel loads in pre-settlement forests*
>
> *"The amount of litter which accumulates on the floor of the old growth forest may be appreciably less than that which accumulates at earlier growth stages. Where regrowth develops following a severe perturbation, the forest floor biomass builds up rapidly to a point of peak fuel energy storage during the forest's rapid early growth stage. This point may be as soon as 35 years in stands of fast growing species. Beyond this point there will be a progressive reduction in the forest floor biomass as wood volume production and the rate of crown expansion and litter fall decline, as the shrubby understorey breaks up, and as the litter accumulated at the point of peak energy storage is incorporated into the soil organic matter.*
>
> *It may be this natural successional process - as much as burning by Aborigines - which limited the build up of forest floor fuels before European settlement, and hence the frequency of more intense and damaging crown fires.* [12]

Further to the above statement on pre-settlement forests, Florence also comments on the effect that burning within protected forests has on fuel loads:

> *As the uncontrolled fires of the post-settlement period damaged the forest ecosystems, the deeply fire-scarred old-growth trees could no longer exert strong site control. Eucalypt regrowth developed in either small patches or more extensively throughout the forests, generating an increase in litter production and hence fuel loads. Fire-stimulated shrubs were now more persistent, contributing a further significant source of potential flame energy.*[13]

8.2 'Thinning' in wet forest regrowth

The proposal to conduct 'thinning' operations in regrowth wet eucalypt forests in Victoria's Central highlands, including in the Goulburn Broken Catchments, will also increase the risk destruction by bushfire.

The intention of thinning is to use mechanical harvesters to extract around 50 per cent of the regenerating stand for pulp wood, and then enable the retained trees to take up the available water to achieve rapid growth. The practice of leaving the tree heads, or 'slash', in the regrowth stand increases the level of fine woody debris and thus increasing the risk of intense bushfire behaviour.

It appears Victorian State forest managers have no published code of practice for this activity nor does it seem any research has been conducted into the environmental impact on ecosystem processes. It appears the intention of this intensive industrial logging program is more focused on converting the natural forest ecosystem into something more akin to a plantation development.

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[12] Florence, R.G. 1994, The Ecological Basis of Forest Fire Management in New South Wales, submission to NSW Cabinet Bushfire Review, Sydney

[13] ibid

Ecologically mature wet eucalypt forest(E.denticulata)

Thinned wet eucalypt forest regrowth (E.denticulata) (Errinundra Plat. Vic)

Forestry Tasmania conducts 'thinning' operations in wet native eucalypt forest regrowth in a climatic zone with considerably less fire risk than that in Victoria's forests. Yet the increased fire risk created by these Tasmanian operations has required prescriptions for these operations.

Forestry Tasmania's Technical Report no. 13 (2001) indicates the increased risk of wildfire destroying a regrowth forest stand due to the increase fuel load from these operations.

> *"One of the major planning constraints associated with thinning is the higher level of fuel present after the operations. It is not considered feasible in Tasmania to carry out fuel reduction burns in thinned coupes because of the high fuel loads and the sensitivity of the retained trees to fire. The location of thinned coupes amongst conventionally logged coupes is problematic, as it is not recommended that any regeneration burn take place within two kilometres of areas with high levels of flash fuel within two years of harvest (Cheney 1988)."*
>
> *"Tree crowns (heads), bark, and other harvest residue make up the fuel load. The climate on the floor of the forest is altered by thinning, with higher wind speeds and temperature, lower humidity, and lower moisture content in the fuel itself. Understorey vegetation characteristics change because of these changes to the microclimate, especially increased light. Bracken ferns and cutting grass may grow vigorously, each having a far higher flammability than the replaced woody species (Cheney and Gould 1991).*[14]

9 Biodiversity protection and ecosystem resilience

There is a significant number of old growth or ecologically mature forest stands scattered throughout the Central Highlands region. Many of these remain as dead, or 'stag', trees and are noted for their importance as nesting sites for a wide range of fauna, including the state's faunal emblem, the Leadbeater Possum (Gymnobelideus leadbeateri). A large number of other threatened species can be found in the highlands and in many cases there is a strong connection between threatened fauna and threatened vegetation communities.

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[14] Forestry Tasmania (2001), Thinning Regrowth Eucalypts – Native Forest Silviculture Technical Bulletin No. 13 Second Edition

By systematically removing trees less than 100 years old, logging causes a major loss of tree hollows (it normally takes this long for hollows to begin forming in eucalypt species), which are critical for shelter and breeding by 98 per cent of Victoria's animal species.[15]

> *Logging radically alters the structure of the forest – the number of big old trees with hollows, the number of fallen logs, the density of the understorey and the canopy vegetation. It also alters the floristic structure of the forest – the number, type and density in the forest. Logging can also create conditions which promote the spread of pest animals and weeds and increase the probability, frequency and severity of fire. Consequently, many plants and animals are now absent from the forest.* [16]

The removal of suitable habitat trees will move many species closer to extinction.[17] While extinction is often associated as an end point, where a species is no longer found on the planet, this is not wholly the case. There is a scale along which a species moves towards this point, and we have the ability to avert this slide.[18]

10 Transition and structural adjustment package

Transitioning away from timber extraction in the Goulburn Broken's wet mountain catchments can be achieved under a Forest Industry Structural Adjustment Package, similar to that produced by the Victorian Government for *Our Forests Our Future* in 2002.[19]

In 2002, the Victorian government was required to reduce the level of logging in Victoria's state native forests in an attempt to maintain a 'sustainable yield' of future sawlog supply. The program was quite successful, with native hardwood yields reducing over the last ten years from 921,000m^3 to 567,500m^3/year.[20] Current sawlog extraction from state forests in eastern Victoria is in the order of 450,000m^3/year.

As stated earlier in this report, 1, 50,000m^3 of sawlogs and 135,000m^3 of residual logs are extracted annually from the Goulburn's ash forest catchments.

The Victorian government could phase out logging in these catchments and reap the greater economic benefits provided by increased water yields by implementing a structural adjustment package on the same principle as that applied to *Our Forests Our Future* in 2002.

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[15] Lindenmayer D, Cunningham R, Tanton M, Smith A, Nix H (1991), 'Charactaristics of hollow bearing trees occupied by arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-east Australia', Forest Ecology and Management, pp289-308

[16] Traill,B. (1995) Woodchips or Wildlife – the case against logging our native forests. Environment papers, Vol 1 Victorian National Parks Association

[17] Possingham H, Lindemayer D, Norton T, Davies I (1994), 'Metapopulation Viability Analysis of the Greater Glider Petauroides volans in a Wood Production Area', Biological Conservation pp227-236

[18] Appendix D - Old-growth forest, water and climate change - some scientific understandings. (Choosing a Future for Victoria's forests. Victorian Forest Alliance 2006)

[19] Our Forests, Our Future - Balancing Communities, Jobs and the Environment http://www.dse.vic.gov.au/dse/nrenfor.nsf/FID/-22A28C77A72588894A256B67000E0B85?OpenDocument

[20] ibid

10.1 Voluntary licence reduction program

Under the 2002 *Our Forests Our Future* program, the Victorian government purchased timber allocation licences back from the industry with up to five years remaining; meaning that after that time all licences would expire and not be renewed. All allocation of timber extraction beyond this time was made at the commercial discretion of the state owned government business enterprise, Vicforests. By 8 July 2003, the government had bought back a total of 268,360m^3 of licensed sawlog volume, achieved at a cost of $31.2 million.[21]

Given Vicforests engages in short to medium term sales contracts of up to five years, it is reasonable to assume that the same rules could apply today. Such contracts would be of similar nature to that of the pre-existing licences given that they also had approximately five years to expiry. The adjustment package requires that 50,000 m^3/year sawlog commitment be retired. So 18 per cent of the *Our Forests Our Future* volume reduction would equate to $5.81 million.

Many Vicforests customers may wish to reconsider their contractual arrangements given the onset of the global financial crisis in mid 2008, ending the obligation and also seek compensation.

10.2 Worker assistance program

Through the 2002 *Our Forests Our Future* Worker Assistance Program, the Department of Victorian Communities helped forest industry workers undertake training, relocate, secure new jobs or retire, if that is what they wanted to do.[22]

10.3 Contractor assistance program

When applications opened for the Contractor Assistance Program in November 2002, the program objective was "… easing the transition for contractors directly affected as a result of the implementation of the Voluntary Licence Reduction Program".

The guidelines established that eligible contractor businesses were those that:

- directly participated in the forest industry or were directly dependent on the industry; and
- were adversely affected by the licence buy-back.[23]

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[21] http://archive.audit.vic.gov.au/reports_par/Forests_Part%203.pdf

[22] ibid

[23] ibid

Proposed Goulburn Forest Industry Structural Adjustment Package (FISAP)

Structural Adjustment Package Components	Item	Our Forests Our Future 2002 [24] Funds allocated	Goulburn Transition Proposed FISAP Package (16% Our Forests Our Future) Funds required
Voluntary Licence Reduction Program	Licence Volume reduction (Our Forests Our Future 2002) or current VicForests contractual obligations	268,360m3 $M 31.2.	50,000m3 $M 5.8
Worker Assistance Program	Job search assistance, relocation, training etc.	$10.9M (40%)	$1.74M
	Industry restructure payments	$16.7m (60%)	$2.67M
Contractor Assistance Program	Payments for plant and equipment	$7m (54%)	$1.3M
	Job search assistance, relocation, training etc.	$2.3m (18%)	$0.43M
	Industry restructure payments	$3.4m (27%)	$0.63M
	Statutory redundancy payments	$0.16m (1%)	$0.03M
		$12.86 (100%)	
Total		**$71.66M**	**$12.6M**

Note: 2002 $ values

Transition and reform will provide additional water yields for the Goulburn River, at no additional infrastructure cost.

