Logging and Water in the Lake Merrimu catchment:
Implications for the supply of water
to Melton and Bacchus Marsh

A Doctors for Native Forests report.
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Summary

Melton and Bacchus Marsh are facing a shortage of water. The main source of supply to these communities is currently Lake Merrimu reservoir. In the longer term, with increasing demand, the ability of Merrimu to supply the water consumed will become increasingly problematic. The connection of these townships to the Melbourne water supply should not be seen a full resolution of the problem, as Melbourne also faces a shortage of water.

Water resource assessments in the region have not taken into consideration the possible effects of global warming on water supply, nor the potential effects of forest management practices, and in particular logging.

In other Australian regions, logging has been shown to reduce water yield from forested areas by up to 50%, 30 years after logging and is projected to take 150 years to return to pre-logged levels. This water loss results because mature forests use very little water, allowing large amounts of water to flow into streams and catchments, while a new growing forest after logging uses large amounts of water, leaving little left over to flow into streams and water supplies.

A modelling framework is developed to explore the potential effect of historical and projected logging within the Lerderderg catchment, which supplies Merrimu Reservoir. The basis of the model is the forest age/yield curve published by the Department of Natural Resources and Environment (NRE) in O'Shaughnessy et al. (1996). The NRE age/yield model is the best available estimate of the extent to which logging may change water yield in the mixed species forests of the Wombat forest.

The modelling reveals that a significant reduction in water yield may occur in the Lerderderg catchment due to logging. The potential yield loss due to logging is estimated at 1920ML per annum should logging continue at current rates, and assuming that logging returns to each area on a 80 year rotation. This water loss is relative to what the forest would produce should it be permitted to mature. This volume of water is equivalent to over 80% of the water used by Bacchus Marsh in a normal year. The maximum annual water loss to logging was projected to be 3500ML in the year 2025, relative to that produced should the forest be permitted to mature.

This potential volume of water lost provides an indication to land and water managers, and the townships of Bacchus Marsh and Melton of the plausible implications of logging within the Lerderderg catchment. The significant scale of the projected water loss highlights the need for an extensive study into logging in the Lerderderg catchment, and the need for logging practices to be taken into consideration when assessing water resources and catchment management in the region.

1. Background

For some decades, there has been concern in both the scientific and general community over the implications of logging in forested water supply catchments. In the Wombat forest region, limited hydrological study has taken place into the effects of logging on water.

2. Data and Methodology

Climactic and hydrological data was primarily sourced from the Bureau of Meteorology and Department of Natural Resources and Environment. Land use information was underpinned by State Forest Resource Inventory (Department of Natural Resources and Environment) and Regional Forest Agreement (Commonwealth and Victorian Regional Forest Agreement Steering Committee) base maps. Topographic information was sourced from Survey and Mapping Victoria 1:25 000 maps. All land use cartography was calculated with a CAD system.

The water/forest age yield curve used in this report was published by the Department of Natural Resources and Environment (NRE) in O'Shaughnessy et al (1996), and currently represents the best estimate of potential water losses after logging in the region. The yield curve was intended to provide an indication of the potential extent of water yield impact, if logging practices were used that removed all trees in a logged area, followed by full stock rates of eucalypt new growth. The O'Shaughnessy et al. (1996) yield curve has been used because logging systems used in the Wombat (shelterwood, seed tree and clearfell) closely approximate this intensity. Although forest age/yield curves are a simplification of complex natural forest catchments, they are widely used to predict water yield changes after logging throughout Australia and in other countries. A simplistic modelling framework has been developed, then applied conservatively and should be appropriate to the quality of data input, and the assumptions underpinning the yield curve itself.

3. Lake Merrimu's limited supply to Melton and Bacchus Marsh

The supply of water to Melton and Bacchus Marsh is essentially limited to a 21 000 ML allocation from Merrimu (with a temporary additional allocation of 20% during drought conditions) and a further 980ML from the smaller Djerriwarrh Reservoir. The ability of this limited supply to meet demand will become increasingly problematic with growth in the region, and is likely to be further reduced by global warming and catchment management practices such as logging. In the short term, the construction of a pipeline to the Melbourne water supply system will significantly ameliorate the regions shortage of supply, however Melbourne's water supply should not be perceived as a bottomless source. Melbourne also faces a water shortage – and, if consumption continues at current rates, is expected to be using all of its current supply capacity by the year 2012.

The main source of water for Melton, Bacchus Marsh, and the smaller townships of Rockbank and Toolern Vale is Lake Merrimu. The water to Merrimu is directly supplied by Coimadai Creek (also known as Pyrites Creek), and by a 1.6km transfer tunnel from Goodmans Creek. A further 4 km tunnel transfers water from the Lerderderg River to Goodmans Creek, discharging water above the first tunnel for transfer to Merrimu.

Lake Merrimu also supplies water for agricultural use. When full, the water in the Lake is shared as follows (Western Water 2000):

	%	Million Litres (ML)
Western Water (Melton, Bacchus Marsh, Rockbank, Toolern Vale)	60	21,000
Southern Rural Water (Agricultural use)	20	7,000
Unallocated	20	7,000

Djerriwarrh Reservoir also supplies a relatively small amount of water to Melton, Bacchus Marsh, Rockbank and Toolern Vale. Djerriwarrh has a storage capacity of 980 ML or less than 3% of the Merrimu storage.

The demand for water in these townships is currently 6500ML/year but this can increase to 7500ML/year during a dry year (Split 65% Melton and 35% Bacchus Marsh) (Western Water 2000).

The supply of water to Merrimu is limited, and therefore the supply to these townships is limited. In times of drought the demand for water has exceeded this limit, such as in October 2000 when the water level of Merrimu dropped to only 23%. At that time it was anticipated that although water restrictions had been initiated for all customers supplied from Lake Merrimu from October 1998, if drought conditions continued, Melton and Bacchus Marsh would run dry before December 2001 (Western Water 2000).

