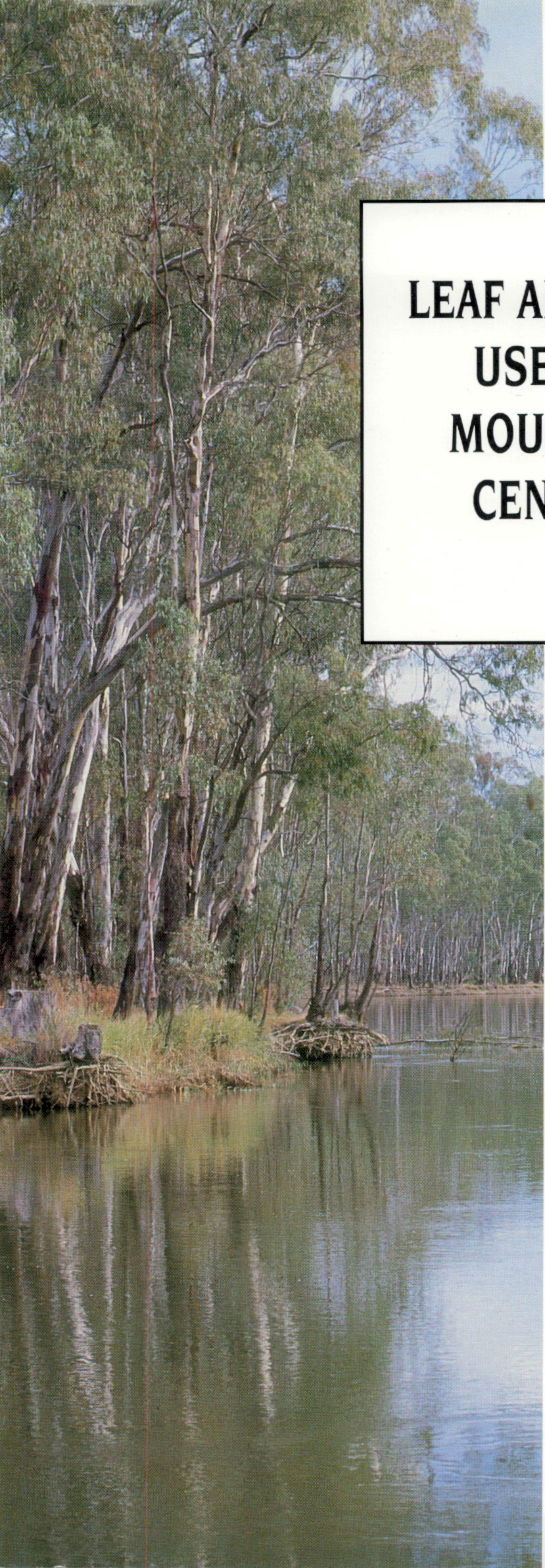

LEAF AREA AND TREE WATER USE IN A 15 YEAR OLD MOUNTAIN ASH FOREST, CENTRAL HIGHLANDS, VICTORIA

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COOPERATIVE RESEARCH CENTRE FOR
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Preface

The material in this report is a contribution to one of the core research projects in the Cooperative Research Centre for Catchment Hydrology, "Development and evaluation of predictive tools for water production in natural, disturbed and managed forests."

The project aims to synthesise our knowledge of forest water balance, to generate key experimental information on the factors that determine how water, soils, trees and landscapes interact, and to produce operational models for water productivity that can be used by resource managers and planners.

This report summarises results from one of the intensive experimental phases of the project. The work has been conducted in catchments that supply water to the city of Melbourne, where planning for future water sources is now a matter of intense public debate. The report makes an important contribution to the scientific understanding needed to make the correct resource management decisions.

The report's authorship (Rob Vertessy, CSIRO, project leader; Richard Benyon, Melbourne Water; Sharon O'Sullivan and Paul Gribben, Monash University) reflects the collaboration that is now well developed between three of the CRC participants. That collaboration already extends into other resource agencies who are participating in the research, and who will benefit from it.

Emmett O'Loughlin
Director
Cooperative Research Centre for Catchment Hydrology

Abstract

This report examines leaf area, sapwood area, tree diameter and water use relationships in a 15 year old mountain ash (*Eucalyptus regnans*) forest stand in the Victorian central highlands. Silver wattle (*Acacia dealbata*) was present in the stand as a sub-dominant overstorey tree along with a dense understorey of mountain hickory (*Acacia frigrescens*).

Leaf area index (LAI) was estimated by (i) destructive sampling of trees, (ii) the use of a LICOR LAI-2000 Plant Canopy Analyser (PCA) and (iii) hemispherical canopy photography. All three methods yielded similar results, with the PCA and photo methods overestimating actual LAI by about 7%. This difference is commensurate with published figures for the woody area index (WAI) of forests. We conclude that the PCA method is a simple, rapid and accurate technique for LAI estimation in young regrowth ash forest.

Tree water use was measured in 19 mountain ash trees and 7 silver wattles using the heat pulse technique over a 39 day period. The mean daily transpiration of the ash trees was 2.3 mm/d. Mean daily sapflow velocities in the mountain ash were almost twice those observed in the silver wattles. Because the silver wattles had only half of the sapwood area of the mountain ash they were responsible for only 25% of the total overstorey transpiration. Water use in the ash trees was found to be highly skewed; the 14 largest trees in the plot of 164 individuals transpired almost 28% of the water while the 90 smallest individuals transpired only 22%.

In the mountain ash trees, tree diameter explained 93% of the variation in leaf area, 96% of the variation in sapwood area and 88% of the variation in mean daily tree water use. We recommend that similar studies be conducted in mountain ash stands of different ages.

Acknowledgements

Funding for this work came from the Cooperative Research Centre for Catchment Hydrology (CRCCH). It was carried out as part of CRCCH Project A2, entitled 'Development and Evaluation of Predictive Tools for Water Production in Natural, Disturbed and Managed Forests'. It involved contributions from staff in CSIRO Division of Water Resources, Melbourne Water, Monash University, the University of Melbourne and the Department of Conservation and Natural Resources, Victoria.

We wish to thank Melbourne Water for providing access to the Mt Monda catchment field site and much of the equipment needed for the field experiment. For assistance in the field our appreciation is extended to the following people:

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Monash University:
Sharon Davis

University of Melbourne:
Katie Collins and Darius Culvenor

Dr Barry Harper of the Faculty of Education, Woolongong University kindly digitised and analysed the hemispherical photos for us. We thank Kent Rich (CSIRO) and John Molloy (Monash University) for helping with the drafting of diagrams and final publication of the report.

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1. INTRODUCTION

Water for the city of Melbourne comes from forested catchments covering an area of 155 000 ha in the Central Highlands to the north and east of Melbourne. Mountain ash (*Eucalyptus regnans*) forests cover just over half the water supply area, yet because they grow on the higher rainfall sites, yield 80% of the streamflow. The water from these catchments is of high quality, so no treatment other than minimal disinfection is required to meet health standards. For this reason, the cost of providing water to Melbourne is relatively low. As catchment managers, Melbourne Water have a vital interest in maintaining the quality and quantity of streamflows from these forests.

In 1939, devastating bushfires swept through Melbourne's water supply catchments. About 80% of the extensive old-growth ash forest was killed and replaced with dense re-growth ash forest. By the early 1950's it became apparent that streamflows from the catchments were declining, indicating that forest age affects water yield.

Analysis of historical streamflow records shows that the conversion of ash forests from an old-growth to a re-growth state results in a dramatic reduction in catchment water yield. Langford (1974, 1976) examined pre- and post-fire streamflows from five catchments affected by the 1939 bushfires. Initial runoff increases gave way to sustained water yield decreases once vigorous re-growth became established. In the three decades following the 1939 fires, mean annual streamflow from the catchments fell from 930 mm to about 500 mm. It was concluded that the reduction in water yield after the fire in each catchment was proportional to the percentage of ash forest burnt. Langford's observations were the first in the world reporting large and sustained water yield declines from forested catchments subject to disturbance and natural regeneration.

Kuczera (1985, 1987) refined and extended Langford's analyses and developed an idealised curve describing the relationship between mean annual streamflow and forest age for ash forest. The curve combines the known hydrologic responses of eight different basins to fire and is constructed for the hypothetical case of a pure mountain ash forest catchment. It indicates that old-growth forest yields on average 1195 mm of runoff per year. After disturbance due to fire or logging and subsequent re-growth, this falls sharply to 580 mm/y until age 27 years, after which yield slowly recovers over a period of around 150 years.

Process studies have been carried out to evaluate the roles of fog drip (O'Connell and O'Shaughnessy, 1975), rainfall interception (Langford and O'Shaughnessy, 1978;

Haydon *et al.*, in prep.) and evapotranspiration (Legge, 1980; Dunn and Connor, 1991; Jayasuriya *et al.*, 1993) in dictating the water yield versus forest age relationship. Most of these studies have concluded that changes in evapotranspiration are the prime cause of water yield changes. Recent studies by Dunn and Connor (1991) and Jayasuriya *et al.* (1993) have emphasised the role of changing leaf area index and sapwood area as being key determinants of changes in evapotranspiration. However, to date, there have been few studies reporting measurements of leaf area index and sapwood area in the mountain ash forests.

Leaf area index (LAI) is commonly used as the primary variable to represent vegetation status in water balance models used in landuse and climate change studies (Running and Coughlan, 1988; Band *et al., 1993;* Vertessy *et al.*, 1993). Such models assume that LAI is a suitable scalar for both evapotranspiration and rainfall interception rate. In many of these models LAI is one of the most sensitive parameters to change and has the greatest impact on computed runoff production (Vertessy *et al.*, 1993).

Despite the importance of LAI in hydrologic models of landuse and climate change there remain two main problems. Firstly, LAI is difficult to measure and few of the many available measurement techniques have been field validated in heterogeneous eucalypt forests. Secondly, there is a dearth of field observations linking LAI to rates of tree water use or rainfall interception in these forests. One would expect the relationship to be positive (i.e. the greater the LAI, the greater the rate of water use and interception) but the shape of the relationship should vary between species according to factors such as crown morphology, leaf inclination angle and leaf shape. It is also possible that the relationship would change according to time of year.

Our hydrologic simulation studies in the Melbourne water supply area have prompted us to evaluate LAI measurement techniques and to investigate the veracity of the link between LAI and rate of tree water use. In this report we evaluate the accuracy of LAI estimates made using the LICOR LAI-2000 Plant Canopy Analyser and explore the relationships between tree diameter, LAI, sapwood area and tree water use. Our study is confined to a 15 year-old mountain ash forest but has relevance to ash forests of other ages.