Future regional forest managers should include water production and carbon sequestration as key commercial components of their revenue stream, and utilise the skills of foresters and the equipment of timber production contractors for the essential forest management tasks of:

- maintaining road access, upgrades and maintenance
- drainage and water infrastructure maintenance
- ecologically and structurally focused forest restoration
- wildfire mitigation measures in re-growth forests
- ecologically planned prescribed burning
- appropriate fire break construction
- providing a larger dedicated fire fighting service

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[24] http://archive.audit.vic.gov.au/reports_par/Forests_Part%203.pdf

11 Conclusion

This report shows there is a great opportunity available to the Victorian Government to capitalise on the natural advantages present in this key public asset.

Changing the focus of natural resource exploitation in the study area – from timber extraction to water and carbon sequestration – would deliver major net present value gains, indicative of the strong rates of return that can then be reinvested into the region.

Key findings of the report reveal:

- Modelling shows that if logging stopped altogether in the wet mountain ash catchments there would be an additional water yield of 3,807 GL delivered over the next 100 years, with the gain rate continuing to increase beyond that time.
- Net present value analysis shows the additional water yield delivered over the next 100 years has a value of $1.68 billion.
- Modelling shows that if logging stopped altogether in the wet mountain ash catchments the additional carbon yield delivered over the next 100 years would be valued at $6.15 billion.
- Water are carbon values far outweigh that of saw logs and residual timber extracted from the catchment over a 100 year cycle, which has a net present value of $811 million.[25]
- Old growth or ecologically mature forests have a much greater resilience to bushfire.
- Stopping logging in the catchment provides a greater economic opportunity, with increased forest related employment, with an affordable transition package that has little impact on the wood product industry sector.

There are greater economic and environmental benefits for Victorians than current timber extraction practices in the catchment's wet mountain forests. The implementation of proactive management to return the forests to ecological maturity will restore ecosystem health, build resilience to climate change, strengthen the forests' potential to survive bushfire events and provide vital flows to the Goulburn River.

---

[25] Based on extraction of 50,000m^3 of saw logs per annum at $100/m^3, and 135,000m^3 of residue at $10m^3, and includes a 2.5 per cent CPI per annum on timber values

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Restoration and Environmental Planning
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Goulburn Broken Water Yield Analysis of Ash Forests

Goulburn Broken Catchment

December 2008

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APPENDICES

FIGURES

1. INTRODUCTION

Practical Ecology Pty Ltd was commissioned by Australian Conservation Foundation (ACF) to analyse the effect of disturbance on water yield in ash-type forests (*Eucalyptus regnans, Eucalyptus delegatensis and Eucalyptus nitens)* within the Goulburn Broken Catchment. The project involved modelling the effects of forest disturbance on water yield using Fred Watson's Water Balance Model (Watson *et.al.* 1999), an updated version of the Kuzcera Bushfire Model (1985). The forest disturbance that was assessed within the analysis was considered an absolute regeneration event such as clearfelling, seed tree retention and wildfire.

The analysis projected the effect of no-logging versus continued logging in the Goulburn Broken Catchment on water yield from the present, 2006, to 2150. This report is a brief of the data, methods and limitations involved in the analysis.

1.1 Aims

This report aims to:

- Present all findings of the water yield analysis and provide background of the methodology.
- Present future projections of logging versus no logging from 2006 until 2150.

1.2 Study Area

The study area is located within the Goulburn Broken Catchment Area. The analysis looked at the public water supply areas and other catchment areas within the southern region of Goulburn Broken catchment. The catchment areas where selected on the basis of the presence of ash-type forest, percentage of ash-type forest that was affected by the 1939 wildfire, direction of streamflow and annual rainfall.

The study area falls within the Victorian Alps and Highlands Northern Fall Bioregions (DSE 2005[online]).

1. METHODS

1.1 Catchment Areas

The catchment areas where selected on the basis of the presence of ash-type forest, percentage of ash-type forest that was affected by the 1939 wildfire, direction of streamflow and annual rainfall. The catchment areas that fulfilled these criteria and analysed within this project were the Upper Goulburn Public Water Supply Area, the Royston/Rubicon, the Acheron, Yea River and Snob's Creek.

1.2 Forest Type and Disturbance

Within this analysis the dominant eucalypt species that were defined as ash-type forest were Mountain Ash *Eucalyptus regnans,* Alpine Ash *Eucalyptus delegatensis* and Shining Gums *Eucalyptus nitens* as defined in previous studies (Reid and Sturgess 1994; Kuzcera 1985). It was assumed where no future forest disturbance data exists that the area clearfelled each year would be a function of area of ash-type forest considering an 80 year rotation. Where these figures did not correlate with previous forest harvesting practises future projections were modified to represent an average of recent clearfelling events.

1.2.1 Existing Information

The most accurate existing records of dominant ash-type species in forest management areas can be sourced from SFRI (State Forest Resource Inventory) data and maps. This data source gives both information on dominant eucalypt groups and previous disturbance history. SFRI maps can be accessed from the DSE website and digitised in ArcView 9.1. and data from DSE.

1.2.2 New Information

The methodology of forest data collection was originally based on gaining information for future harvesting purposes. The SFRI information is based on what resources are available and it is now being applied to analyses that focus on water yield and climate change. The method of forest data collection in the future will most likely be more easily applied to the current forest investigation topics and methods.

1.2.3 Limitations

The SFRI forest data is an incomplete dataset and, as mentioned above, this information is being applied to analyses that were not intended by the data collection and collation method. However, it is currently the most complete and accurate dataset to be applied to this project.

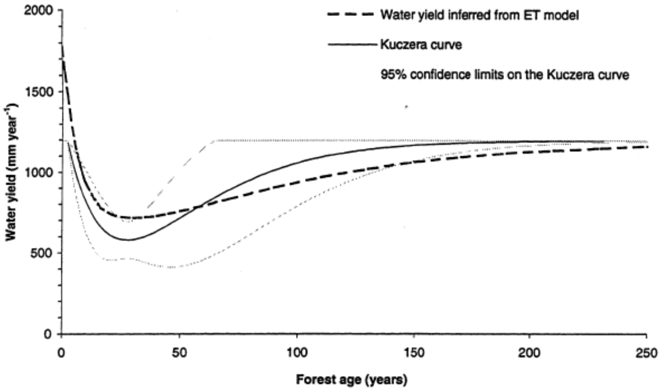
1.3 Modelling

The modelling method chosen for this project was based on the best available data and timeframe of the analysis. The Watson's Water Balance Curve (Watson *et.al.* 1999) is a modification of the frequently quoted and exercised Kuzcera Curve. The Watson Curve defines the initial response of an ash-type forest to disturbance more accurately (Patrick Lane *pers, comm.*; Watson *et.al.*1999). When an ash forest is clearfelled or burnt by wildfire there will be an initial increase in water yield.

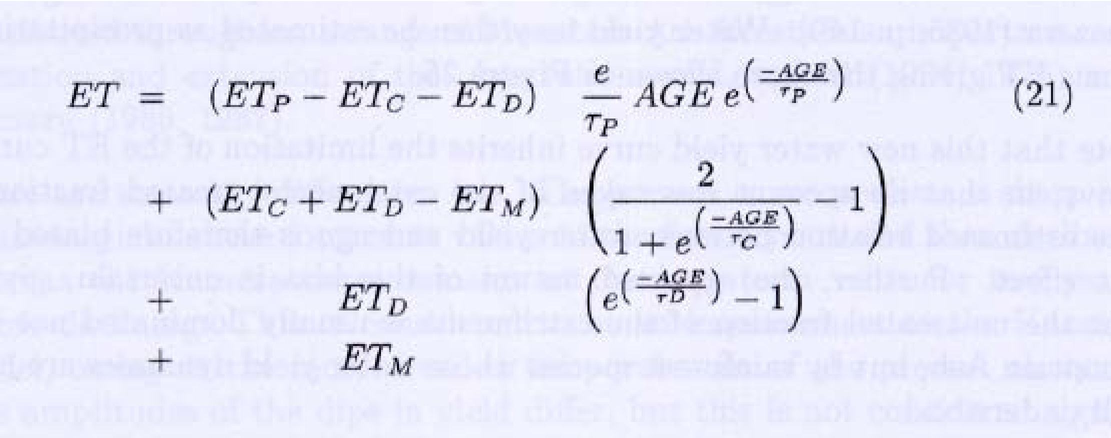
1.3.1 Existing Information

Previous studies including Read Sturgess (1994), Peel *et.al.* (2002), Peel *et.al.* (2000), Hughes (2003), Watson *et.al.* (1999), Zhang *et.al* (1999) and Sinclair Knight Merz (2000) were reviewed. These studies explored static and dynamic modelling approaches to analyse the effect of forest disturbance on water yield. Commonly used models are the Macaque Model involving process-based catchment modelling developed by Dr. Fred Watson. Previous to process-based modelling, water yield in ash-type forests was predicted by an empirical based model, the Kuczera Curve, developed by George Kuczera (1985). The 'Kuczera Curve' shows the relationship of water yield to forest stand age of an ash-type forest (Peel *et.al.* 2000). The curve implies that there is an initial decrease in water yield after disturbance, reaching a minimum at 20-30 years and then gradually increases and re-stabilises at around 100 years (Peel *et.al.* 2000; Watson *et.al.* 1999). The decline in water yield has been correlated to the leaf area index (LAI), which relates to younger ash-type species having a greater leaf area and foliage, therefore a higher evapotranspiration rate. Watson adapted this curve to the Water Balance Curve (1999) to incorporate the initial increase in water yield after forest disturbance; a comparison of the two curves is shown in Figure. 1 below. The parameters used in the Macaque model are based on the Water Balance Curve.