The heavy rains in late October 2000, which allowed water restrictions to be lifted in November 2000, and a grant of 7000 ML of unallocated water in May 2002 have delayed, not solved, this crisis. While the lifting of water restrictions may have tended to lower awareness of water as a crucial issue in the region, the regions water shortage not only remains, but is effectively worsening.

In the longer term, the shortage of supply will become increasingly problematic with growth in consumption. Both Melton and Bacchus Marsh are experiencing population growth, and are also actively seeking to attract business and employment to the region. It is estimated that Melton's and Bacchus Marsh's demand for water will grow at 2 to 3% each year (Western Water 2000). Economic development in the region essentially depends upon the availability of water.

A number of options have been investigated to ameliorate this shortage of supply, as part of the 'Melton & Bacchus Marsh Water Resources Review'. including:

- purchase water from Melbourne Water and deliver to Melton via a pipeline
- purchase additional water from irrigators through trading water entitlements
- increase the amount of water harvested from the Lerderderg catchment by improving the Goodmans Creek tunnel and weir system
- raise the concrete spillway at Lake Merrimu and increase the storage level by 2.0 metres
- increase the storage of the Lake Merrimu by raising the embankment 9.5m to its ultimate design level

The option supported by the Western Water board is the building of a new 16km long pipeline from the Melbourne water supply system at Sydenham to the Melton and Bacchus Marsh system. The cost of construction has been estimated at 10million dollars. The construction of the pipeline has been postponed for 5 to 7 years due to the break in severe drought conditions and the grant of Merrimu's unallocated water to Western Water.

While the pipeline will add considerable security to the region's water supplies, the Melbourne supply system is not an endless source of water. Melbourne's water use is currently increasing at a rate of approximately 0.9%, due to factors such as population growth. If Melbourne's water use continues to grow at its current rate, it is projected to be using all available water by 2012 (WRSCMA 2001). The connection of all additional sources (such as the Tarago Reservoir) would only extend this period to 2034 (WRSCMA 2001). A committee has been set up to investigate possible methods to reduce consumption and therefore extend the period that Melbourne's water storages will continue to meet consumer demand. The water shortages Melbourne face will have implications for Melton and Bacchus Marsh upon completion of the connecting pipeline. If water restrictions are introduced in Melbourne then communities supplied from the pipeline would also be put on water restrictions (Western Water 2000).

The effects of global warming and land use practices, such as logging, have received very little, if any attention in the assessment of water resources for the region. These two factors may have very significant impacts on the availability of water to Melton and Bacchus Marsh, and are explored further in the following sections.

4. Global warming

An international network of 2,500 scientists has recently agreed that global warming is occurring and is due to human activities (Macquarie University 2001).

According to Dr Graeme Pearman, Chief of Atmospheric Research, CSIRO: Observations are providing reliable evidence that the Earth has warmed by about 0.6 C through the twentieth century and that warming is clearly visible in Australian measurements (CSIRO 2000, p13)

The need of crops and ecosystems for water will increase as temperatures and evaporation rise, particularly if there is also the predicted decrease in winter precipitation in southern states (ENRC 2001). Water quality will decline due to spread of salinity and lower stream flows (Watson and Zinyowera 1988-a-d). The extent to which each of these effects will be felt will vary with region and success with efforts to reduce greenhouse gas emissions.

Global warming will potentially reduce streamflow due to reduced rainfall, increased evaporation and increased plant transpiration. Scientists have concluded that global warming could significantly reduce streamflows in South eastern Australia. CSIRO's Atmospheric Research and Land and Water Unit, in collaboration with Hassell and associates and government agencies, modelled the impacts of global warming on the Macquarie River catchment in NSW as a case study to indicate possible effects of the enhanced greenhouse effect on catchments in south-eastern Australia (Jones *et al.* 2001). The research concluded that climate change poses a significant risk (up to a 20% reduction in flows) to water supply within the next thirty years and a substantial risk (up to a 45% reduction in flows) within the next seventy years (Jones *et al.* 2001).

Another study showed the Murray Darling river system facing constraints on existing irrigation uses and/or harm to the riverine environment as a result of reduced precipitation, particularly as snow (Watson and Zinyowera 1988-a-d).

According to Dr Barrie Pittock, formerly head of the CSIRO's Climate Impact Group, global warming is inevitable. He has stated that "The whole management of salinity and environmental flows in rivers will be seriously affected over a period of 20-30 years by the magnitude of the climate change we anticipate" (Stevenson 2001)

5. Land use within the Lerderderg, Goodman and Pyrites catchment

Forested public land covers the majority of all three catchments.
Pyrites Creek Catchment: the entire area of public forests is protected in State Park and reserves. Private land covers a smaller proportion of the catchment, which is mostly used for agricultural purposes.

Goodmans Creek Catchment: the public forests in this catchment are entirely protected in dedicated reserves. Private land covers a smaller proportion of the catchment, which is mostly used for agricultural purposes.

Lerderderg Creek Catchment: the minority of the public forest is protected in the Lerderderg State Park. The remaining the majority of public forest falls outside the park, where extensive logging operations have taken place over the last three decades and much of this forest remains open to logging. The area of forest subjected to logging occurs in the high altitude, high rainfall portion of the catchment – the area that delivers the most water and is therefore most important to water supply. A small proportion of the catchment is private agricultural land. Few, if any, plantations (tree farms) have been established. The township of Blackwood lies within the catchment.