2. SITE DETAILS

The study was carried out in the North Maroondah Experimental Area, located 80 km north east of the city of Melbourne (see Figure 1). This forms part of the water

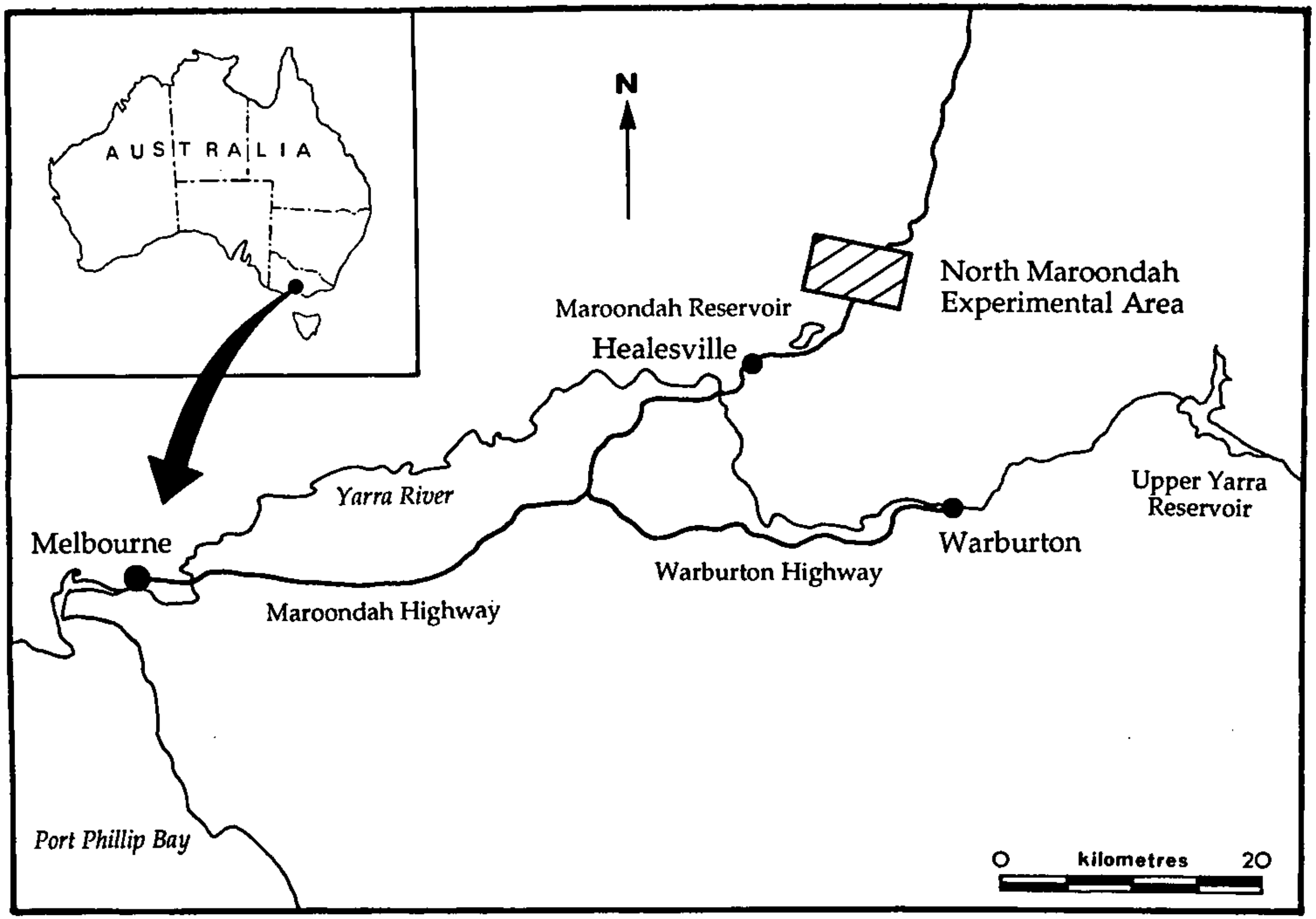

Figure 1. Location of the North Maroondah Experimental Area.

Table 1. Diameter (at breast height over bark) statistics for all overstorey trees in the 50 x 50 m plot.

Statistic	Ash	Wattle
Number	164	124
Minimum (cm)	9.6	10.0
Maximum (cm)	39.2	27.1
Mean (cm)	20.4	15.6
Median (cm)	18.6	15.0
Standard deviation	6.6	4.3
Kurtosis	-0.19	-0.59
Skewness	0.69	0.62

supply catchment system for the city of Melbourne and has been the focus of detailed hydrologic studies by Melbourne Water (formerly the Melbourne and Metropolitan Board of Works) since 1970 (Langford and O'Shaughnessy, 1977).

Our experimental plot was situated in a 15 year old stand of mountain ash where silver wattle (*Acacia dealbata*) was a sub-dominant species. The site is located at an elevation of 890 m, has a mean annual rainfall of 1713 mm and a mean daily temperature of 9.3 °C. The stand of trees is even aged, having regenerated from direct seeding after a clearfelling operation performed in 1978. The stocking density of ash trees has decreased from 8500 stems/ha in 1983 to 2500 in 1988 and 765 in 1991. At the time of this study in November 1993, the stocking density of mountain ash was 656 stems/ha while the stocking density of silver wattle was 496 stems/ha.

A 50 x 50 m plot was established, containing an overstorey of 164 mountain ash and 124 silver wattle trees. The understorey consisted of mountain hickory (*Acacia frigescens*), rising to a height of 3 m and assorted ferns reaching about 1 m in height. Mean height of the trees was 27.3 m for the ash (n=19) and 23.8 m for the silver wattle (n=2). The diameter at breast height over bark (referred to hereafter as dbh) of each of these 288 trees was measured. Table 1 shows that the mean dbh values for the ash and wattle trees were 20.4 and 15.6 cm respectively. Minimum dbh values were 9.6 and 10.0 cm, and maximum dbh values were 39.2 and 27.1 cm respectively. The cumulative frequency distributions of tree dbh values for both overstorey species are plotted in Figure 2.

Within the 50 x 50 m plot, 19 ash and 7 silver wattle trees were selected for detailed

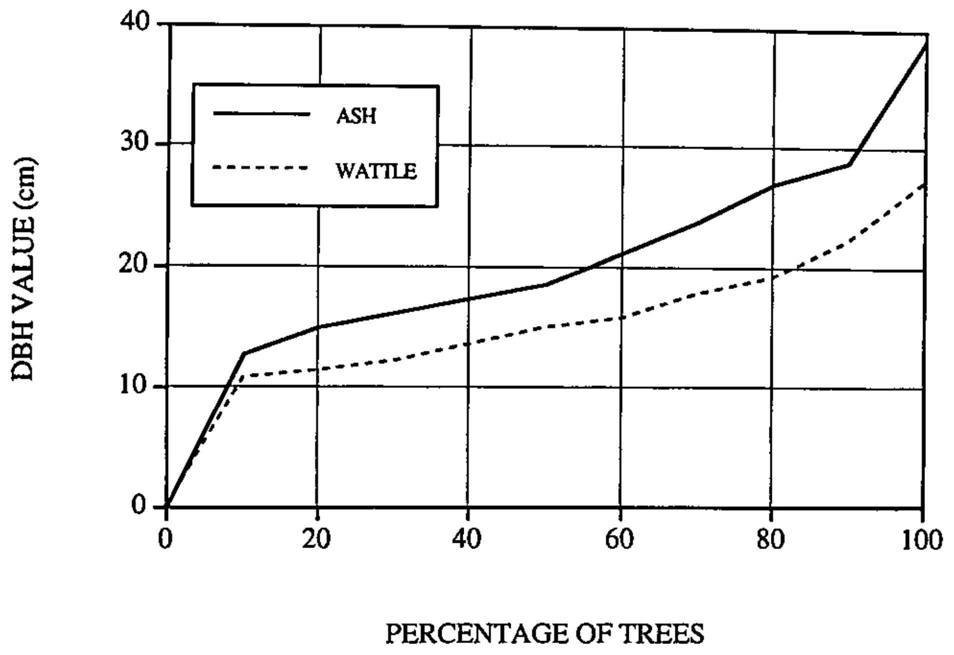

Figure 2. Cumulative frequency distribution of dbh values for all mountain ash and silver wattle trees in the 50 x 50 m plot.

examination. For each of these trees we measured the height, dbh, total leaf weight, sapwood area at breast height (sabh), stem area and half-hourly tree water use over a six week period. The sample trees were selected to span the range of dbh values measured in the 50 x 50 m plot because one of our objectives was to calculate an LAI value for the plot, based on an LAI versus dbh relationship for the 26 sample trees. Measurements of dbh, height and total leaf weight for each of these 26 trees are listed in Table 2.

3. LEAF AREA

All 19 sub-sampled ash trees and two of the seven sub-sampled silver wattles were destructively sampled. This involved felling the trees as close to ground level as possible. The total leaf mass was harvested from each tree, then weighed on electronic laboratory scales which were accurate to ±10 g. The height of each tree was measured, as was the tree diameter at 1 m increments along the stem. The height of the tree at the base of the live crown was recorded so that the depth of canopy could be obtained. Stem discs were cut at breast height and at the base of live crown to enable accurate measurements of sapwood area at these points.

A large number of mountain hickory understorey trees were also destructively sampled. Five circular plots, each having a radius of 5 m, were established within the 50 x 50 m plot. Together, the five circular plots covered an area of 392.75 m^2 or 15.7% of the 50 x 50 m plot. The circular plots were selected to capture the observed

Table 2. Statistics for the 26 overstorey trees selected for detailed examination. Prefix e denotes ash tree, prefix w denotes silver wattle. Dash denotes no data available.