Figure 1. Comparison of Water Balance and Kuczera Curve (Figure 26. Watson *et.al.* 1999)



The Watson curve is derived from on the equation below (Watson *et.al* 1999).

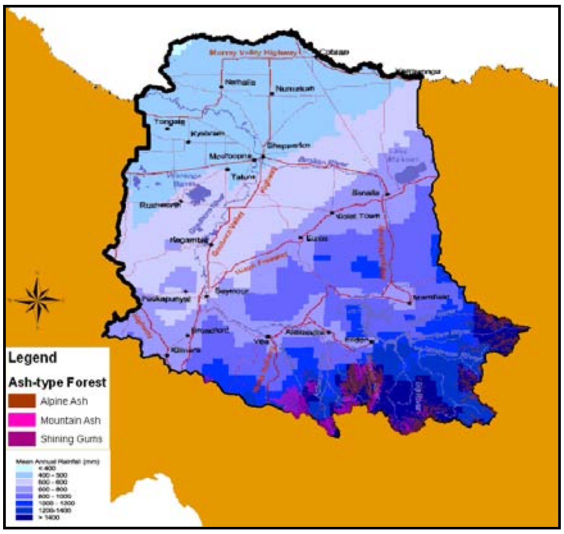


$$\begin{aligned} ET = \; & (ET_P - ET_C - ET_D) \quad \frac{e}{\tau_P} AGE \, e^{\left(\frac{-AGE}{\tau_P}\right)} \qquad (21) \\ + \; & (ET_C + ET_D - ET_M) \left(\frac{2}{1 + e^{\left(\frac{-AGE}{\tau_C}\right)}} - 1 \right) \\ + \; & ET_D \left(e^{\left(\frac{-AGE}{\tau_D}\right)} - 1 \right) \\ + \; & ET_M \end{aligned}$$

As the above models were developed within the Maroondah and Thomson Catchments the annual rainfall assumption of 1800-2000mm was inaccurate for application of the curve to the Goulburn Broken Catchments. The Model parameters were re-calibrated based on rainfall overlays indicating 1600+mm annual rainfall in areas of ash-type forest (Figure 2.) and a study completed by Zhang *et.al.* (1999). Zhang *et.al.* (1999) looked at water yield as a function of evapotranspiration (ET) versus annual rainfall for approximately 250 different forest areas and grasslands (Figure 3.). The ET used in this analysis was scaled proportionally to the change in ET from 2000mm-1600 mm given by Zhang *et.al.* (1999).

Figure 2. Annual Rainfall Overlays on Ash-type Forest

a. Victorian Resources on line **b. Bureau of Meterology**



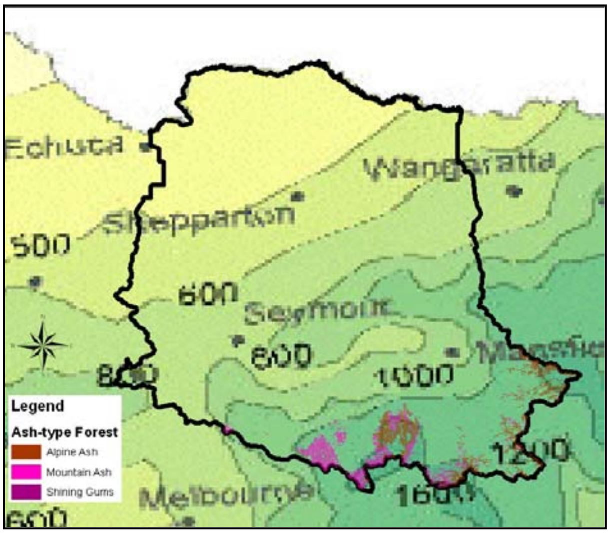


Figure 3. Water yield as a function of ET versus annual rainfall (Zhang *et.al.* 1999)

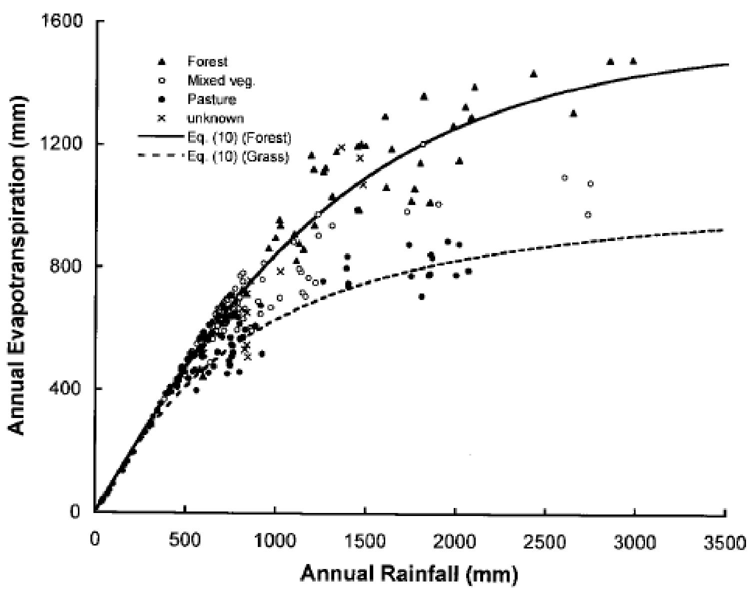


Fig. 10. Relationship between annual evapotranspiration and rainfall for different vegetation types

1.3.2 Limitations

The Water Balance Curve was applied to this analysis considering the available data in the Goulburn Broken Region and the timeframe of the project. Like the Kuzcera curve the Water Balance Curve is an average of various conditions over space and time. Many variables effect water yield such as soil type and depth, climate, geology, understorey and overstorey biomass, rainfall distribution and topography. These variables would not be constant over all the areas looked at in this analysis therefore this empirical model must be viewed in light of these assumptions.

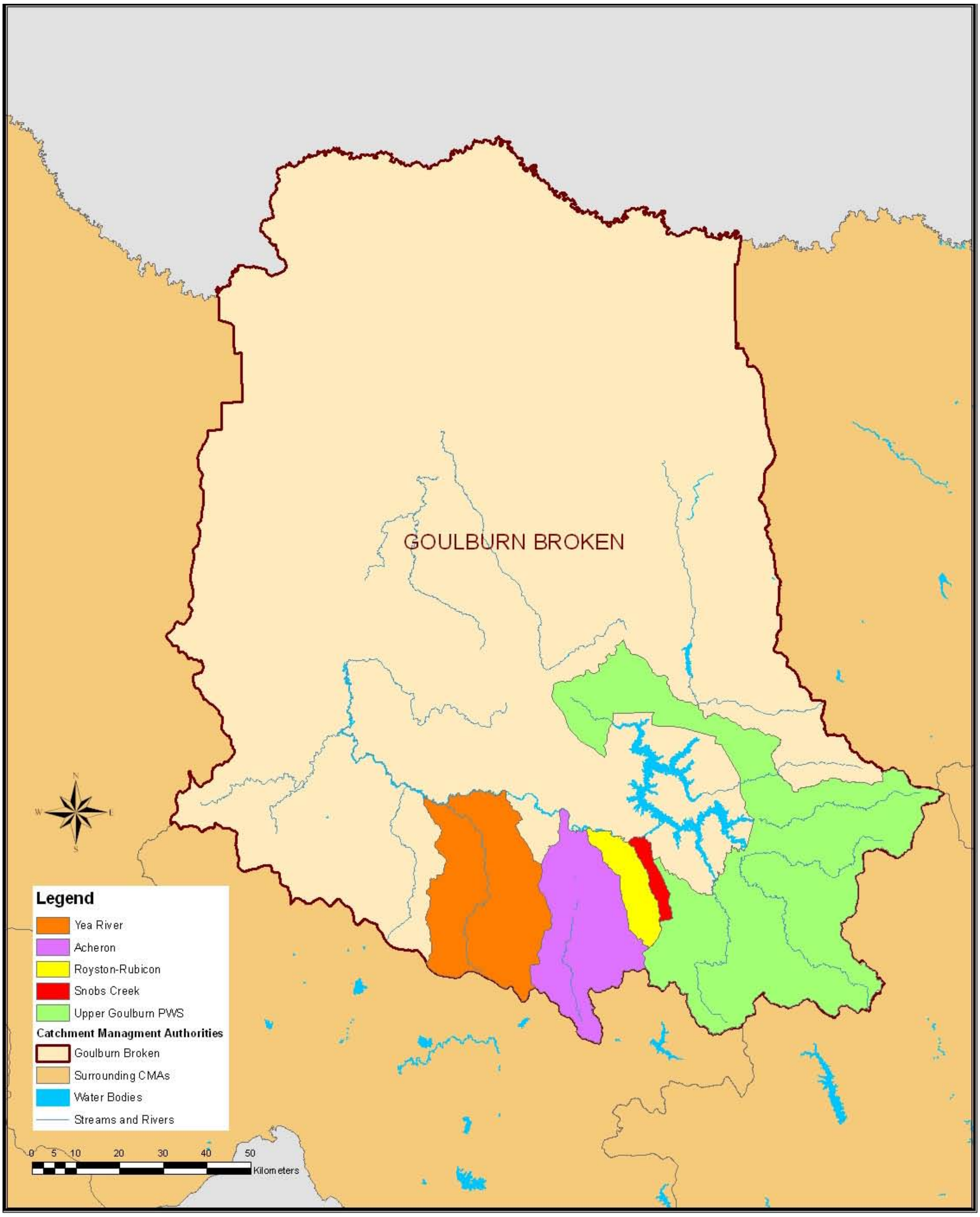
The model did not consider future rotations in terms of forest location, each area cleared was considered to be at the age defined by the last recorded disturbance. In reality areas would be re-logged which would re-start the water use “clock”, resulting in a different water yield sequence for those areas. This would include the initial post-disturbance yield increase.