6. Logging and Water in the Lerderderg catchment

For some decades, there has been concern in both the scientific and general community over the implications of logging in forested water supply catchments. In other Victorian regions, logging has been shown to significantly reduce water yield (O'shaughnessy & Jayasuriya 1991). This is because mature forests use very little water, allowing large amounts of water to flow into streams and catchments, while a new growing forest after logging uses large amounts of water, leaving little left over to flow into streams and water supplies (Vertessy et al. 1998). In studying catchment water yields, hydrologists have also realised how difficult it can be to detect the effects of logging. This has quite serious implications because hugely important changes to streamflow can occur undetected. For example, logging in the Alpine Ash forests of north east Victoria was estimated to result in an average annual loss of 51GL of water per year (equivalent to 51 000 Olympic swimming pools), yet this would be difficult to detect (O'Shaughnessy & Bren 1998). The difficulty in detecting streamflow changes due to logging is primarily due to the delay between cause and effect, and separating the natural variability of a complicated natural system influenced by climate etc. with catchment activities such as logging. The delay between logging and the impact of that logging on water can be decades or possibly centuries (Kuczera 1985). This delay spreads the impact of logging out over many years and making detection additionally difficult. In the Wombat forest region, limited hydrological study has taken place into the effects of logging on water. Although a study published in 1995 by NRE "A report on the effects of forest harvesting on water yield and quality in the Lerderderg catchment" failed to detect changes to water quality and yield as a result of logging in the Lerderderg catchment, this is not an indication that logging is, has or will not effect water. The duration and scope of the study were too short to definitively or even tentatively claim that logging is not affecting water. The very limited data available to researchers made detection of streamflow changes particularly difficult and thus the failure to observe changes can only be regarded as flimsy evidence that logging is not having an effect. The department of Natural Resources and Environment have frequently grossly misrepresented the report by claiming that it shows logging has not effected water (Rawson 95). The authors of the report have themselves recognised that logging was likely to be changing water yield even though changes had not been detected. The authors also concluded that increases in the intensity of logging would increase the risk of significant streamflow reductions (O'Shaughnessy et al 1995). In order to estimate the effect logging could be having on the catchment, given that changes in streamflow had not been detected, a yield curve was developed predicting the maximum yield reductions following logging.

This Doctors for Native Forests report analyses the possible cumulative effect of logging on water flows into the Lake Merrimu Reservoir, based on the revised version of the yield curve by consultants O'Shaughnessy, Fletcher and Bren (1996) and published by the Department of Natural Resources and Environment.

Since the publication of the O'Shaughnessy et al. (1996) report, interstate studies are increasingly showing that logging in dry mixed species forests is increasingly likely to result in reductions to water yield. Streamflow reductions have now been observed after logging in the Karuah catchment (Cornish & Vertessy 2001) and after logging in the mixed species forest at Tantawangalo, NSW (Lane & Mackey 2001).

THE FOREST AGE / WATER YIELD CURVE

O'Shaughnessy et al (1996) developed a worst case unit area water yield curve for mixed species eucalypt forests in Central Victoria (including the Wombat Forest). The yield curve was never applied to predict the possible impacts on water across the regions catchments. This is of serious concern as this yield curve represents the best estimate of the extent of water loss due to logging and therefore the possible extent on the water resources of the region and in particular Merrimu.

The water yield curve predicts:

a) After clearfelling an initial yield increase of 330mm three years after logging.
b) After three years, a period of decline reaching pre-treatment levels seven years later or 10 years after logging.
c) A further decline to 50% of pre-treatment streamflow reaching a minimum 30 years after logging
d) A period of recovery back to pre-treatment levels taking some 70 years.