Tree (cm)	dbh (m)	Height (kg)	Leaf Weight
e004	22.4	24.1	15.061
e008	18.3	24.4	9.051
e019	27.9	28.4	26.962
e037	18.2	27.0	6.691
e049	30.6	30.3	27.977
e053	21.2	24.5	10.835
e065	15.6	22.3	3.685
e068	23.8	27.3	26.130
e069	31.5	29.8	27.499
e072	22.5	25.8	13.504
e074	16.4	22.3	3.688
e110	28.4	29.2	26.156
e112	20.5	27.2	17.086
e119	27.0	28.3	25.401
e146	37.1	30.8	60.854
e149	39.2	31.4	63.124
e158	25.8	27.1	27.532
e161	34.7	30.5	55.696
e165	36.6	28.0	63.486
w007	25.0	-	-
w036	27.1	25.5	11.952
w080	24.9	-	-
w083	23.7	-	-
w089	15.4	22.2	0.461
w106	20.7	-	-
w120	20.7	-	-

range of understorey foliage density. All hickory trees within each plot were felled, bulked then weighed. This gave us the total hickory leaf weight for each of the five plots.

Leaf sub-samples were taken from each of the felled trees and the circular plots. These were weighed then fed through a planimeter to obtain a leaf area to weight ratio for all three tree species examined. We had difficulty measuring the leaf area of the silver wattle trees for two reasons. Firstly, there was substantial leaf loss when the silver wattle trees hit the ground. Secondly, it was very difficult to feed silver wattle leaves through the planimeter because their pinnate leaves had a tendency to fold over. Consequently, we felled only two silver wattle trees and have relatively poor estimates of leaf area to weight ratios for this vegetation type.

3.1 Mountain ash: destructive sampling

For the mountain ash vegetation, a leaf mass sub-sample of 4.136 kg yielded a leaf area of 9.98 m^2. This resulted in a leaf area/weight ratio of 2.412 m^2/kg. This ratio is lower than that reported by Orr *et al.* (1986) who measured a leaf area/weight ratio of 3.02 m^2/kg in 15 year old ash forest in the Picaninny catchment (see their Appendix 1).

In Table 3 we multiply the leaf weight of each of the 19 felled ash trees by our leaf area/weight ratio to obtain the leaf area for each tree. In Figure 3, the total leaf area for each tree is regressed against that trees dbh. A power function gave the line of best fit to the data and resulted in an r^2 value of 0.929 (n=19). A power function was selected because it passes through the origin and hence reflects the growth process.

The regression equation relating ash leaf area to dbh was used to estimate total leaf area for all 164 ash trees in the 50 x 50 m plot. This yielded an estimate of 5341.9 m^2 of ash leaf area for the 2500 m^2 plot which is equivalent to an LAI of 2.1 m^2/m^2.

3.2 Silver wattle: destructive sampling

For the silver wattle vegetation, a leaf mass sub-sample of 0.657 kg yielded a leaf area of 0.713 m^2. Because the pinnate wattle leaves had a tendency to fold over

Table 3. Measured leaf areas for all destructively sampled ash and silver wattle trees.

Tree	dbh (cm)	Leaf Area (m^2)
e004	22.4	36.33
e008	18.3	21.83
e019	27.9	65.03
e037	18.2	16.13
e049	30.6	67.48
e053	21.2	26.13
e065	15.6	8.89
e068	23.8	63.02
e069	31.5	66.32
e072	22.5	32.57
e074	16.4	8.89
e110	28.4	63.08
e112	20.5	41.21
e119	27.0	61.27
e146	37.1	146.78
e149	39.2	152.26
e158	25.8	66.41
e161	34.7	134.34
e165	36.6	153.13
w036	27.1	23.34
w089	15.4	0.90

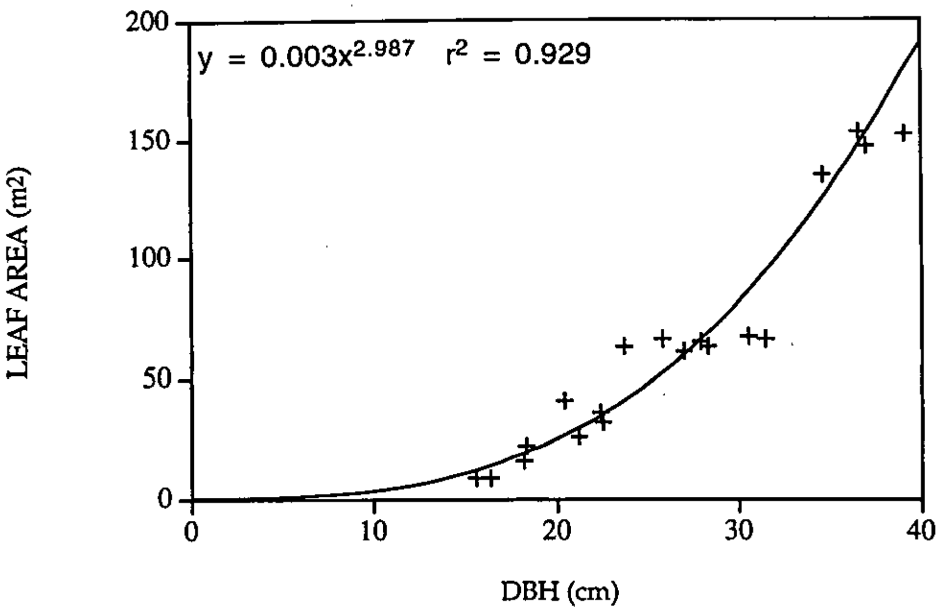

Figure 3. Relationship between dbh and leaf area for all 19 ash trees.

during passage through the planimeter, we chose to multiply the computed area by a factor of 1.8. This resulted in an area of 1.283 m^2 and hence a leaf area/weight ratio of 1.953 m^2/kg. Only two of the silver wattle trees were destructively sampled (tree numbers w089 and w036). The leaf masses for these trees were 0.461 kg and 11.952 kg respectively. These convert to leaf areas of 0.900 m^2 and 23.342 m^2. Tree w036 was the largest silver wattle in the plot with a dbh of 27.1 cm, while tree w089 was one of the smallest, with a dbh of only 15.4 cm.

In Figure 4 we plot silver wattle leaf area against dbh. Although there are only two data points available for this vegetation type we fit a power function through these points and the origin as in Figure 3 for the ash trees. The resulting line of fit indicates that leaf area (y) is related to dbh (x) by the following equation:

$$y = 0.00000013x^{5.76} \qquad (n=2)$$

Fitting such a function to only two data points is crude, but we believe it is justified on three grounds. Firstly, the function passes through the origin whereas a linear function would have produced a large negative y-intercept value. Secondly, the data includes the largest tree in the 50 x 50 m plot and while 45% of the silver wattle trees have a dbh smaller than that of tree w089 (Figure 2), they would constitute a tiny fraction of the silver wattle leaf area in the plot. Thirdly, the use of a power function seems justified based on our experience with the ash vegetation at this site.

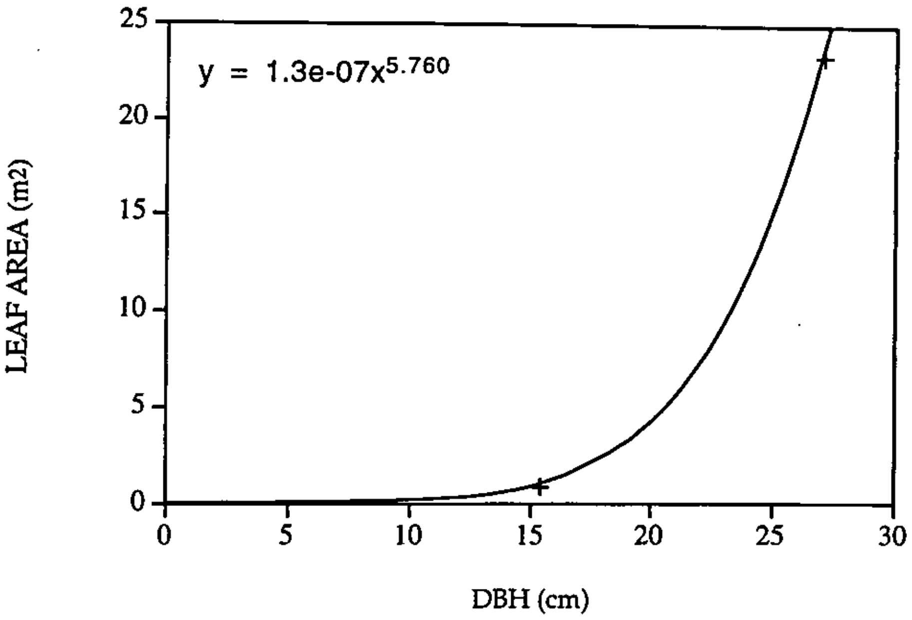

Figure 4. Relationship between dbh and leaf area for the silver wattle trees.

The regression equation relating silver wattle leaf area to dbh was used to estimate total leaf area for all 124 silver wattle trees in the 50 x 50 m plot. This yielded an estimate of 290.2 m^2 of silver wattle leaf area for the 2500 m^2 plot which is equivalent to an LAI of 0.1 m^2/m^2. This estimate is surprisingly small given the number of silver wattle stems in the 50 x 50 m plot. Fitting a different function to the two data points would give a different result, but even if this changes the computed leaf area by a factor of 2 or 3, then the silver wattle leaf area is still very low compared to the ash. More silver wattle trees need to be destructively sampled to refine LAI estimates for this vegetation type.

3.3 Mountain hickory: destructive sampling

For the mountain hickory vegetation, a leaf mass sub-sample of 0.891 kg yielded a leaf area of 3.249 m^2. This resulted in a leaf area/weight ratio of 3.646 m^2/kg. The

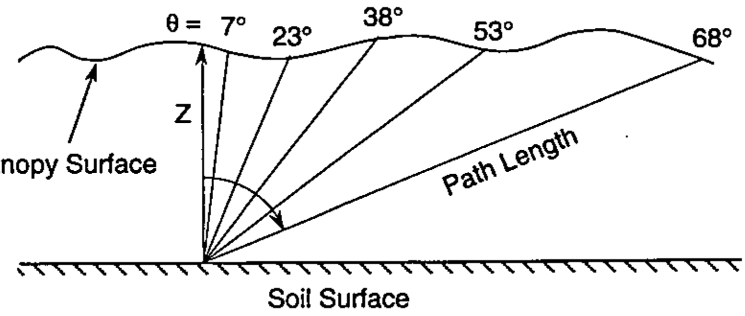

Figure 5. Zenith angles viewed with the LICOR LAI-2000 Plant Canopy Analyser.

total leaf weight harvested from the 5 circular plots was 194.38 kg. Using the ratio of 3.646 m^2/kg we obtain a total leaf area of 708.7 m^2 for the 5 circular plots. The total area of the 5 plots was 392.75 m^2, so the LAI of the hickory is 1.8 m^2/m^2.