2. RESULTS

2.1 Catchment Areas

The areas used in this analysis are presented in Figure 4. below.

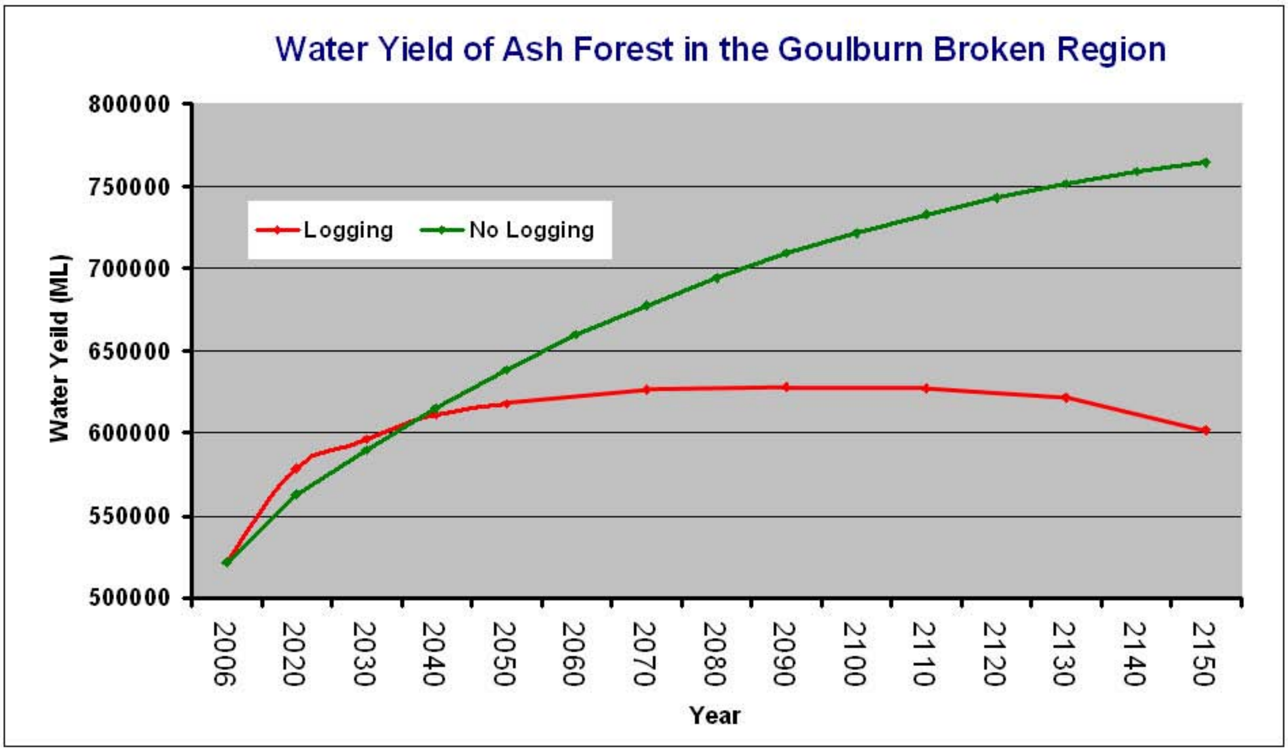
Figure 4. Catchment Areas in Goulburn Broken CMA used in the Analysis



2.2 Modelling

The results of modelling of effect of forest disturbance is summarised in Figure 5. below. Appendix 1. represents a more detailed summary of the all the results below.

Figure 5. Water Yield of Ash-type forest in the Goulburn Broken Region depicting logging versus no logging scenarios 2006-2150



3. DISCUSSION

3.1 Results of Modelling

The Results as predicted indicate that if logging within the ash-type forest continued into the future it would decrease the water yield of these catchment areas. Due to the nature of the Water Balance Curve there is an initial increase in water yield and it is not until 2035 that the no future logging scenario shows a greater water yield. The results are only considering water yield in areas that ash-type forest reportedly exists.

4. CONCLUSION

Current clearfelling logging practices in ash-type forests and bushfires have shown to decrease water yield in catchments. The available modelling methods, such as the Kuczera Curve, the Water balance curve and the Macaque have also proven this with best available data. As methodologies consider more real life parameters and variability the closer we will be to predicting how forest disturbance events will effect of public water supplies and catchments. This current study explored the effect of disturbance on water yield in ash-type forest in the Goulburn Broken catchment which unlike its neighbouring catchments has not been extensively analysed. The models mentioned above were all developed within the Maroondah and Thomson catchments and if they were applied in a different state, country and to different species the results would be questionable. However the Goulburn Broken catchment borders these catchments and using these existing models in this area would provide a plausible estimation of how water yield would be affected by forest disturbance in ash-type forest, subject to the stated assumptions and model uncertainty.

The results presented here do not consider any other future disturbance such as wildfire or the effect of climate change, both of which have the potential to impact profoundly on forest water yield. There is also no consideration of alternative silvicultural techniques to clearfelling, particularly thinning, which may have a different hydrologic outcome.

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APPENDIX 1. Summary of Results

Year	Yield of whole catchment (ML) AREA = 476772.37ha	Yield of ash forest (ML)	Cumulative yield of ash forest (ML)	Yield Cumulative difference (ML)	% Yield Cumulative difference	Yield difference due to logging (snapshot) (ML)	Yield of ash forest (ML)	Yield in year (snapshot) (ML)	Increase or decrease	%
2006	2480123.67737033000	521859.59069614300	521859.59069614300				521859.59069614300	521859.59069614300		
2007	2496219.66127604000	524770.61622056900	1046630.20691671000				524770.61622056900			
2008	2512323.08995000000	527682.98816224400	1574313.19507896000				527682.98816224400			
2009	2528425.52162354000	530595.17979225500	2104908.37487121000				530595.17979225500			
2010	2544518.91010756000	533505.73592389000	2638414.11079510000				533505.73592389000			
2011	2560595.59044583000	536413.27031798900	3174827.38111309000				536413.27031798900			
2012	2576648.26506358000	539316.46317785500	3714143.84429095000				539316.46317785500			
2013	2592669.99038909000	542214.05872970700	4256357.90302065000				542214.05872970700			
2014	2608654.16392782000	545104.86288499700	4801462.76590565000				545104.86288499700			
2015	2624594.51177138000	547987.74098133700	5349450.50688699000				547987.74098133700			
2016	2640485.07652416000	550861.61559899500	5900312.12248598000				550861.61559899500			
2017	2656320.20563259000	553725.46445018900	6454037.58693617000				553725.46445018900			
2018	2672094.54010248000	556578.31833856800	7010615.90527474000				556578.31833856800			
2019	2687803.00359101000	559419.25918645100	7570035.16446119000				559419.25918645100			
2020	2703440.79186057000	562247.41812752100	8132282.58258871000			16458.78160	562247.41812752100	578,706.20	increase	2.92732
2021	2719003.36258260000	565061.97366279500	8697344.55625151000				565061.97366279500			
2022	2734486.42547960000	567862.14987777400	9265206.70612928000				567862.14987777400			
2023	2749885.93279469000	570647.21471881600	9835853.92084810000				570647.21471881600			
2024	2765198.07007779000	573416.47832679100	10409270.39917490000				573416.47832679100			
2025	2780419.24727869000	576169.29142620500	10985439.69060110000				576169.29142620500			
2026	2795546.09013684000	578905.04376803200	11564344.73436910000				578905.04376803200			
2027	2810575.43185891000	581623.16262454500	12145967.89699370000				581623.16262454500			
2028	2825504.30507456000	584323.11133449900	12730291.00832820000				584323.11133449900			
2029	2840329.93406210000	587004.38789710100	13317295.39622530000				587004.38789710100			
2030	2855049.72723522000	589666.52361320400	13906961.91983850000	331861.9361	2.386300746	6722.720967	589666.52361320400	596,389.24	increase	1.140089
2031	2869661.26988274000	592309.08177226500	14499271.00161070000				592309.08177226500			
2032	2884162.31715340000	594931.65638361300	15094202.65799440000				594931.65638361300			
2033	2898550.78727799000	597533.87095064300	15691736.52894500000				597533.87095064300			
2034	2912824.75502135000	600115.37728658100	16291851.90623160000				600115.37728658100			
2035	2926982.44535701000	602675.85437051900	16894527.76060210000				602675.85437051900			
2036	2941022.22735746000	605215.00724244500	17499742.76784450000				605215.00724244500			
2037	2954942.60829329000	607732.56593604900	18107475.33378060000				607732.56593604900			
2038	2968742.22793459000	610228.28444810200	18717703.61822870000				610228.28444810200			
2039	2982419.85304818000	612701.93974326300	19330405.55797200000				612701.93974326300			
2040	2995974.37208459000	615153.33079319400	19945558.88876510000			-4018.88656	615153.33079319400	611,134.44	decrease	-0.65331
2041	3009404.79004864000	617582.27764888500	20563141.16641400000				617582.27764888500			
2042	3022710.22354791000	619988.62054515200	21183129.78695920000				619988.62054515200			
2043	3035889.89601348000	622372.21903627700	21805502.00599550000				622372.21903627700			
2044	3048943.13308727000	624732.95116180400	22430234.95715730000				624732.95116180400			
2045	3061869.35817093000	627070.71264152600	23057305.66979880000				627070.71264152600			
2046	3074668.08813094000	629385.41609874100	23686691.08589750000				629385.41609874100			
2047	3087338.92915500000	631676.99031085800	24318368.07620840000				631676.99031085800			
2048	3099881.57275489000	633945.37948650100	24952313.45569490000				633945.37948650100			
2049	3112295.79191102000	636190.54256823700	25588503.99826310000				636190.54256823700			
2050	3124581.43735428000	638412.45256012400	26226916.45082330000	190779.0223	0.727416899	-20611.59155	638412.45256012400	617,800.86	decrease	-3.22857
2051	3136738.43398052000	640611.09587926800	26867527.54670250000				640611.09587926800			