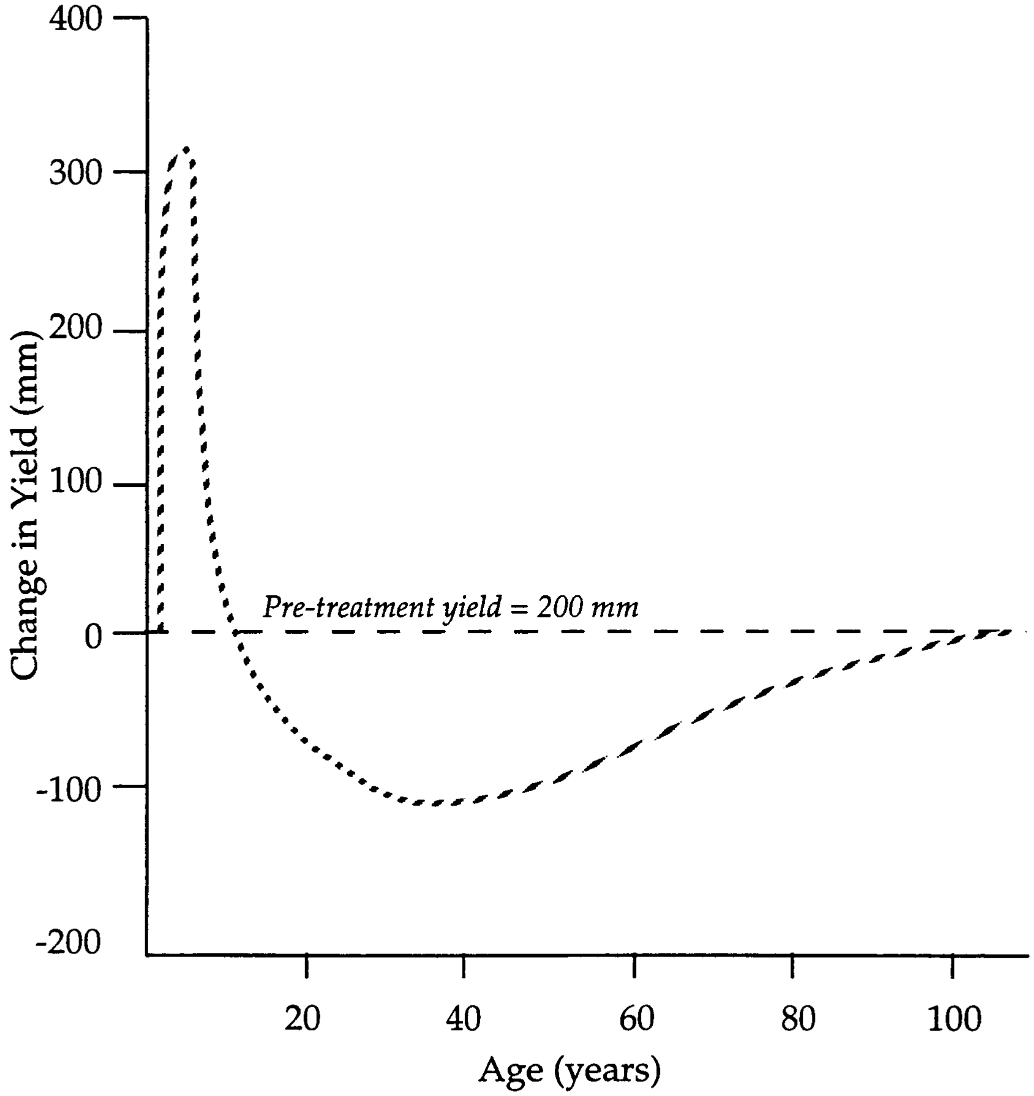


Figure 1. Approximate worst case age/yield curve for an even aged mixed species eucalypt forest in Central Victoria (O'shaughnessy et al. 1996)

The yield curve constructed by O'Shaughnessy et al. (1996) was to be applied on the condition that particular logging intensities were being used, intensities that essentially describe current logging practices in the Lerderderg catchment. The logging practices concerned describe the felling of all trees in the logged area, followed by full stock rates of eucalypt new growth. The O'Shaughnessy et al. (1996) yield curve can be applied because the logging systems used in the Wombat (shelterwood, seed tree and clearfell) closely approximate this intensity (see appendix 1 for further detail), and the yield curve can therefore project the extent of possible yield impacts.

Although acknowledged as a simplification of reality, forest age / water yield curves have been widely used throughout Australia and in other areas of the world to estimate changes in water yield following logging.

By analysing the yield curve, it is possible to draw further conclusions than those drawn by O'Shaughnessy et al. (1996), while remembering that the yield curve is approximate, but still represents the best estimate to date of the full extent of logging on water yield.

The yield curve has been applied to the Lerderderg catchment to estimate

1. The projected volume of water that would be lost due to historical logging (to 1999), and assuming those areas already logged will be re-logged on an 80 year rotation. This volume of water lost is relative to that produced by a mature forest
2. The projected volume of water lost due to the combined effect of historical logging and assuming currently available mature forest is logged on an 80 year rotation, compared to the volume of water that would be produced by a mature forest.
3. The projected volume of water lost sequentially each year due to historical logging
4. The projected volume of water lost each year due to historical logging, plus that lost assuming the remaining available forest is logged at current rates.

For the full methodology, calculations and assumption set used in the application of the model, see Appendix 1.

RESULTS

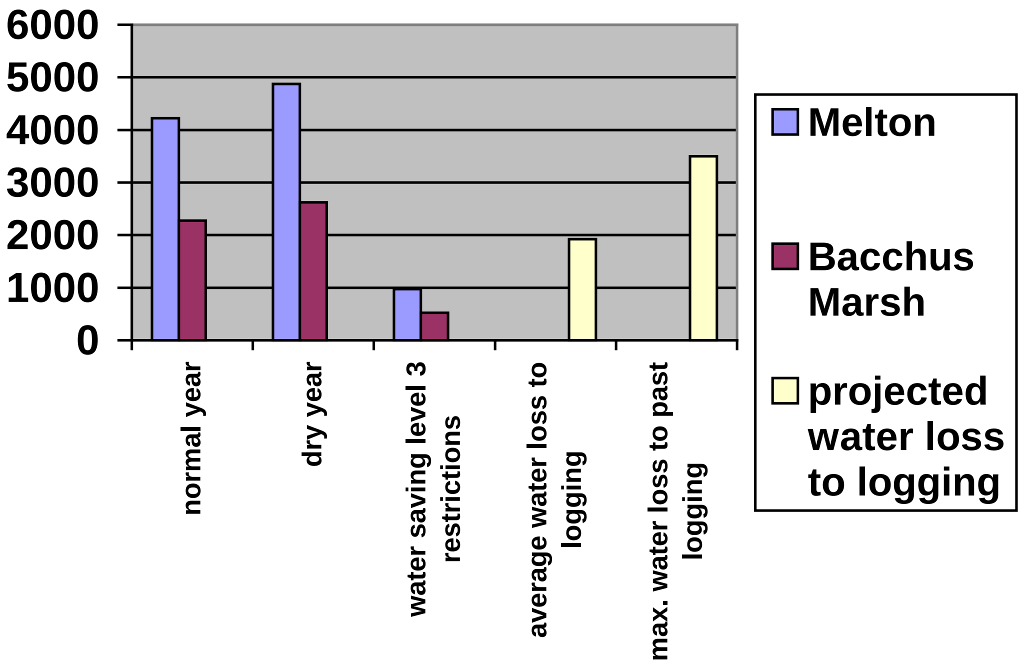
1. Average projected volume of water lost in the Lerderderg catchment due to historical logging, averaged over an entire 80 year rotation = 1438 ML per year, compared to that produced should the forest be permitted to mature
2. Average projected volume of water lost in the Lerderderg catchment due to historical and future logging of available mature forest, averaged over an entire 80 year rotation = 1920 ML per year, compared to that produced should the forest be permitted to mature
3. Maximum projected yield reduction due to historical logging (1973-1999) is expected to reach a maximum of approx. 3500ML in the year 2025.
4. Maximum projected yield reduction due to historical and projected future logging of the available forest area completely is expected to reach a maximum of approximately 4400 ML in the year 2030. These projections indicate that historical logging (to 1999) may not reduce streamflow in the Lerderderg until the year 2003, while, if logging of all the available forest in the catchment progresses at the anticipated rate, yield reductions may not occur until 2007. These initial yield increases are as a result of the initial increase in yield immediately after logging, and illustrate the long delays that may occur between cause and effect.

7. Discussion

The size of the projected average annual loss of 1920 ML / annum due to logging in the Lerderderg catchment should be of great concern to land managers, water authorities, local residents and irrigators.