3.4 Whole plot estimate: destructive sample estimates combined

The independent estimates of ash, silver wattle and mountain hickory leaf area index are 2.1, 0.1 and 1.8 m^2/m^2 respectively. From this we obtain a total LAI value of 4.0 m^2/m^2.

3.5 Whole plot estimate: plant canopy analyser (PCA) results

The LICOR LAI-2000 plant canopy analyser (PCA) was used to measure LAI in the 50 x 50 m plot. The PCA device measures radiation above and below the forest canopy using a fish-eye optical sensor. The sensor contains five separate concentric rings which detect light transmission values centred on five zenith angles (see Figure 5). Each ring views a different portion of the sky or canopy. For each ring, the ratio of the above and below canopy radiation reading is assumed to be the canopy gap fraction.

Leaf area is computed by summing the logarithms of canopy gap fraction values for each ring (Welles and Norman, 1991). The equation used in the PCA device to compute LAI is:

$$\mathrm{LAI} = -2\sum_{i=1}^{5} \ln(T(\theta_i)) \cos\theta_i \, w(\theta_i) \qquad \text{... (1)}$$

where $T(\theta_i)$ is the gap fraction for each ring (i) with view angle centred at θ_i and $w(\theta_i)$ is the view field weighting factor for each ring.

In tall forests it is impractical to get above the canopy or to walk out into a clearing so two PCA devices are used. One unit (referred to as the reference sensor) is left in a clearing to record light conditions automatically every 15 seconds. The other is used to measure light conditions beneath the canopy, with the operator walking around the site making multiple measurements. After the measurements are completed, the two units are linked together via a RS-232 communications cable, enabling the above- and below-canopy readings to be merged into a single file for processing.

The PCA technique is founded on four major assumptions. The first is that the foliage is black. This means that the technique should not be applied whenever the foliage is lit by direct sun. The second assumption is that the foliage elements are small relative to the area of view of each ring. This requirement is satisfied in tall forests where the leaves are a long distance from the sensor. Thirdly, it is assumed that foliage is azimuthally randomly oriented. This requires that the leaves face all compass directions, though it does not matter if the leaves are inclined in a non-random manner. Finally, the technique assumes that the foliage is randomly distributed within each foliage containing envelope. This requirement is also met in eucalypt forests.

The PCA has a large view field. For instance, in an application where no view cap is used and the vegetation is 30 m tall, the device integrates over a circular plot 74 m in radius. This reduces to a radius of 41 m if only the four inner rings of the sensor are used. Hence, many of the measurements we report "look" outside of the 50 x 50 m plot. However, we do not believe that the plot vegetation differs significantly from that in the surrounding forest.

All PCA measurements were made in overcast conditions or at dawn or dusk when there was no direct sunlight on the canopy. The reference sensor was placed in a clearing located about 1.5 km away. All measurements in the forest and clearing were made over a 360° field of view.

Three different sampling protocols were used in the application of the PCA device to the Monda site. We refer to these as the random, transect and fixed position methods. Using the random method the PCA operator moved around the plot making readings at random locations. The random measurements were repeated on four different occasions to capture a variety of sky conditions. In the case of the transect method the PCA operator made measurements at roughly 1 m intervals along two 50 m transects laid out across the plot and two 70 m transects running along the diagonals of the plot. One of the 50 m transects was measured twice, while the other 50 m transect was measured three times. Using the fixed position method the PCA operator made repetitive measurements at fixed points, designated as the centroid of each of the six circular plots. Fixed measurements were made at each of the six plots on six different occasions. Hemispherical canopy photos were also taken at these points.

Table 4 lists means of all of the LAI estimates made for the 50 x 50 m plot using the three different methods. With all methods multiple runs were made under varying light conditions so as to obtain the best possible average value of LAI. Two different

Table 4. LAI estimates for the 50 x 50 m plot made using the PCA method.

Run #	Method	n	LAI (5 rings)	LAI (4 rings)
1	Random	228	3.0	3.6
2	Random	200	3.9	4.5
3	Random	60	4.0	4.5
4	Random	200	3.6	3.8
5	Transect 1.1	50	3.9	4.4
6	Transect 1.2	50	3.9	4.2
7	Transect 2.1	55	4.0	4.4
8	Transect 2.2	55	4.4	5.0
9	Transect 2.3	55	4.0	4.5
10	Transect 3	130	3.5	3.9
11	Fixed position	36	3.6	4.1
Mean	**All methods**	**1119**	**3.8**	**4.3**

LAI estimates are shown for each of the eleven runs. The first is based on light transmittance readings obtained from all five rings in the PCA sensor. The second is based on readings from the four inner rings only.

Based on all five rings, the mean LAI values for the random, transect and fixed methods were 3.6, 4.0 and 3.6 respectively. The average for all readings obtained using all methods with all five rings was 3.8. Using light transmittance values from the inner four rings of the PCA sensor only, all LAI estimates increased. Based on the four inner rings, the mean LAI values for the random, transect and fixed methods were 4.1, 4.4 and 4.1 respectively. The average for all readings obtained using all methods with the four inners rings was 4.3. The four ring estimates of LAI are greater than those based on five rings because large gaps appear at low zenith view angles, particularly in tall vegetation. For these reasons, many users of the LICOR LAI-2000 choose to ignore light transmittance values from the outer ring when computing LAI for tall forest.

Mean LAI estimates for the each of the six circular plots are listed in Table 5. Mean values ranged between 3.1 and 3.8 using five rings and 3.2 and 4.5 using four rings. The mean LAI value for all six plots was 3.6 for the 5 ring estimate and 4.1 for the 4 ring estimate.

3.6 Whole plot estimates: hemispherical photo analysis

Multiple hemispherical photos were taken from the centroids of all six circular plots. Photo negatives were sent to Dr Barry Harper at the University of Woolongong to be scanned and analysed. The negatives were scanned using a PC-Vision Plus

Table 5. LAI estimates for the six circular plots, obtained via the PCA and hemispherical canopy photos methods.

Plot #	LAI (5 rings)	LAI (4 rings)	GFAI (Photo)
1	3.1	3.2	3.7 ± 0.8
2	3.6	4.1	4.0 ± 0.6
3	3.8	4.5	6.1 ± 1.3
4	3.7	4.2	3.7 ± 1.4
5	3.7	4.3	4.2 ± 1.0
6	3.6	4.1	4.4 ± 2.1
Mean	**3.6**	**4.1**	**4.4 ± 0.3**

video digitiser system giving a 512 x 512 8-bit image. The images were then analysed to determine the percent canopy gap as a function of zenith and azimuth angles. This gap data was then used as input to the PISCES program developed by Jupp *et al.* (1980) to determine the generalised foliage area index (GFAI) which is analogous to LAI. Although the scanned images extended to a zenith angle of 84.3° the foliage was so dense that measurements beyond 65° had little influence on the analysis. In this regard the hemispherical photo and PCA methods have comparable fields of view. It is also important to note that the gap fraction models used to estimate GFAI and LAI are very similar for the two techniques.

GFAI estimates based on image analysis of canopy hemispherical photographs are summarised in Table 5. Values for the six plots ranged between 3.7 and 6.1 and were very similar to the 4-ring PCA estimates for all but one case (plot 3). Error bounds are given for the GFAI estimates based on canopy hemispherical photos. These are quite large for individual photos (up to ± 2.0) but small for the overall mean value of GFAI for the plot (only ± 0.3).

3.7 Intercomparison of LAI estimates based on different methods

Three independent estimates of LAI were obtained for the 50 x 50 m plot based on (i) destructive sampling, (ii) the LICOR LAI-2000 PCA device and (iii) image analysis of canopy hemispherical photographs. All three methods gave similar results, the mean LAI values being 4.0, 4.3 and 4.4 respectively. The PCA and photo methods should overestimate LAI slightly because they also measure light interception caused by tree stems and branches.

3.8 Discussion

In an earlier (unreported) application of the LICOR LAI-2000 to an 8 year old ash forest in February 1993 we found good correspondence between estimated and observed leaf area. The study site was on the edge of the Myrtle II catchment, located about 4 km away from the Monda site used in the present study. The study plot had a stocking density of 5440 stems/ha, a mean dbh of 6.4 cm and a maximum canopy height of 15.7 m. The PCA device yielded an LAI estimate of 6.2. Destructive sampling of a 10 x 25 m plot of trees revealed the actual LAI of the stand to be 5.8, comprised of 5.1 for the ash trees and 0.7 for the understorey species.

The Myrtle II and Monda validation exercises both indicate that the PCA device overestimates the leaf area index by about 7%. GFAI estimates based on hemispherical canopy photography at the Monda site were in error by a similar amount. The difference between actual and estimated LAI is probably attributable to the fact that both the PCA device and photo method are affected by all light intercepting surfaces; that is, they 'see' branches and stems as well as leaves. In two studies based in oak-hickory forest in the United States , the woody area index (WAI) was estimated to be 9.8% (Neumann *et al.*, 1989) and 12% (Chason *et al.*, 1991) for total plant area index (PAI) values of 5.1 and 4.9 respectively. Lang *et al.* (1991) found WAI to be 6.6% for *Pinus radiata* forest.

In conclusion, if the projected woody area index is accounted for, then both the PCA device and canopy photo method give accurate estimates of LAI in young mountain ash forest.

4. SAPWOOD AREA

4.1 The anatomy and function of sapwood

The stem of a tree is composed of the cambium, the xylem or sapwood and the phloem or bark (see Figure 6). The centre of the tree is composed of dead wood, known as heartwood, while the outer few centimetres of the woody part of the stem is composed of bark and sapwood (Figure 6). Water and minerals for photosynthesis are conducted from the roots to the leaves of trees through the sapwood. In eucalypts (and all other flowering plants), the water conducting function is performed by specialised cells known as vessels. In mountain ash these are hollow, tube like cells, about 0.2 mm diameter, which join end-to-end to form continuous pipelike networks. The vessels comprise about 20% of the total sapwood volume (Dadswell, 1972).