2052	3148766.77739372000	642786.47173062900	27510314.01843310000				642786.47173062900			
2053	3160666.53057334000	644938.59150430400	28155252.60993750000				644938.59150430400			
2054	3172437.82066211000	647067.47819458400	28802320.08813200000				647067.47819458400			
2055	3184080.83587025000	649173.16584006800	29451493.25397210000				649173.16584006800			
2056	3195595.82249227000	651255.69898414100	30102748.95295620000				651255.69898414100			
2057	3206983.08203283000	653315.13215517500	30756064.08511140000				653315.13215517500			
2058	3218242.96843805000	655351.52936579100	31411415.61447720000				655351.52936579100			
2059	3229375.88542870000	657364.96363056900	32068780.57810780000				657364.96363056900			
2060	3240382.28393218000	659355.51650160400	32728136.09460940000				659355.51650160400			
2061	3251262.65960986000	661323.27762130800	33389459.37223070000				661323.27762130800			
2062	3262017.55047665000	663268.34429191600	34052727.71652260000				663268.34429191600			
2063	3272647.53460993000	665190.82106112000	34717918.53758370000				665190.82106112000			
2064	3283153.22794468000	667090.81932332000	35385009.35690700000				667090.81932332000			
2065	3293535.28215211000	668968.45693595800	36053977.81384300000				668968.45693595800			
2066	3303794.38259891000	670823.85785044900	36724801.67169340000				670823.85785044900			
2067	3313931.24638458000	672657.15175721300	37397458.82345070000				672657.15175721300			
2068	3323946.62045410000	674468.47374435000	38071927.29719500000				674468.47374435000			
2069	3333841.27978345000	676257.96396948900	38748185.26116450000				676257.96396948900			
2070	3343616.02563571000	678025.76734437800	39426211.02850890000	-553220.4258	-1.403179284	-51949.00130	678025.76734437800	626,076.77	decrease	-7.6618
2071	3353271.68388504000	679772.03323179300	40105983.06174070000				679772.03323179300			
2072	3362809.10340664000	681496.91515433800	40787479.97689500000				681496.91515433800			
2073	3372229.15453018000	683200.57051474700	41470680.54740980000				683200.57051474700			
2074	3381532.72755466000	684883.16032729100	42155563.70773700000				684883.16032729100			
2075	3390720.73132267000	686544.84895992500	42842108.55669700000				686544.84895992500			
2076	3399794.09185188000	688185.80388679200	43530294.36058380000				688185.80388679200			
2077	3408753.75102204000	689806.19545075400	44220100.55603450000				689806.19545075400			
2078	3417600.66531532000	691406.19663558400	44911506.75267010000				691406.19663558400			
2079	3426335.80460841000	692985.98284750800	45604492.73551760000				692985.98284750800			
2080	3434960.15101445000	694545.73170576700	46299038.46722340000				694545.73170576700			
2081	3443474.69777313000	696085.62284187900	46995124.09006530000				696085.62284187900			
2082	3451880.44818727000	697605.83770732900	47692729.92777260000				697605.83770732900			
2083	3460178.41460430000	699106.55938935400	48391836.48716190000				699106.55938935400			
2084	3468369.61744111000	700587.97243458200	49092424.45959650000				700587.97243458200			
2085	3476455.08425062000	702050.26268022600	49794474.72227670000				702050.26268022600			
2086	3484435.84882875000	703493.61709257200	50497968.33936930000				703493.61709257200			
2087	3492312.95036038000	704918.22361252100	51202886.56298180000				704918.22361252100			
2088	3500087.43260279000	706324.27100791000	51909210.83398970000				706324.27100791000			
2089	3507760.34310540000	707711.94873240000	52616922.78272210000				707711.94873240000			
2090	3515332.73246442000	709081.44679068200	53326004.22951280000			-81239.31503	709081.44679068200	627,842.13	decrease	-11.457
2091	3522805.65361129000	710432.95560977500	54036437.18512260000				710432.95560977500			
2092	3530180.16113353000	711766.66591621300	54748203.85103880000				711766.66591621300			
2093	3537457.31062702000	713082.76861889400	55461286.61965770000				713082.76861889400			
2094	3544638.15807847000	714381.45469739800	56175668.07435510000				714381.45469739800			
2095	3551723.75927702000	715662.91509557600	56891330.98945070000				715662.91509557600			
2096	3558715.16925391000	716927.34062020900	57608258.33007090000				716927.34062020900			
2097	3565613.44174924000	718174.92184456800	58326433.25191550000				718174.92184456800			
2098	3572419.62870476000	719405.84901668500	59045839.10093210000				719405.84901668500			
2099	3579134.77978176000	720620.31197216700	59766459.41290430000				720620.31197216700			
2100	3585759.94190324000	721818.50005138400	60488277.91295570000	-3454976.033	-5.711810871		721818.50005138400			
2101		723000.60202087200					723000.60202087200			

2102	724166.80599878900		724166.80599878900			
2103	725317.29938428400		725317.29938428400			
2104	726452.26879062000		726452.26879062000			
2105	727571.89998191400		727571.89998191400			
2106	728676.37781336400		728676.37781336400			
2107	729765.88617482400		729765.88617482400			
2108	730840.60793759600		730840.60793759600			
2109	731900.72490432400		731900.72490432400			
2110	732946.41776186900	-106247.19933	732946.41776186900	626,699.22	decrease	-14.4959
2111	733977.86603704500		733977.86603704500			
2112	734995.24805510100		734995.24805510100			
2113	735998.74090086100		735998.74090086100			
2114	736988.52038238900		736988.52038238900			
2115	737964.76099710300		737964.76099710300			
2116	738927.63590022800		738927.63590022800			
2117	739877.31687549900		739877.31687549900			
2118	740813.97430801400		740813.97430801400			
2119	741737.77715917300		741737.77715917300			
2120	742648.89294358200		742648.89294358200			
2121	743547.48770787800		743547.48770787800			
2122	744433.72601136800		744433.72601136800			
2123	745307.77090842000		745307.77090842000			
2124	746169.78393253300		746169.78393253300			
2125	747019.92508200200		747019.92508200200			
2126	747858.35280712700		747858.35280712700			
2127	748685.22399888800		748685.22399888800			
2128	749500.69397902400		749500.69397902400			
2129	750304.91649146000		750304.91649146000			
2130	751098.04369501700	-129588.5086	751098.04369501700	621,509.54	decrease	-17.2532
2131	751880.22615734600		751880.22615734600			
2132	752651.61285004300		752651.61285004300			
2133	753412.35114487100		753412.35114487100			
2134	754162.58681106100		754162.58681106100			
2135	754902.46401362600		754902.46401362600			
2136	755632.12531264200		755632.12531264200			
2137	756351.71166346100		756351.71166346100			
2138	757061.36241779800		757061.36241779800			
2139	757761.21532566000		757761.21532566000			
2140	758451.40653806400		758451.40653806400			
2141	759132.07061052200		759132.07061052200			
2142	759803.34050723600		759803.34050723600			
2143	760465.34760597600		760465.34760597600			
2144	761118.22170360900		761118.22170360900			
2145	761762.09102223500		761762.09102223500			
2146	762397.08221590400		762397.08221590400			
2147	763023.32037788200		763023.32037788200			
2148	763640.92904843500		763640.92904843500			
2149	764250.03022309800		764250.03022309800			
2150	764850.74436140600	-163023.35378	764850.74436140600	601,827.39	decrease	-21.3144

Appendix B – Water vs Wood. Net Present Value Analysis (ACF)

Value of water yields from the Goulburn Broken Catchment under a 'no logging' scenario:

Value of water in 2009 ($/ML):	$2253 per ML[1]
Value of water beyond 2009 – increase based on Consumer Price Index:	2.5% increase per annum
Water yield volumes:	Taken from Practical Ecology report – Appendix A
Total water yield from study area over 100 year period with no logging:	65,462 GL
NPV of total water yield from catchment under a 'no logging' scenario over 100 year period (2% discount rate):	$188,902,391,295 ($188.9 billion)
Total *additional* water yield from study area over 100 year period with no logging:	3,807 GL
NPV of total *additional* water yield compared to business as usual logging under a 'no logging' scenario over 100 year period (2% discount rate):	$1,683,023,978 ($1.68 billion)

NPV of total *additional* water yield above business as usual logging under a 'no logging' scenario over 80 year period – decade by decade breakdown (2% discount rate):	**Years:**	**Net Present Value:**
	2010-2019	-$200,556,107
	2020-2029	-$245,747,928
	2030-2039	-$38,266,764
	2040-2049	$230,763,011
	2050-2059	$568,445,526
	2060-2069	$888,446,335
	2070-2079	$1,191,998,596
	2080-2089	$1,490,751,111

In order to calculate the NPV of water and carbon over a long time frame (100 years), we undertaken research to choose an appropriate rate of discount. Analysis for this report has applied a low discount rate of 2% in keeping with precedent set by leading global reports on costs of climate change – both the UK Stern Review and Australia's Garnaut Review.