This projected volume of water lost is equivalent to over 80% of the volume of water used by Bacchus Marsh in a normal year, and over three times the volume of water saved by Bacchus Marsh under level 3 water restrictions (see graph below).

Figure 2. Comparison to other consumers of projected water loss should logging in the Lerderderg catchment continue (ML/year).



Notes

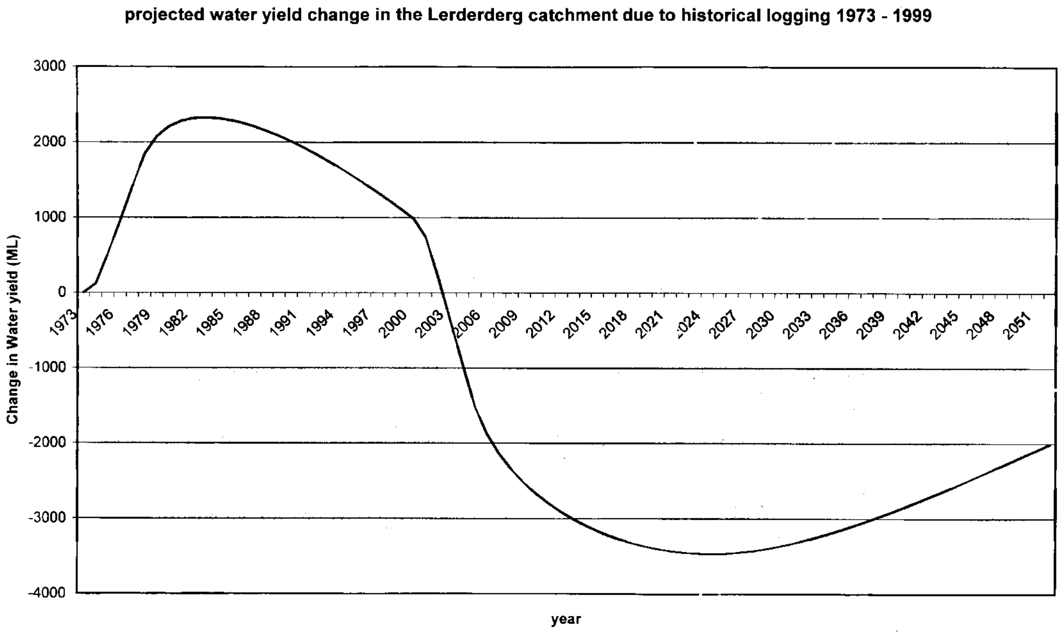
1. Bacchus Marsh / Melton consumption source: calculated from Western Water (2000)
2. Water restrictions source: Western Water (2000) states that Level 3 restrictions (banning the use of sprinklers for water gardening) reduced water total annual water consumption by approximately 20%

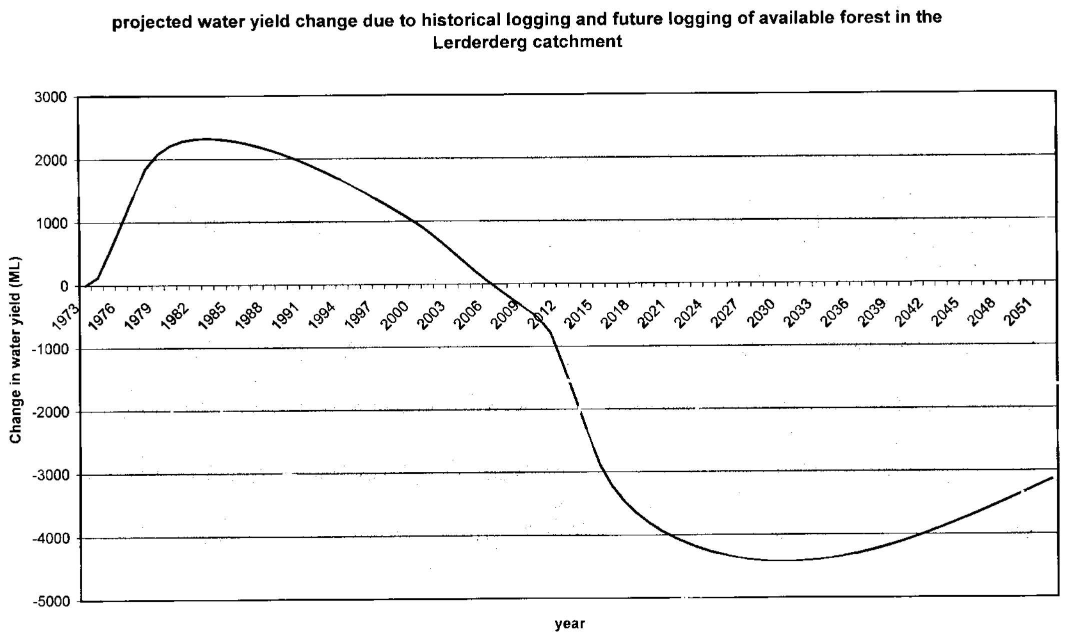
The value of this projected water loss to logging is also considerable. Bacchus Marsh and Melton residents pay $680 for a megalitre of water (WWAR 2001). At these prices, logging consumes

= Water lost (continued logging, average over entire 80 year rotation) x price
= 1920 x 680 = $1.3 million per annum

Maximum annual projected yield reduction due to historical logging (1973-1999) is expected to reach a maximum of approximately 3500ML in the year 2025. The value of the projected water loss in that year, at the current price for Melton/Bacchus Marsh residents of $680 per ML (WWAR 2001), is $2.38 million dollars.

Maximum projected yield reduction due to historical and assumed future logging of the available forest area completely is expected to reach a maximum of approximately 4400 ML in the year 2030. The value of the projected water loss in that year, at the current price for Melton/Bacchus Marsh residents of $680 per ML (WWAR 2001), is $3.0 million dollars.