4.2 Measurement of sapwood cross-sectional area

Sapwood width in the 19 sampled ash trees and 7 sampled silver wattles in the

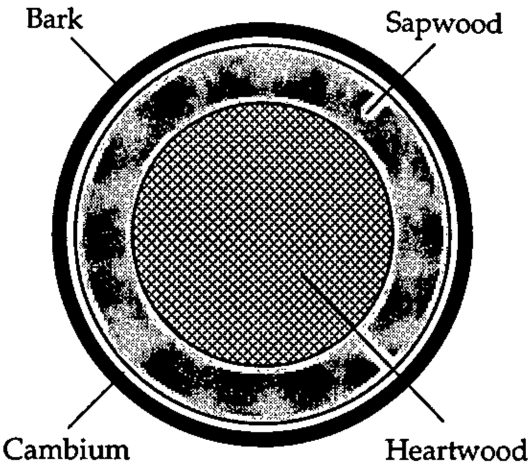

Figure 6. Diagrammatic representation of a tree stem in cross-section, showing the locations of bark, cambium, sapwood and heartwood.

50 x 50 m plot was distinguished using 5 mm diameter increment cores extracted from standing trees, and in wood discs cut from the trees felled for destructive measurement of leaf area. Increment cores were extracted from all sample trees for estimation of sapwood widths prior to implanting heat-pulse sensors.

In eucalypts, the vessels of the heartwood are usually blocked by polyphenols and tyloses. In the sapwood however, the vessels are open to permit the passage of water. The increment cores from the ash were held up to a bright light and oriented so that the light passed through the vessels. The open vessels of the sapwood were clearly visible as pinpoints of light, while the blocked vessels of the heartwood did not transmit light. In the case of the silver wattles, the boundary between sapwood and heartwood was clearly visible as a colour change.

On completion of the destructive sampling program for leaf area, more accurate measurements of ash sapwood width were made, to enable determination of sapwood cross-sectional area at breast height (1.3 m above ground level). These measurements were made on wood discs collected from the felled trees. Using this technique, the sapwood was distinguished from the heartwood by colour. After a day or two of exposure to air, the ash heartwood became brown, while the sapwood remained straw coloured.

There was considerable variation in sapwood width in some discs. In each disc, accurate estimates of mean sapwood area were obtained by measuring sapwood width at between 7 and 14 points spaced roughly evenly around the circumference. Bark thickness was also measured at several points on each disc. Twice the mean bark thickness was subtracted from mean disc diameter to give stem diameter under bark. Twice the sapwood mean width was subtracted from this value to give mean heartwood width. Stem cross-sectional area under bark and heartwood cross-sectional area were then computed and the sapwood area calculated by subtraction.

4.3 Sapwood area estimates

The sapwood areas of the 19 sample ash trees and 7 sample silver wattle trees are listed in Table 6. In the ash trees, sapwood width ranged between 12 mm (e065) and 47 mm (e146) and averaged 28 mm. Sapwood areas in the ash trees ranged between 50.5 and 451.8 cm^2 and averaged 207.8 cm^2. In the silver wattle trees, sapwood width ranged between 17 mm (w089) and 45 mm (w007) and averaged 30 mm. Sapwood areas in the silver wattle trees ranged between 72.1 and 278.5 cm^2 and averaged 184.5 cm^2.

Table 6. Mean sapwood width and sapwood area for all sample trees.

Tree	Mean Sapwood Width (mm)	Sapwood Area (cm^2)
e004	20	121.3
e008	20	96.1
e019	29	215.0
e037	14	66.0
e049	28	233.0
e053	16	93.5
e065	12	50.5
e068	36	212.6
e069	31	261.0
e072	24	140.0
e074	14	62.5
e110	31	234.7
e112	21	116.1
e119	33	236.4
e146	47	451.8
e149	38	401.1
e158	30	198.0
e161	39	352.9
e165	42	406.4
w007	45	278.5
w036	32	236.2
w080	31	204.5
w083	34	208.3
w089	17	72.1
w106	33	178.3
w120	20	113.7

Figure 7a shows that for ash trees, sapwood area (y) could be reliably predicted from dbh (x) using the equation:

$$y = 0.101x^{2.306} \qquad (r^2=0.95, n=19)$$

Using this equation, the sapwood area for every ash tree in the 50 x 50 m plot was estimated. Total sapwood area for the 164 ash trees was 20,102.4 cm^2, or 8.04 m^2/ha. Dunn and Connor (1991) cite sapwood area values for 50, 90, 150 and 230 year old ash forests of 6.74, 6.09, 4.23 and 4.04 m^2/ha respectively.

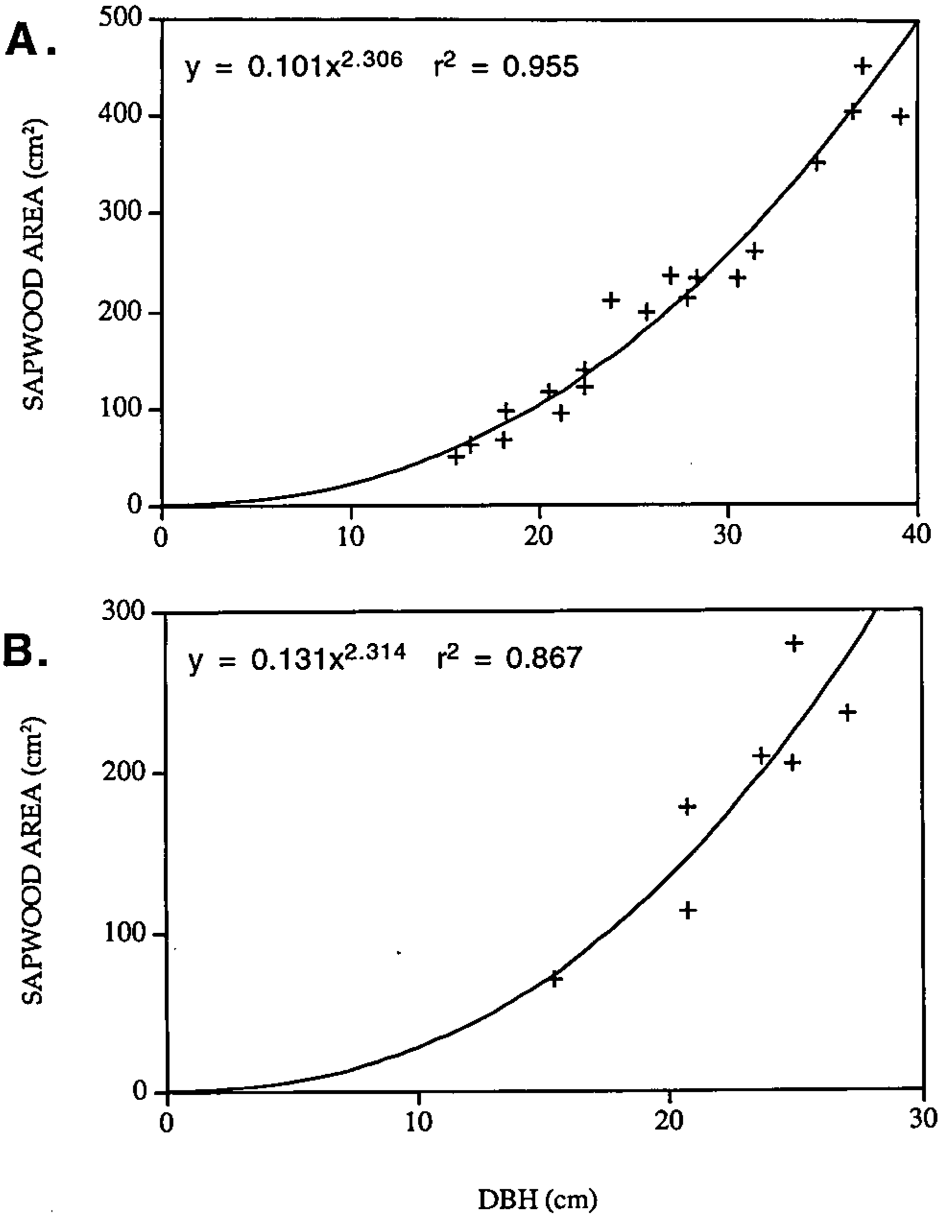

Figure 7. Relationships between dbh and sapwood area for (a) 19 ash trees and (b) 7 silver wattle trees.

Figure 7b shows that for silver wattle trees, sapwood area (y) could also be reliably predicted from dbh (x) using the equation:

$$y = 0.131x^{2.314} \qquad (r^2=0.87, n=7)$$

This equation is very similar to that obtained for the ash trees. Extrapolating on the basis of the known silver wattle dbh distribution, the sapwood area for all 124 silver wattle trees in the 50 x 50 m plot was computed to be 10,401.8 cm^2, or 4.16 m^2/ha. This is equivalent to 34.1% of the combined overstorey sapwood area.

4.4 Variability of sapwood width within individual trees

Accurate measurement of sapwood area is essential in calculating tree water use. Heat pulse studies rarely involve destruction of the sample trees and usually rely on a small number of increment cores for determination of mean sapwood width. Table 7 indicates that even in young ash trees that appear uniform in cross-section, there is considerable variation in the width of the sapwood at breast height within individual trees. In most cases, a single sample of sapwood width in these trees would not have provided an accurate estimate of the mean sapwood width. For instance, Table 7 shows that in the worst case (e149), a single sample may have

Table 7. Variability of sapwood widths within individual ash trees.

Tree	dbhob (cm)	Mean Sapwood Width (mm)	Standard Deviation (mm)	Range of Values (mm)	Number of Measurement Points	Number of Samples Needed*
e004	22.7	20	3	15-23	8	2
e008	18.3	20	1	18-22	8	1
e019	28.1	29	2	28-32	8	2
e037	18.2	14	3	10-18	8	2
e049	30.6	28	4	21-33	12	3
e053	21.2	16	2	14-20	8	2
e065	15.6	12	1	10-13	8	1
e068	23.8	36	2	33-40	7	2
e069	31.5	31	3	26-36	8	2
e072	22.5	24	5	15-31	8	4
e074	16.4	14	2	12-17	8	2
e110	28.4	31	6	22-42	12	6
e112	20.9	21	3	18-26	8	2
e119	27.3	33	3	29-37	8	2
e146	37.1	47	3	41-53	10	4
e149	39.2	38	8	25-48	13	10
e158	25.8	30	3	27-33	8	2
e161	34.7	39	3	29-38	8	2
e165	36.6	42	6	32-52	14	6

*(to achieve 95% confidence limits of ±5mm)

produced an estimated sapwood width between 25 and 48 mm when the true mean was 38 mm. However, in most of the 19 ash trees analysed, two or three core samples would give an estimate of the mean sapwood width within 5 mm of the true mean with 95% confidence.