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[1] Based on a $2253/ML price as reported in the GHD report to the Department of Environment, Water, Heritage and the Arts - *Murray-Darling Basin Water Entitlements summary of market prices (approved transfers).* Price is for Victorian Goulburn high reliability entitlement, at an average price for the first half of 2008/09.

In both of those reviews, a discount rate of close to zero was considered appropriate for the long term environmental impact of climate change (0.05% in Garnaut Review)[2]. Both authors argued that when considering long term impacts, the welfare of future generations should not be considered less valuable to those of us alive today. The impact of water availability and carbon emissions both have an equal importance to all humans whether today or in 50 years time. Due to the applicability of this theory to water and carbon over a century, we have followed the precedent of Stern and Garnaut in choosing a low discount rate, however, in order to remain conservative, we have chosen a 2% discount rate, rather than 0.05% to reflect the natural human tendancy to value today above tomorrow.

For consistency in our analysis, we have applied the same low discount rate to timber values. This presents a different probelsm, however, in that timber is being extracted by a government business enterprise charged with making a profit from Victoria's natural resources. In reality then, VicForests should be undertaking their business decisions based on a discount rate closer to 6+% (it could be argued up to 10%). However, to make the three assets of water, carbon and timber comparable, we have applied the same low discount rate for all three assets.

Value of timber harvested in Goulburn Broken Catchment under a business as usual logging scenario:

Hectares harvested per annum:	500 hectares
Sawlogs harvested per annum:[3]	50,000 m3
Residual timber harvested per annum:	135,000m3
Average cost sawlog:[4]	$100/m3
Average cost residual:	$10/m3
Value of timber beyond 2009 – increase based on Consumer Price Index:	2.5% increase per annum
NPV of timber harvested over 100 years at 500 hectares per annum (at 2% discount rate):	$811,118,345

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2 Garnaut, R. (2008), Garnaut Climate Change Review Final Report page 18.

3 Timber volumes taken from internal ACF research based on VicForests own publicly disclosed information

4 Timber prices taken from publicly available timber auction results – sawlogs average auction results 2006; residual average prices paid by Midway

Appendix C - Analysis of the Value of Carbon sequestration potential (ACF)

Additional value of carbon in the Goulburn Broken Catchment above business as usual under a 'no logging' scenario:

Total carbon per hectare:	640 tonnes
Total carbon sequestered per hectare per annum:	12 tonnes
Total CO2-equivalent sequestered per hectare per annum:	43.2 tonnes
Total forest logged per annum:	500 hectares
Total tonnes CO2-equivalent sequestered in year 1 under 'no logging' scenario:	21,150 tonnes (per 500 hectares per annum)
Price of carbon – 2010 – 2050[1] - Based on Treasury modeling – low carbon reductions scenario of -5% by 2020:	$20 - $115
Price of carbon post-2050 – indexed to Consumer Price Index	2.5% per annum
NPV of total additional carbon sequestered by forests under a 'no logging' scenario over 100 year period (at 2% discount rate):	$6,152,322,601 ($6.15 billion)

Summary of value of carbon using indicative 10 year values (modeling has been undertaken annually):

Year:	**Carbon price, based on Treasury modeling figures ($ per tonne)**	**Value of carbon sequestered per annum:**
2010:	$20	$0.85 million
2020:	$35	$8.88 million
2030:	$62	$28.85 million
2040:	$89	$60.24 million
2050:	$115	$102.15 million
2060:	$147	$161.90 million
2070:	$188	$247.10 million
2080:	$247	$381.74 million
2090:	$309	$535.52 million
2100:	$395	$769.11 million

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[1] Treasury (2008), Australia's Low Pollution Future, based on data under the low CPRS-5 scenario (5% reduction by 2020)

Appendix D

Old-growth forest, water and climate change -
Some scientific understandings.

Old-growth

Old-growth forests are an important part of Victoria's natural heritage. They contain many of Australia's endemic plant and animal species and, as such, contain unique communities found nowhere else in the state. However, they have been systematically destroyed by logging and clearing over the past century. Since European settlement, 65% of Victoria's forest cover has been cleared and much of that has been old-growth forest.[1]

Logging began during the gold rush days of the 1840's and from this time up to the 1950's most logging was selective, with individual trees felled and removed. The modern method of clearfelling entire forest stands started in the 1960s this process removes nearly all of the trees from a selected area.

The logging of old growth forests directly leads to the destruction and the direct removal of habitat needed for the survival of old-growth forest dependent species. The destruction of habitat through activities like logging has been identified as the main past (and present) cause of biotic endangerment and extinction in all vegetated countries on Earth. [2] [3] [4] [5] [6]

Logging does not simply destroy habitat - it leads to the fragmentation of continuous species' population into a series of small residual populations. Research has shown that these isolated pockets of populations are far more susceptible to extinction through processes associated with genetic inbreeding and increasing vulnerability to the effects of fire and disease. [7] [8]

In Victoria, the permanent loss of old-growth forest habitat has led to a serious decline in both the abundance and distribution of many plant and animal species.[9] It has been found that many plants and animals simply do not come back after logging operations have taken place.[10] Many of these species are supposedly protected by state and federal law, including the Leadbeaters possum, Long footed potoroo and Spotted-tailed quoll.

The present reserve system, that attempts to protect species against processes that drive extinction has been criticised extensively by the scientific community. [11] [12] Currently, in Victoria, 15% of each forest type is set aside to ensure biodiversity is maintained. This level of reservation is insufficient for securing the conservation of Victoria's biodiversity for a number of reasons:

- A large number of species simply do not occur in a protected forest and therefore have no protection status.

- Even the largest old-growth forests in Victoria are too small and vulnerable to broad area disturbance. The long-term survival of populations of threatened species within the present Victorian National park is now limited as a consequence of the fire.

- The relative isolation of many old-growth forest reserves to its neighbours is another significant limitation. The exchange of individuals of threatened species within the reserve system is necessary to overcome problems associated with genetic inbreeding, yet many reserves are too isolated for this

> gene flow to occur. The small size and isolation of reserves do not leave much scope for plants and animals to adapt to long-term climate change, either through dispersal or by evolution.

These issues mean that a complete reassessment is necessary if the species inhabiting old-growth forests are to persist in the future. This is not the only reason such a reassessment is required. Fire is an ever present issue for wildlife and humans inhabiting Victoria and the processes of logging of old-growth forests contribute to an increase in the frequency and intensity of fires. This is because logging reduces the resistance of these forests to fire. The process changes the very nature of the forest's microclimate, resulting in a change in plant composition and structure. An old-growth forest goes from a fire resistant 'wet' forest to a much 'drier', fire-prone ecosystem. [13]

The present conservation strategy for Victoria makes little or no attempt to synthesize the parts of each threatened ecosystem into a working whole. It is not valid to assume that just because certain elements are included in a reserve system, the entire ecosystem is protected and that biodiversity and ecological processes that the forest provides will somehow be preserved in the long term. Perhaps more importantly, the current reserve system does not take into account climate change at all. It is now believed that accelerated anthropogenic global climate change will be the major driver of biodiversity change and species extinctions in the near future [14] [15] [16] [17] [18] [19] [20] and that the process has already contributed to species extinctions [21] [22] [23] [24] [25] [26]. Species are expected to respond to the changing climate by migrating to track the environmental conditions to which they are adapted. [27] [28] [29] [30] [31] [32]

This means that the only way species will survive the influence of climate change in Victoria is to ensure that connectivity within the landscape is maintained. There must therefore be suitable habitat sufficiently connected to enable threatened animals to move between isolated pockets of old-growth. If species are unable to track their distribution among old-growth forest remnants when local changes in the climate occur, then local extinction will be the only outcome.

The current system of island like parks in Victoria cannot meet the needs of many species, or enable the dispersal and re-establishment of wildlife following events associated with climate change. The protection of biodiversity within old-growth forest ecosystems is a complex problem and requires detailed analysis. Protected areas need to ensure that viable populations of individual species occur across their entire range, and that adequate contact between these populations is maintained to allow genetic interchange and to overcome inbreeding while allowing evolutionary processes to continue. [33] Enough suitable habitat must therefore be maintained, in the right locations, in adequate amounts and in a connected manner to allow this to occur.

In Eastern Victoria according to the most recent data available only 668,396 ha (DSE Modeled Old-growth coverage) of old-growth forest remains this is only about 10% of the land area. The vast majority of this area was forest and woodland at the time of European settlement.

As a result of logging a major loss is that of the number of trees containing hollows. It normally takes around 100 years for hollows to begin to form in eucalypt species[34] and logging is systematically removing this age class from the public native forests. Tree hollows are needed by 98% of Victoria's animal species for shelter and breeding. [35] The resulting decrease in the number of available hollows will move species closer to extinction. [36] We often think of extinction as an end point where a species is no longer found on the planet. This is however not the case. There is a scale along which a species moves towards this particular point.