These projections indicate that historical logging (to 1999) may not reduce streamflow in the Lerderderg until the year 2003, while, if logging of all the available forest in the catchment progresses at the anticipated rate, yield reductions may not occur until 2007. These initial yield increases are as a result of the initial increase in yield immediately after logging, and illustrate the long delays that may occur between cause and effect. Note that these curves are based on the assumption that historical logging occurred at an average rate over the period 1973-1999, which is a conservative approach. The intensification of logging during the 1990's in the Wombat forest would tend to result in greater maximum and minimum yield changes and further delay the transition from increased yield to yield reductions.

This study is not intended to be interpreted as a definitive finding of the volume of water lost to logging in the Lerderderg catchment. Application of an age/yield curve is always a significant simplification of the complexity of forest catchment systems. Some of the factors are likely to be important but are ignored include: tree species and forest structure, soil type and depth, topography and aspect. This report applies the O'Shaughnessy et al. (1996) yield curve because current logging practices in the Lerderderg catchment closely approximate those that the yield curve was developed to be applied under. The results give an indication of the volume of water lost to logging in the catchment, and is intended to provide an indication of the implications of logging within the Lerderderg catchment, using the best available yield curve for this region published by the Department of Natural Resources and Environment. These findings highlight the need for accurate assessment of the implications of logging given the potential scale of impact. The figures presented in this report are not a worst case scenario as the model has been applied conservatively. The volume of water lost to logging could be significantly higher than that predicted here. Given the importance of Lerderderg water to the region, a far more significant study of the effects of logging in this catchment is highly recommended.

Removing logging from the Lerderderg should be considered as an option for increasing the security of water supply to Lake Merrimu. This approach has been recognised as a guiding principle in planning the future of Melbourne's water resources "Yield from existing sources should be maximised to make the system more flexible, supportive of the natural environment and responsive to variability in supply." (WRSCMA 2002)

8. Findings

1. The average volume of water consumed by historical logging in the Lerderderg catchment, averaged over an entire 80 year logging rotation, is projected to be 1438 ML. This loss is relative to that produced should the forest be permitted to mature.
2. The volume of water consumed, should logging be permitted to continue in the Lerderderg catchment, averaged over an entire 80 year rotation, is projected to be 1920 ML per year. This loss is relative to that produced should the forest be permitted to mature
3. The maximum annual yield reduction due to historical logging is projected to reach 3500ML per year in the year 2025. This loss of water is relative to that produced by a mature forest. The value of this water at current Bacchus Marsh / Melton residential rates is $2.38 million dollars.
4. The maximum annual yield loss due to historical logging and if all available forests are logged in the catchment at current rates is projected to reach 4400ML per year in the year 2030, compared to that produced should the forest be permitted to mature. The value of this water at current Bacchus Marsh / Melton residential rates is $3.0 million.
5. Yield reductions are not projected to have taken place in the Lerderderg catchment to date. However, long term reductions over many decades are projected. The yield changes are estimated to have resulted in increased yields from 1973 to the present, with decreased yield projected from the year 2007 if logging continues at the current rates.
6. The figures presented in this report are not a worst case scenario as the “worst case yield model” has been applied conservatively. The volume of water lost to logging could be significantly higher than that predicted here.
7. land use practices such as logging have generally been overlooked in the regions water resource assessments
8. the possible effects of global warming have generally been overlooked in the regions water resource assessments
9. further research into mixed species eucalypt water use in Victoria’s forests, as strongly recommended in O’Shaughnessy et al. (1996) has not been undertaken or applied in the Wombat forest.

9. Recommendations

1. Given the regional importance of the Lerderderg catchment, removing logging from the catchment should be considered as an option for increasing security of water supply to Merrimu
2. that comprehensive hydrological modelling into the impacts of logging on the mixed species forests of the Wombat be undertaken, including development of an age/yield curve using direct measurements such as sap flow. The development of such a model would make accurate rainfall / climate modelling worthwhile – which may show the actual yield loss to be greater than predicted in this report due to underestimation of rainfall/streamflow
3. timber royalties paid by the logging industry for access to publicly owned forests should reflect the cost of water consumed

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WRSCMA (2002) Strategy Directions Report: Stage 2 in developing a Water Resources Strategy for the Greater Melbourne area. Water Resources Strategy Committee for the Melbourne Area.

Appendix 1. Methodology, Assumptions, Calculations

The area of the O'Shaughnessy et al. (1996) yield curve above the "0 change in yield line" represents the increased water yield per unit area. The area of the graph below the "0 change in yield line" represents the decrease in water yield. Analysis of these two areas provides an approximation of the maximum impact of logging a mature forest on water yield, compared to leaving that mature forest unlogged. Note that this may overestimate the actual current impact of logging in the Lerderderg catchment, because the water yield from the forest may be increasing due to historical logging. However, the value of this calculation is in comparing the effect of logging on the potential of the forest to produce water if it was allowed to grow unlogged to old growth.

Note: some inconsistencies exist in O'Shaughnessy et al. (1996) between the written description of the worst case yield curve, and the illustration of the curve (Figure 1). Where these inconsistencies occur, a conservative approach has been taken by using the option resulting in minimum predicated water losses due to logging. The variety of inconsistencies in scale along the x-axis have been left unaltered as drawn in O'Shaughnessy et al. (1996).