In the stem discs analysed, sapwood width was more variable in the larger diameter trees due to slight buttressing. In these trees, wider sapwood occurred at the buttresses, while the narrower sapwood occurred between the buttresses. If relying on cores for sapwood area estimation, a more accurate estimate would be obtained by avoiding obvious buttresses and depressions between buttresses. We recommend that several core samples be taken in each tree, and preferably well above the buttressed stem.

4.5 Relationship between sapwood area and leaf area

Figure 8 shows that there is a strong relationship between sapwood area and leaf area in the ash trees. Again, the line of best fit is a power function. It shows that leaf area (y) can be reliably predicted from sapwood area (x) using the following equation:

$$y = 0.063x^{1.288} \qquad (r^2=0.96, n=19)$$

Insufficient leaf area measurements for the silver wattle trees preclude us from developing a comparative equation for the silver wattles.

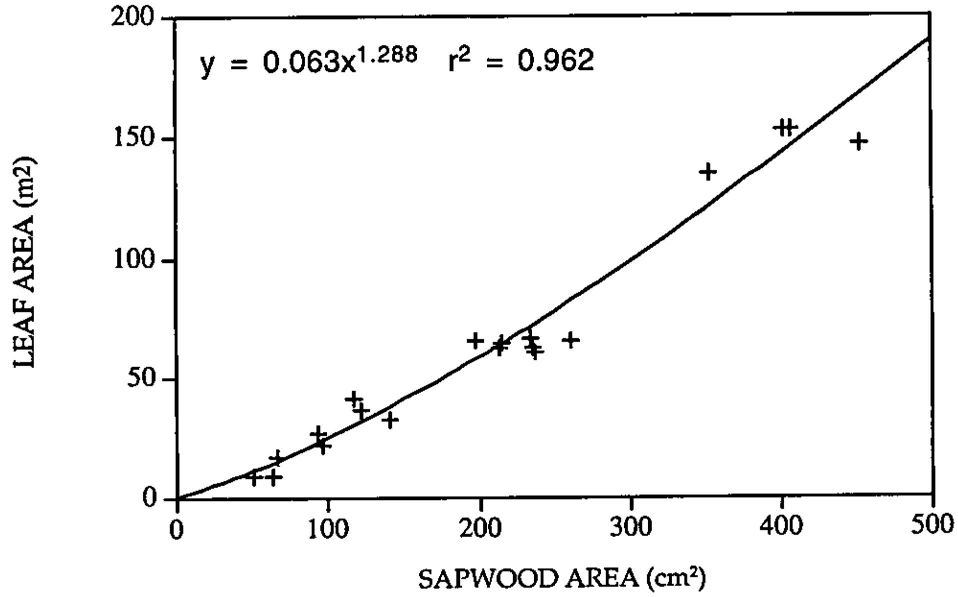

Figure 8. Relationship between sapwood area and leaf area for all 19 ash trees.

5. TREE WATER USE

In the tree water use component of this study we deployed six Greenspan Technology Sapflow Sensors for a period of 39 days using a fixed/roaming sensor technique. This involved leaving one sensor in a reference ash tree (tree e004) and another in a reference silver wattle tree (tree w036) for the entire 39 day measurement period. The other four sensors were then moved from tree to tree after a short measurement period, varying in length between five and nine days. For each of the six measurement periods, three of these roaming sensors were deployed in ash trees and the fourth in a silver wattle tree. The periods of record are shown in Figure 9. No water use measurements were made in the mountain hickory vegetation.

5.1 Climatic conditions

Daily patterns of radiation, temperature and wind run for the measurement period are graphed in Figure 10. These data were recorded at the nearby Slip Creek catchment in the Coranderrk Experimental Area at a similar elevation to that of the Mt. Monda catchment. The record is incomplete due to failure of the climate station logging system during the first half of the experiment. Climate data is only available for the final 18 days of the experiment (21/10/93 - 7/11/93).

Period	Sampled Trees	Start	End
A	e004, e019, e112, e119, w036, w106	24 / 9	1 / 10
B	e004, e068, e072, e158, w036, w080	6 / 10	12 / 10
C	e004, e069, e074, e161, w036, w089	12 / 10	21 / 10
D	e004, e053, e149, e165, w036, w007	21 / 10	27 / 10
E	e004, e037, e049, e110, w036, w120	27 / 10	1 / 11
F	e004, e008, e065, e146, w036, w083	2 / 11	8 / 11

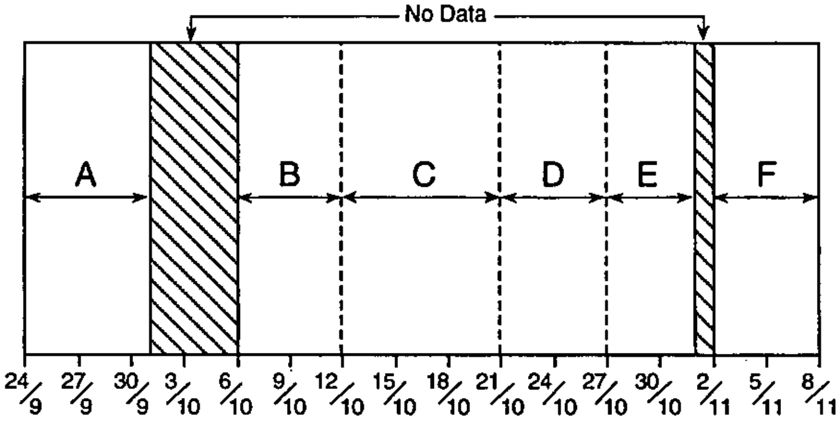

Figure 9. Timeline of heat pulse measurements.

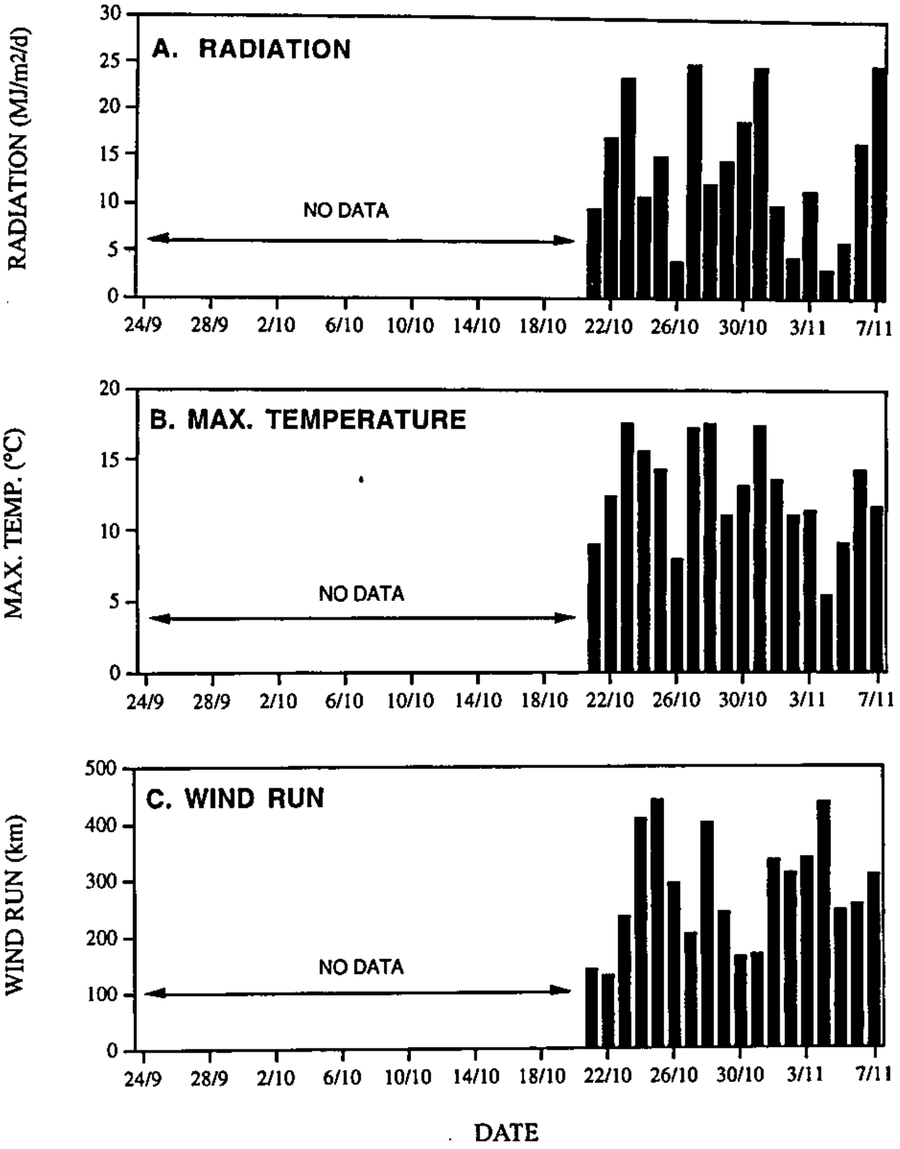

Figure 10. Total daily solar radiation, maximum daily temperature and daily wind run during the time of the experiment.

Mean daily minimum and maximum temperatures for the period of record were 4.4°C and 12.8°C respectively. These values are slightly lower than the long-term average temperatures for the site in October/November (7.3°C and 13.4°C) (Langford and O'Shaughnessy, 1977). Total solar radiation varied between 3.1 and 25.1 MJ/m^2/d during the period of record, with a mean value of 13.9 MJ/m^2/d. According to Langford and O'Shaughnessy (1977), the mean daily radiation for October/November (based on three years of record) for this area is 13.2 MJ/m^2/d. Mean above canopy wind speed during the 18-day period of record was 3.2 m/s. Over the last 18 days of the experiment there were four rain days in which a total of 44 mm of rain fell. This is well below the reported average number of rain days and rainfall amount measured for this time of year at the site (Langford and O'Shaughnessy, 1977).

5.2 Mountain ash water use

Figure 11a shows the daily water use of the reference ash tree (tree e004) over the 39-day measurement period. Water use varied between 9 and 43 l/d during this period, the mean value being 25 l/d. Water use declined during the latter part of the experiment as weather conditions deteriorated.