Logging radically alters the structure of the forest – the number of big old trees with hollows, the number of fallen logs, the density of the understorey and the canopy vegetation. It also alters the floristic structure of the forest – the number, type and density in the forest. Logging can also create conditions which promote the spread of pest animals and weeds and increase the probability, frequency and severity of fire. Consequently, many plants and animals are now absent from the forest. [35]

Research by botanists Keely Ough and Murphy from the Victorian Department of Conservation and Environment (now Department of Sustainability and Environment), found that four common shrub and tree species never returned after logging. Tree ferns are also mostly eliminated by logging. These tree ferns play a vital role in maintaining the moisture of the forest floor and providing protection for the growth of other forest plants. [37]

These magnificent old-growth forests which pre-date the arrival of the first European ships will not regenerate to their original state for between 1,500 and 2,500 years. [38]

There is now a need to expand the definition of old-growth forest to include the class "late mature", as many of the last remaining stands of old-growth forests have been removed from the Victorian landscape over the last decade. If species are to survive the onset of climate change in our changed landscape it has become evident that the preceding age class to 'old growth' must be included in the old-growth definition.

This preference has also been advocated by forests managers. The technical report by Natural Resources and Environment in 2000 A *Study of the Old-growth Forests of East Gippsland* stated that the preference should be extended beyond old-growth forest to negligibly-disturbed younger forests and forest with a mature growth stage which have the potential to become the old-growth forests of the near future. The long term conservation of old-growth forests must therefore include a wider class range. There are many natural processes constantly shaping and re-shaping the extent and characteristics of these forests. New areas will be recruited as trees reach their older growth stages or as the effects of past disturbance become negligible. [39]

Water

Water is Australia's most precious and scarce resource. The Wilderness Society considers that three major factors will potentially have dire effects on water supply. Namely, increasing public demand in both rural and city regions, climate change and continuing land clearing and logging in water catchments.

Victoria is in a water shortage crisis, and old-growth forests produce far cleaner and high volumes (around 12 megalitres of water per hectare per year) than regrowth[40] forests. Logging is extensive in the rain-soaked upper catchments of the rivers that supply water to Melbourne, to the irrigation districts of West Gippsland and to the stressed rivers of the upper Murray.

A key challenge facing Victoria is the management of water resources to ensure that we have sufficient clean clear water in the future. To do this sustainably we need to look beyond old solutions, such as the building of dams and continually extracting more water from river systems.

As our demand for water continues to increase and with the added pressure recent drought years have placed on available supply, concerns within the general community are growing.

If Melbourne's water consumption continues to grow at present rates, it is projected we will be using all available water by the year 2012.[41] Stream flow reductions due to logging will compound other changes to the reliability of stream flow expected as a result of climate change. [42] [43]

In order to achieve long-term water sustainability we need not only to focus on demand management, but more importantly, on resource management in order to achieve maximum resource yield and quality for all end users.

Protecting water catchments has shown to be economically beneficial to the community. For example, The New York Department of Environment and Conservation estimates that the expenditure of US $1.5 billion in catchment management has allowed the City of New York to cancel proposed water treatment plants with an estimated cost of US $6.7 billion. [44]

Water for consumptive use in Victoria is taken from reservoirs, streams and aquifers under entitlements issued by the Victorian Government and authorised under the *Water Act 1989*.

Generally, water for consumptive use is allocated to either water authorities, who are granted bulk entitlements, or to individuals who are issued a license. Exceptions to this include private power generating companies in the Latrobe Valley, which hold bulk entitlements, as does Southern Hydro, and the Minister for Environment.

Water authorities also have licenses to extract surface water and groundwater to supply urban areas. There are also many situations in which private individuals have the right to take water for domestic and stock use without a license (e.g. from a farm dam or a groundwater bore).

Table 3-1 Water allocated for consumptive use in Victoria (State Water Report 2003-2004: a statement of Victorian water resources DSE June 2005)

Entitlement Total (ML)

Surface Water

Bulk entitlements (1)	4,619,970
Licenses (2)	233,300
Private right (farm dams) (3)	512,670

Groundwater Licenses	804,065
Total water entitlements	6,170,005

The supply of clean water is emerging as one of the biggest, possibly the biggest issue the world has to face over the next 50 years.[45]

Research has conclusively shown that logging adversely affects water yield. [46] In the Thomson catchment logging operations have already, and will have in the future, considerable implications for the supply of water to Melbourne. If logging were phased out of the Thomson catchment by 2020, this would result in a saving of 20,000 ML per annum by the year 2050 [47] .

As water becomes scarcer in future years, it will become increasingly important to protect this resource. Water is far more valuable to the community than native forest wood, for which there are existing plantation alternatives. [48] [49]

It is generally agreed that, Australia-wide, insufficient long-term funds are being committed to Integrated Catchment Management (ICM). [50] It is estimated that potential agricultural production foregone due to land and water degradation could be as high as $0.6 Billion a year in Victoria [51].

Government bodies or water authorities could either buy out the sawlog licenses, compensating saw millers, employees and contractors, or procure wood requirement from plantations should they be available. The protection of water catchments would not only result in increased water yield but would also have environmental gains.

A cessation of logging in water catchments would increase water yield to rural communities. Catchments need to be protected to prevent changes in water quality, volume, salinity and nutrient levels. Maintaining intact healthy catchments will assist rural communities in their attempt to buffer themselves against drought.

The Victorian Infrastructure Planning Council discussed a couple of principles that could be applied nationally to catchments. Managers should have a duty of care to not damage the resource, but where damage occurs the responsible party, if identifiable, should pay. It was also recommended that improvements should be paid for by government. Assisting a transition out of headwater catchments and into lowland plantations would not only improve catchment health, it would result in increased water yields to all.

Management of Water Resource

A recent Strategic Water Review undertaken in Melbourne found that if catchments were logged, a decrease in water yield would result.[41]

Principles governing the implementation of catchment management in Chapter 5 on Water in the Victorian Infrastructure Planning Council document of 2002 [52] state that

- A duty of care not to damage the natural resource base (remedying any damage incurred) by users and managers of the natural resource;
- Beneficiary pays, where it is not possible to identify the cause of damage; and
- Government contributions, where activities generate public benefits for both existing and future users. The Government has undertaken to meet the cost of statewide planning, resource; monitoring and assessment, research and investigation where they are crucial to sustainable resource management.

The logging taking place in many of Victoria's water catchments is leading to severe damage to catchments in Victoria and substantial reductions in water supply. [53] Instead of responding in the traditional way by harvesting more water or building more dams, we could extract more water from catchments simply by ending logging in these areas.

Research on water yield in Alpine Ash/ Mountain Ash/ Mixed Species Forests

Several studies undertaken across Australia have investigated the effect logging has on water yield, determined by forest type, soil, rainfall and soil depth. [54] The most comprehensive study was undertaken by Kuczera (1985) after the 1939 wildfire in the Central Highlands. This study found that burnt or logged areas experience a reduction in water yield.