Potential yield loss compared to mature forest water yield:

Overall water yield change (truncated at 80 years) = area above yield curve – area below yield curve

= 1708 – 4830

= -3122 mm.years/unit area

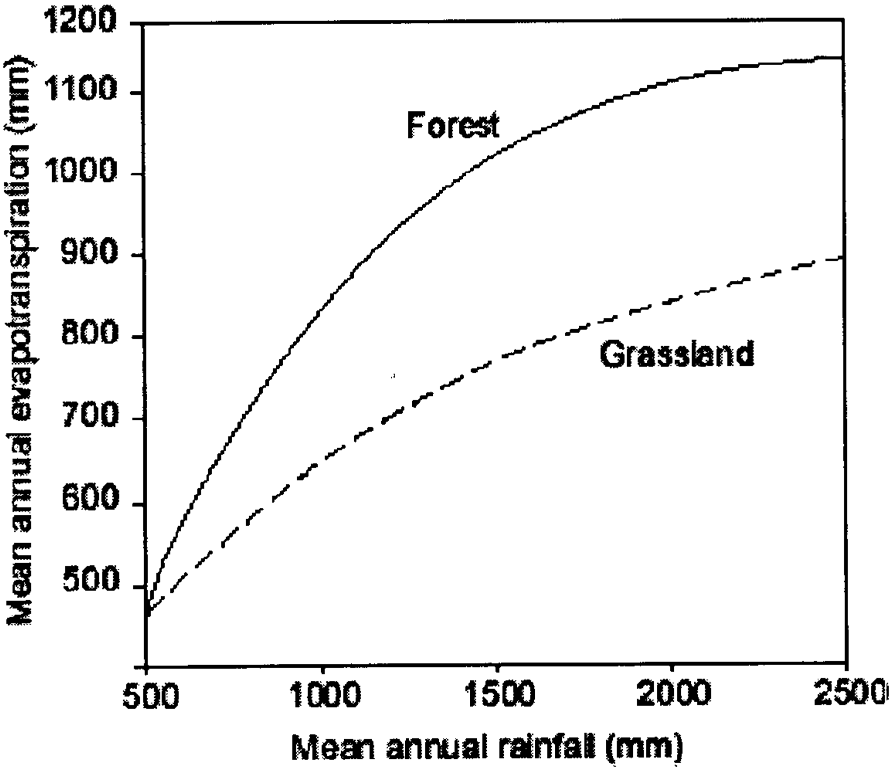
= - 31.22 ML.years/ha

i.e. the yield curve predicts a maximum water loss of approximately 31.22 ML per hectare logged on an 80 year rotation compared to mature forest for rainfall corresponding to streamflow of 200mm.

MODELLING YIELD CHANGES IN THE LERDERDERG CATCHMENT

Assumptions/approaches used:

1) adopt the age/yield curve constructed by O'Shaughnessy et al. (1996), being conservative where inconsistencies occurred.
2) Assume, across the entire catchment, an average annual rainfall of 1000mm resulting in an average streamflow of 175mm, which are the approximate statistics measured at Blackwood (O'Shaughnessy et al. 1996). This approach is conservative and would tend to underestimate the maximum possible effect on water yield. Relevant issues and methodology include
    a. There is a generally recognised relationship between the volume of water lost to logging and rainfall. That is, the higher the rainfall in the area logged, the larger the volume of water lost. This has been observed in studies of actual catchments. For example the volume of water lost in the Piccaninny catchment (mean annual rainfall ~1200mm) after logging was far lower than that in the Mountain Ash forests catchments studied by Kuczera (mean annual rainfall ~1950mm) (Vertessy 1999) It is plausible to assume that the magnitude of the age/yield response curve is directly proportional to rainfall (this essentially assumes that water consumption by the forest is optimised to local rainfall conditions). For example if the decrease in water yield from a 15 year old forest for a mean annual rainfall of 1000mm is predicted to be 100mm, then the yield decrease for a forest subjected to 20% higher rainfall is simply 20% greater (i.e. 120mm). This assumption of direct proportionality has been used in modelling by Sinclair Knight Merz in both NSW (SKM 1998) and the Otway Ranges (SKM 2000).
    b. The "worst case yield model" illustrated in O'Shaughnessy et al (1996) is then scaled down to rainfall of 1000mm. The illustrated model is for a streamflow of 200mm. A quick estimate of its corresponding rainfall is calculated from the mean annual evapotranspiration curves shown below from Homes and Sinclair (1986).



Source: SKM (2000) Adapted from Holmes and Sinclair (1986)

It should be noted that these curves are an approximation, however they should be sufficiently accurate given the purpose of the calculation is to create an appropriately conservative yield curve. If streamflow is assumed to be the difference between rainfall and evapotranspiration, then these forest curve predicts that a streamflow reduction from 200mm to 175mm would correspond to a reduction in rainfall of about 8%.

c. The actual rainfall across the logged areas is likely to be significantly higher than at Blackwood because rainfall increases with altitude. The rain gauge at Blackwood is located at an elevation of 560m (BOM 2002), while virtually all logged areas identified in the catchment (SFRI 2000) are above this elevation. Only a tiny amount of logging (less than approximately one percent), in the very lowest areas are below 560m elevation, while the remainder is well above this elevation, with significant areas above 700m. Average rainfall across the logged areas is therefore likely to be significantly higher than the 1000mm assumed here.

3) Apply the model to both areas of shelterwood 1 and regrowth (assuming regrowth to be either shelterwood 2, seed tree or clearfell coupes) identified in the State Forest Resource Inventory (SFRI 1999), excluding stream buffers. An allowance of 2% has been made for non-logging road areas. The worst case water yield model constructed by O'Shaughnessy et al. (1996) was to be applied to areas completely converted to a regrowth condition, fully stocked without any old growth overhead canopy. The shelterwood, seed tree and clearfell logging systems used in the Wombat approach this criteria because:

a. In the clearfell system, virtually all trees are logged on a site, except occasional trees retained as "habitat" and stream buffers. The yield modelling approach used here excludes stream buffer areas from analysis.
b. In the shelterwood system, logging takes place in two cuts. The first cut removes the majority of mature trees, followed by (generally ten years later) a second cut removing the remainder of the mature trees (NRE 1996). Because these overhead canopy trees are logged only 10 years after the Shelterwood 1 cut (20 years before the Shelterwood 1 growth is predicted to reach maximum water use, it is assumed they will result in less than a 10% difference in water yield.
c. In the seed tree system, all trees are logged except those retained as seed or habitat (trees are often chosen to serve both purposes). Usually 4 to 5 per hectare are retained (VicRFASC 1996). These silvicultural practices are relevant across the West RFA region (VicRFASC 1999). If these trees are assumed to have an average crown diameter of 15m (O'Shaughnessy et al. 1996) this results in a residual crown cover of about 900 square metres per hectare (9% of the logged area)
d. Eucalypt stocking rates across the West RFA region have been measured as successful in 93 to 96 percent of the logged area after treatment, and with re-treatment, all areas were deemed to have acceptable stocking rates (Murphy and Fagg 1996).