Daily water use values for the other 18 ash trees were regressed against daily water use from tree e004. The regression details are listed in Table 8. The statistical association between daily water use in different trees was very strong with r^2 values exceeding 0.9 in over half the cases. Slopes of the relationships varied between 0.230 (for tree e065) and 5.810 (for tree e149).

Total and mean daily water use over the 39-day measurement period was estimated for all 19 ash trees (Table 9). Total water use varied between 259 l (tree e065) and 5874 l (tree e146), thus varying by over a factor of 20. The mean of the 19 total water use estimates was 2416 l. The five highest water-using ash trees (e049, e146, e149, e161 and e165) used 48% of the total for all 19 trees. Mean daily water use varied between 6.6 l/d (tree e065) and 150.6 l/d (tree e146). Mean daily water use for all 19 ash trees was 62 l/d.

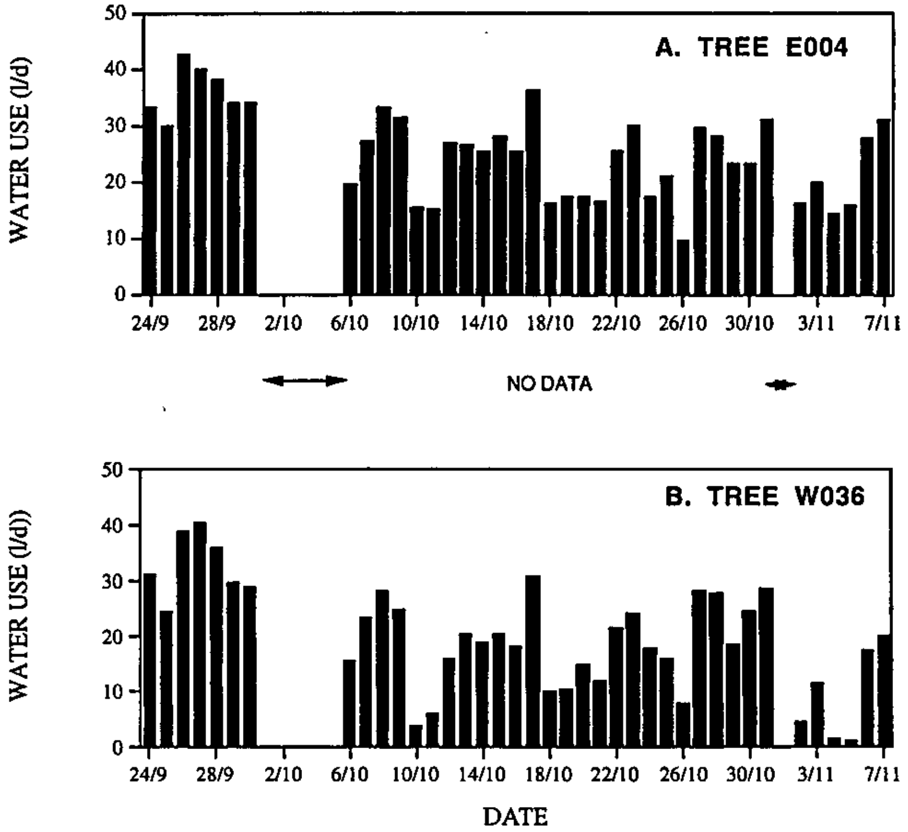

Figure 11. Daily water use by trees e004 and w036 during the experiment.

Table 8. Details of linear regressions of daily ash tree water use relative to tree e004.

Tree #	r^2	n	y-intercept	Slope
e008	0.42	5	7.1	0.601
e019	0.92	7	13.1	1.719
e037	0.81	4	12.7	0.418
e049	0.94	4	-17.3	4.124
e053	0.96	5	-2.5	1.219
e065	0.46	5	0.8	0.230
e068	0.88	5	-0.8	2.953
e069	0.92	8	-8.9	3.024
e072	0.96	5	8.3	1.179
e074	0.85	8	7.1	0.319
e110	0.92	4	-11.5	3.430
e112	0.77	7	13.8	0.867
e119	0.71	7	31.5	1.481
e146	0.88	5	9.5	5.559
e149	0.96	5	-12.4	5.810
e158	0.96	5	-9.0	2.891
e161	1.00	8	-15.3	5.139
e165	0.96	5	-11.2	3.899

The average mean daily sapflow velocity for all 19 ash trees was 11.9 cm/h. Dunn and Connor (1991) list mean daily sapflow velocities for several trees in four different age groups (50, 90, 150 and 230 years of age), measured during two periods (8/1/90 - 4/4/90 and 28/10/90 - 16/4/91). For their 50 year old trees (n=19) the mean

Table 9. Total and mean daily water flux and mean sapflow velocity for all 19 ash trees over the 39 day measurement period.

Tree #	Total Flux (l)	Mean Flux (l/d)	Mean Velocity (cm/h)
e004	990	25.4	8.7
e008	872	22.4	9.7
e019	2213	56.7	11.0
e037	909	23.3	14.7
e049	3408	87.4	15.6
e053	1020	26.2	11.7
e065	259	6.6	5.5
e068	2893	74.2	14.5
e069	2647	67.9	10.8
e072	1491	38.2	11.4
e074	593	15.2	10.1
e110	2947	75.6	13.4
e112	1397	35.8	12.8
e119	2695	69.1	12.2
e146	5874	150.6	13.9
e149	5269	135.1	14.0
e158	2511	64.4	13.6
e161	4491	115.2	13.6
e165	3424	87.8	9.0

velocity over both periods of record was 11.5 cm/h. Mean velocity values for their 90, 150 and 230 year old trees (n=5, 5 and 7 respectively) were 11.4, 9.9 and 11.8 cm/h respectively. The observed mean velocity of 11.9 cm/h for the Monda trees is thus very similar to that reported by Dunn and Connor (1991) despite the younger age of the Monda forest and the shorter period of record. However, we do note large variation in mean sapflow velocity amongst the 19 ash trees sampled. Mean daily sapflow velocity ranged between 5.5 cm/h (tree e065) and 15.6 cm/h (tree e049) over the 39-day measurement period. There was no systematic relationship between tree size and mean sapflow velocity.

A strong association is evident between mean daily tree water use and leaf area amongst the 19 ash trees. Figure 12 plots mean daily water use of each ash tree (y) against its leaf area (x), yielding the following power function regression equation:

$$y = 1.536x^{0.890} \qquad (r^2 = 0.914, n = 19)$$

It is interesting to note that the relationship between leaf area and water use is almost linear. Contrary to expectation, the larger trees appear to have a slightly lower water use per unit leaf area than the smaller trees. This is surprising because the dominant trees receive more radiation and are subject to higher wind speeds and lower humidity.

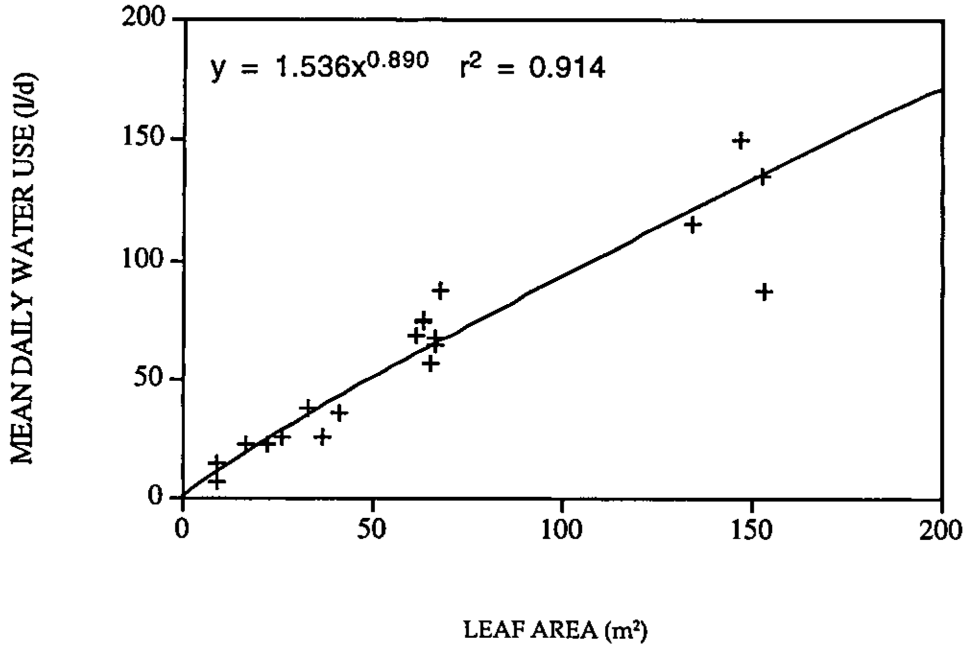

Figure 12. Relationship between leaf area and mean daily tree water use for all 19 ash trees.

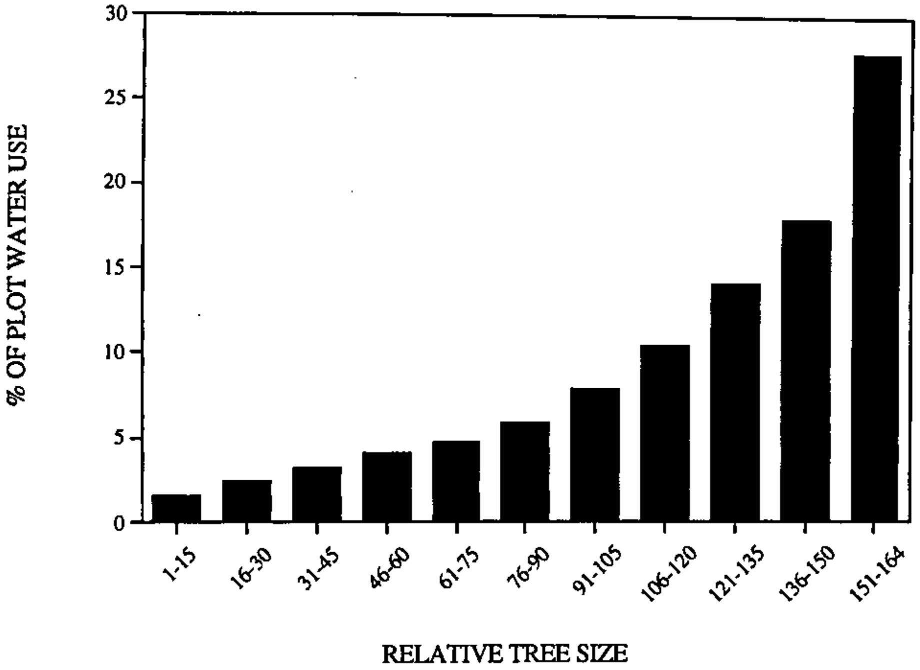

Figure 13. Relative water use by ash trees of different sizes in the 50 x 50 m plot.