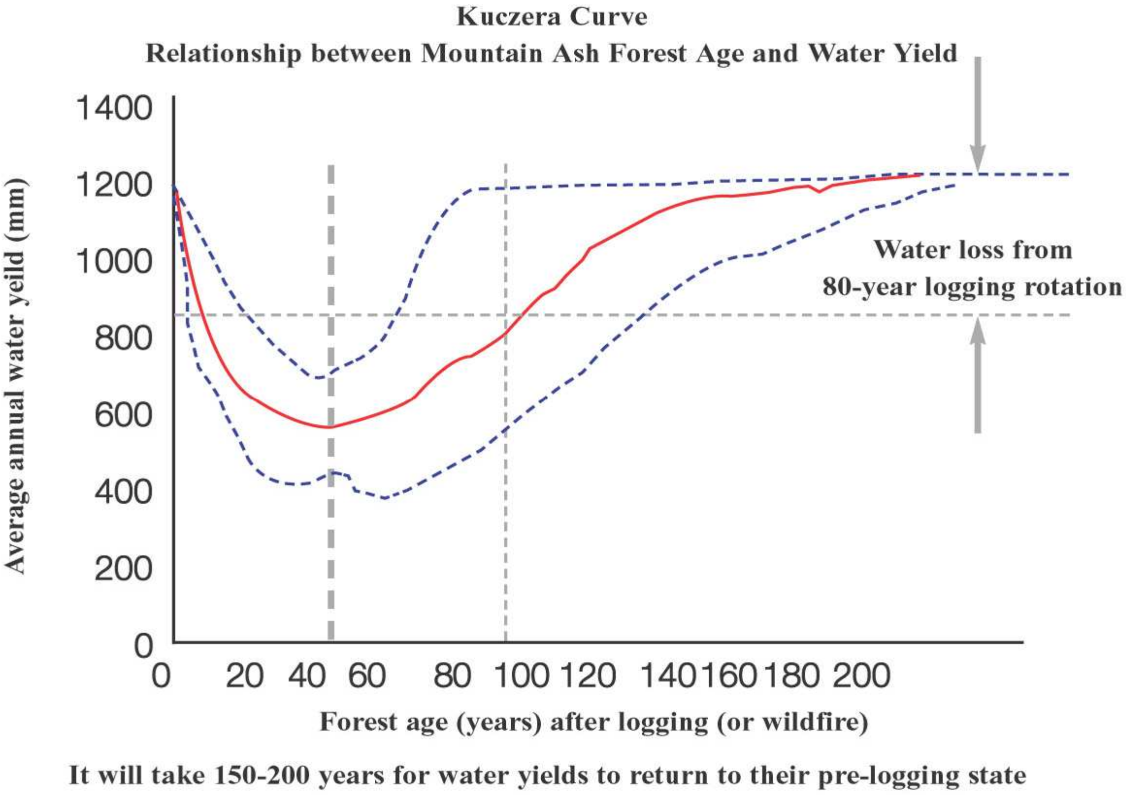

Figure 1: Correlation of annual water yield and forest age

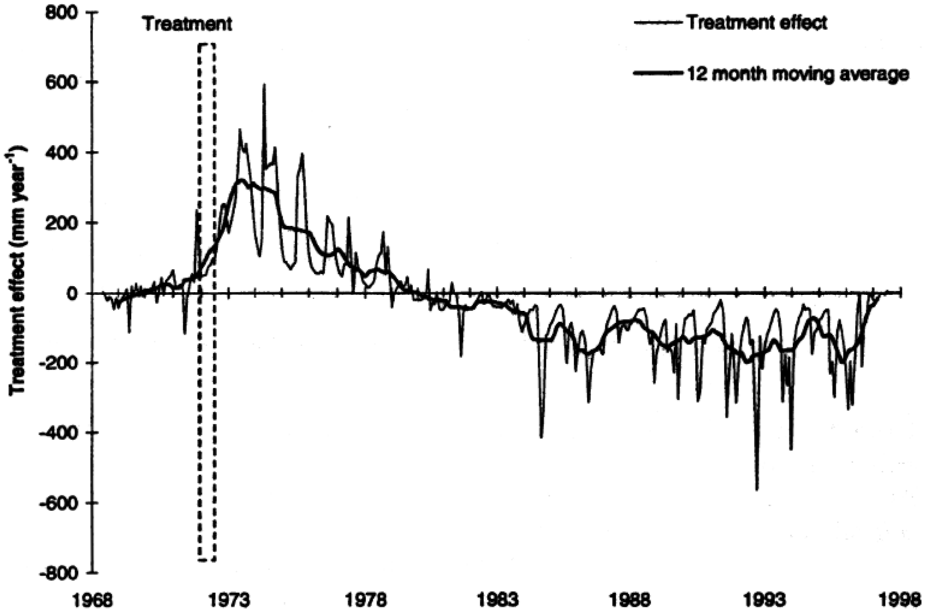

Figure 2. Treatment Effects on monthly stream flow at Picaninny [55] .

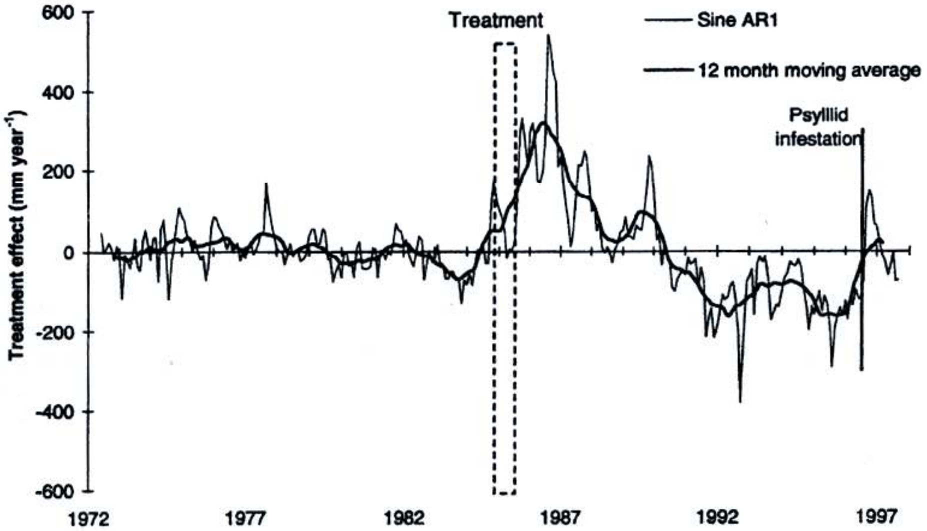

Figure 3. Treatment effect on monthly stream flow at Myrtle 2 [56]

Once logging takes place and the area is burnt, there is an initial increase in water yield as rain falling runs straight off the cleared areas and into adjacent streams. However, after 5-10 years water yield drops drastically as young forests begin to grow. These young forests have high evapotranspiration rates (they consume large volumes of water during their growing phase). It takes approximately 150 years for water levels to return to those experienced prior logging.

Further studies comparing the effect logging has on water yield have corroborated this early research. [40] The length of the logging rotation has a particular effect on the water yield of a catchment. In ash type forests, a rotation length of 50 years produces the maximum reduction in water yield. In the Thomson and Yarra Tributary catchments the logging rotation is 60 years or less [56] , not 80 to 120 years as recommended in the Comprehensive Regional Assessment. [57]

Historically, not much is known about the correlation between forest age and water yield in mixed species forests. However, recent research in the Tantawanglao Creek Catchment in New South Wales has shown that logging has a detrimental effect on water yield. [58]

There are several research studies undertaken throughout Victoria and NSW which highlight the detrimental effect logging has on water yield [Coranderrk];[59] [60] [61] West Kiewa Study [62] Delegate River Study [63] and a study on aquatic plants to measure stream flow decline, the Otways Moran Study]. [54]

Further Research on water quality

The Victorian Infrastructure Planning Council [64] states that water quality is intrinsically linked to the health of Waterways and Catchment Management. Sediment sources were then identified as the primary cause of the water quality decline.[65] The researchers identified the two main sources of sediment likely to be contributing to the water quality decline as agriculture and logging. [66] Decreased water quality, such as increased sedimentation and turbidity (suspended sediment) are known to reduce the effectiveness of filtration and disinfection – requiring higher level treatment at greater cost. Although several practices are employed by the Department of Sustainability and Environment to ameliorate these impacts, the attempt to evaluate the effectiveness of these measures is minimal.

Many streams that flow for less than 90% of the year are termed non-permanent, as a result these streams do not have filter strips [67], logging therefore takes place right up to the edge of the stream, resulting in an increase in temperature as well as sediment load. Solar radiation, responsible for stream temperature, will increase in these exposed streams, with a detrimental effect on the breeding cycle of many temperature sensitive species. [68]

Forestry practices contribute significantly to the sedimentation of streams and lakes. Sediment production rates of 90 tonnes/ha/annum have been measured from roads in the Maroondah catchment in the Central Highlands.[69] Erosion rates of120 tonnes/ha/annum have been measured from log landings in the Cuttagee catchment in NSW. [70] These enormous movements of sediment are a clear risk to water quality.

Regeneration burns further compound the decline in water quality. When regeneration burns occur the soil is dramatically heated. The heating of the soil causes the soil to become less permeable to water resulting in increased runoff. Eucalypt forests appear particularly prone to this phenomenon. [40]

The Financial Cost of logging water catchments

The logging industry does not pay for the loss of water; it is paid for by the Victorian community. The logging industry has therefore gained subsidized access to water because the overall decline in supply is not factored into the price of logs removed. This means that alternative sources, such as plantations and farm forestry, must unfairly compete with catchment wood resource.

Water lost due to logging has an economic value. A study of future options for harvesting logging and harvesting water from the Thomson catchment [48] (largest of Melbourne's catchments) revealed that the value of water from catchment outweighs that of the wood in the forest. Extending the current harvest rotation from 80 to 200 years increases the catchments net present value by $81 million, while shorter 20-year rotations would decrease it by $525 million and requires the building of a $250 million water treatment works (Prime Ministers Science, Engineering, and Innovation Council, 2002 this is from a 1994 report cited in this document). Present logging rotations are 60 years or less, according to the Department of Primary Industries Wood Utilization Plans.

Forests as carbon stores

It is becoming increasingly clear that logging of old growth forests is not a 'greenhouse neutral' process. Old growth forests have been found to play an extremely important role in acting as a carbon sink at regional and continental spatial scales, and hence, their conservation would be an important step in ameliorating the impacts of climate change.[71] In a seminal study of the impacts of logging on old growth forests conducted, the authors showed that logging of forests in the Styx Valley (an old growth forest in Tasmania) would produce approximately a thousand tonnes of greenhouse gases per hectare.[71] In simpler terms, clearing 1000 hectares of Styx old growth forest would produce greenhouse gas pollution equivalent to all the cars in Tasmania in a year. The authors also found that undisturbed old growth forest can store up to 1500 tonnes of carbon per hectare. [71] Logging greatly reduces the carbon stored in the forest to levels much lower than levels estimated after severe wildfire. Stand replacement wildfires left between 1000 and 1100 tonnes of carbon stored per hectare. After successive logging scenarios, it was found that carbon stored in a regenerating forest could be reduced to around a total of 485 tonnes per hectare.

These results reflect a review of the global literature[72], which found the amount of Carbon stored in the forest ecosystem to be related to the age class of the forest. There are a number of associated reasons why logged forests contain far less carbon than old growth forests:

(i) logged forests have relatively more frequent fires that emit gaseous carbon,
(ii) when a forest is logged, wood products are not returned to the soil,
(iii) logged forests often contain a vegetation understorey that is under-developed when compared to old growth forests and
(iv) trees in logged forests often only grow to around 60% of the size they would in an old-growth forest.
(v) forest soils can also lose carbon due to logging because of:
  (a) a loss of nutrients,

(b) changes in the physical properties of the soil due to disturbance by logging machinery,
(c) changes to the microclimate as a result of the loss of forest canopy.

Protecting our old-growth forests will make a significant contribution to keeping carbon sequestered rather than volatilized to the atmosphere as smoke and methane.

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