Therefore, to be conservative, the logged area will be assumed to be 10% smaller than shown on logging history maps.

4) It is assumed that those area's logged between 1973 and 1999 will be permitted to grow to 80 years of age before being re-logged (i.e. 80 year rotation) Except areas of shelterwood 1 which will be assumed to have a shelterwood 2 cut. The O'Shaughnessy et al. yield curve is then truncated at 80 years to reflect this.
5) In calculating the area of forest to be logged in the future, it is assumed that the available area is the area of mature forest defined in (SFRI 2000) excluding streamside buffers, steep slope exclusions, a 2% area allowance for non logging roads and an allowance for 5% of the area to remain unlogged due to the constraints of uneconomically small areas to log etc (in line with Vanclay & Turner 2001).
6) Projected logging of the available area of forest in the catchment is assumed to take place on an 80 year rotation. The O'Shaughnessy et al. (1996) yield curve is then truncated at 80 years to reflect this.

CALCULATIONS

1) HISTORICAL LOGGING

Assumption/approach No. 1, 2, 3 & 4 applied.

Scaling down the original "worst case yield curve" to reflect 1000mm rainfall (175mm streamflow). I.e. a reduction of 8%

Original worst case yield loss = 31.22 Mlyear/ha

Worst case yield loss (1000mm rainfall) = 31.22 x 0.92
= 28.72 ML.year/ha

2) Apply this yield loss to areas of shelterwood1 and regrowth identified in (NRE 2000) within the Lerderderg catchment.

Area of regrowth (calculated from NRE 2000)	= 2123 hectares
Area of Shelterwood 1 (calculated from NRE 2000)	= 2415 hectares
Total area logged (regrowth + shelterwood 1)	= 4538 hectares
Reduce area by 12% (for "seed/habitat trees & non-logging roads)	= 3993 hectares

Predicted water lost to logging in the Lerderderg
= area logged x water loss per hectare
= 3993 x 28.72 = 115, 000 ML over 80 year period (from date of logging)

Potential water lost due to historical logging on average per year = 115, 000 / 80
= 1438 ML per year

2) HISTORICAL AND FUTURE LOGGING OF AVAILABLE AREA

Assumption/approach No. 1, 2, 3, 4, 5 & 6 applied.

The area of forest available in the Lerderderg catchment for future logging was calculated, based on (SFRI 1999) and (VicRFASC 2000) maps. The area of mature forest, excluding stream buffers, exclusions of steep slopes, protected areas, a 2% allowance for non-logging roads, and 5% allowance for other constraints was calculated using a CAD package, resulting in an area of approximately 1360 hectares.

Total
= (shelterwood area + regrowth area + available mature area) x water loss per hectare
= (3993 + 1360) x 28.72 = 153 700 ML over an 80 year period

Potential water loss (historical + future logging) on average per year
= 153 700 / 80
= 1920 ML on average per year

3) PROGRESSIVE CHANGE IN WATER YIELD EACH YEAR

Historical logging case:
Assumption/approach No. 1, 2, & 3 applied.

Historical and projected logging case:
Assumption/approach No. 1, 2, 3 & 5 applied.

As the yield of water from a logged area varies with time, there may be periods where the overall catchment yield is greater affected than others. This is particularly likely as very intensive logging has occurred in the catchment over the last few decades.

Historical logging presented in the Department of Natural Resources maps (SFRI 2000) is assumed to occur between 1973, when Shelterwood was first introduced into the Wombat (NRE 1996), and 1999. Logging in the period 1973 – 1999 is assumed to have taken place at an average rate of:

Historical logging rate = area logged / number of years
= 3993 / 27
= 148 hectares per year

Future logging is assumed to occur throughout the entire available area of forest in the catchment by 2009. This rate is arguably the most reasonable to use, as current logging rates in the Wombat forest continue at a similar rate to the past, even though this rate was announced as needing to be reduced by 80% to provide sustainable wood volumes in the Victorian Government's 'Our Forest Our Future' statement (Bracks & Garbutt 2002). Logging rates have not been reduced to date since the announcement, and appear to be continuing for the foreseeable future under current licence commitments. Future logging of the available area is therefore projected to have begun in 2000 and end in 2009.

Future logging rate of available forest
= area available / number of years
= 1360 /10
= 136 hectares per year

The area under the yield curve presented in O'Shaughnessy et al. (1996) was calculated for each year, using a CAD package to calculate the areas. As previously, the conservative option was chosen where inconsistencies occurred and differences along the X-Scale were left as presented in the original report.

These year by year areas were scaled for 1000mm rainfall, and then input into a spreadsheet application to calculate progressive yield changes.

Averaging the area logged is a conservative approach because logging intensities are likely to have increased throughout the 1990's in the catchment. This increase in intensity is could result in larger annual peak yield changes than presented here.

Results:
Maximum potential yield reduction due to historical logging (1973-1999) is expected to reach a maximum of approximately 3500ML in the year 2025.

Maximum potential yield reduction due to historical and projected future logging of the available forest area completely is expected to reach a maximum of approximately 4400 ML in the year 2030.

These projections indicate that historical logging (to 1999) may not reduce streamflow in the Lerderderg until the year 2003, while, if logging of all the available forest in the catchment progresses at the anticipated rate, yield reductions may not occur until 2007. These initial yield increases are as a result of the initial increase in yield immediately after logging, and illustrate the long delays that may occur between cause and effect.