The distribution of ash tree water use in the 50 x 50 m plot is highly skewed. Figure 13 shows the relative water use (expressed as a percentage of the plot total) of ash trees of different size classes. The size classes used are ranked dbh values where the 164 ash trees are grouped into eleven classes. Hence class 1-15 refers to the 15 ash trees with the smallest dbh values in the plot. Figure 13 shows that the 14 largest ash trees in the plot are responsible for 27.8% of the total ash water use in the plot. On the other hand, the 90 smallest ash trees in the plot are responsible for only 21.8% of the total ash water use in the plot.

5.3 Silver wattle water use

Figure 11b shows the daily water use of the reference silver wattle tree (tree w036) over the 39-day measurement period. Water use varied between 1 and 40 l/d and the mean daily water use was 20 l/d during this time. Water use in tree w036 was similar to that in e004 on high water use days (i.e. > 20 l/d). However, on low water use days (when low radiation conditions prevail) water use in the silver wattle fell away significantly relative to that in tree e004.

Daily water use for tree w036 was regressed against that measured for the other six silver wattle trees sampled. Statistically significant relationships were obtained for only three of the other six silver wattle trees (Table 10). Trees w007, w080 and w089 displayed daily water use behaviour similar to tree w036 ($r^2>0.9$). Table 11

Table 10. Details of linear regressions of daily silver wattle tree water use relative to tree w036.

Tree #	r^2	n	y-intercept	Slope
w007	0.94	5	-9.65	3.344
w080	0.98	5	16.38	1.443
w083	0.96	6	0.84	0.863
w089	0.06	8	n/a	n/a
w106	0.31	7	12.35	0.413
w120	0.04	4	n/a	n/a

lists the total and mean daily water use values and mean daily sapflow velocity for these three trees and the reference tree over the 39 day measurement period. We have excluded the other three trees from the foregoing analyses.

Total water use varied between 772 l (tree w036) and 2296 l (tree w007). The mean of the four total water use values for the silver wattles was 1400 l. Mean daily water use varied between 19.8 l/d (tree w036) and 58.9 l/d (tree w007). The average mean daily water use for the four silver wattle trees was 35.9 l/d.

Mean daily water use values for the silver wattle trees are about 58% of those observed for the 19 sampled ash trees. However, the difference between the two species is far greater than this simple comparison suggests. Trees w007, w036, w080 and w083 were amongst the largest silver wattles in the 50 x 50 m plot. On the basis of dbh values they were in the top 35% of trees in the plot (see Table 2 and Figure 2). On the other hand, the 19 sampled ash trees span the full range of ash tree size classes in the plot. Hence, the four silver wattles we refer to above tend to exaggerate the relative importance of this species in the plot water balance.

Mean daily sapflow velocities for the four silver wattles varied considerably, ranging between 3.5 cm/h (tree w036) and 9.2 cm/h (tree w080). The average value for the four trees was 6.4 cm/h which is just over half the average value observed for the

Table 11. Total and mean daily water flux and mean sapflow velocity for 4 silver wattle trees over the 39 day measurement period. Note: Totals were not computed for trees w089, w106 and w120 due to poor correlations with tree w036.

Tree #	Total Flux (l)	Mean Flux (l/d)	Mean Velocity (cm/h)
w007	2296	58.9	8.8
w036	772	19.8	3.5
w080	1756	45.0	9.2
w083	779	20.0	4.0

19 sampled ash trees. The observed value of 6.4 cm/h is almost twice that reported by Dunn and Connor (1991) for a 50 year old *Acacia frigrescens* understorey beneath a 230 year old ash canopy. This is not surprising given that the silver wattles at the Monda site are relatively closer to the canopy than the *Acacia frigrescens* sampled by Dunn and Connor (1991).

5.4 Estimates of tree water use for the 50 x 50 m plot

Mountain ash tree water use was strongly related to dbh (Figure 14). This enabled us to extrapolate our sub-sampled ash tree water use measurements across the entire 50 x 50 m plot where we have recorded the dbh of all 164 ash trees in the plot. The regression equation in Figure 14 relates mean daily tree water use (y) to dbh (x) using the following equation:

$$y = 0.008x^{2.706} \qquad (r^2 = 0.879, n = 19)$$

Using this equation the mean daily water use for all ash trees in the 50 x 50 m plot was 5740 l/d. Expressed on an area basis, this converts to 2.3 mm/d.

Unlike in the ash trees, there was no consistent relationship between mean daily water use and dbh for the silver wattles (*sensu* equation in Figure 14). This restricts us from computing a proper plot water use figure for this species, though an estimate can be made using observed sapwood area to tree water use ratios.

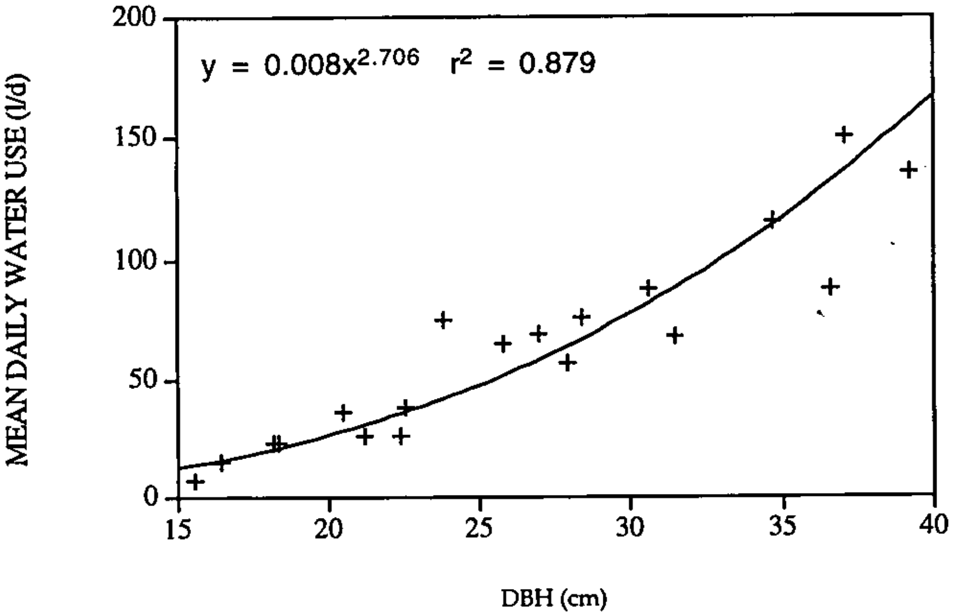

Figure 14. Relationship between dbh and mean daily tree water use for all 19 ash trees.

The mean sapwood area and mean daily water use for the 19 sampled ash trees was 207 cm^2 and 62 l/d respectively. Comparative values for the four silver wattles were 232 cm^2 and 35.9 l/d. This indicates that for roughly the same sapwood area the silver wattle used about half as much water as the ash. Given that the ash has twice as much sapwood area within the 50 x 50 m plot (section 4.3) we can infer that the mean daily silver wattle water use would be about 25% of the value for the ash. This amounts to 0.6 mm/d.

Based on the reasoning outlined above, the mean daily water use for the ash and silver wattle combined over the 39 day measurement period was 2.9 mm/d. Transpiration from the hickory understorey and soil evaporation are not accounted for in our estimate of the plot water balance.

6. SUMMARY

A 50 x 50 m plot was established in a 15 year old mountain ash (*Eucalyptus regnans*) forest stand adjacent to the Monda III catchment in Melbourne Water's North Maroondah experimental area. The stand contained silver wattle (*Acacia dealbata)* as a sub-dominant overstorey species and mountain hickory (*Acacia frigrescens*) as a understorey species. There were 164 ash trees and 124 silver wattle trees in the plot. Mean heights of these trees were 27 and 24 m respectively. During October and November 1993 a survey was conducted of tree diameters, leaf area, sapwood area and tree water use.

Leaf area index (LAI) was estimated by (i) destructive sampling of trees, (ii) the use of a LICOR LAI-2000 Plant Canopy Analyser (PCA) and (iii) digitisation of hemispherical canopy photos. The destructive sampling was restricted to 19 ash trees, 2 silver wattle trees and hickory covering a ground area of 393 m^2. Destructive sampling revealed the LAI of the ash to be 2.1 and the LAI of the hickory to be 1.8. The LAI of the silver wattle was only 0.1, resulting in a total plot LAI of 4.0. The LAI estimates from the PCA and photo analysis methods were 4.3 and 4.4 respectively. The PCA device and photos method both overestimate LAI by about 7%. This difference is commensurate with published figures for the woody area index (WAI) of forests. We conclude that the PCA method is a simple, rapid and accurate technique for LAI estimation in young ash forest.

Sapwood area was measured in 19 ash trees and 7 silver wattles. There was a strong association between sapwood area and tree dbh in both species (r^2 values were 0.95 and 0.87 respectively). This enabled a robust plot estimate of sapwood area to be made for both tree types. The plot-based sapwood areas for the ash and silver wattle were 8.04 and 4.16 m^2/ha respectively. Sapwood width was found to be quite variable in the ash trees. It is recommended that multiple cores be taken in each sampled tree for a robust estimate of sapwood width.

Tree water use was measured in 19 ash trees and 7 silver wattles using the heat pulse technique over a 39 day period. Three of the silver wattles gave anomalous results so robust water use data are available for only four silver wattles. Mean daily water use for the ash was 62 l/d and 36 l/d for the silver wattle. The silver wattle estimate significantly exaggerates the relative water use of this species in the plot because it is based on four of the largest trees in the plot. Mean sapflow velocities for the ash and silver wattle trees sampled were 11.9 and 6.4 cm/h respectively.

In the ash trees there was a strong association between mean daily water use and tree dbh (r^2=0.91). Scaling up individual tree water use to a whole plot on the basis of our ash dbh census, we found the mean daily transpiration of the ash trees to be 2.3 mm/d. The association between tree water use and dbh was less strong for the silver wattle trees, due in part to the small number of silver wattle trees sampled. Our best estimate of mean daily water use for the silver wattle component of the plot is 0.6 mm/d. This is a high figure given the small amount of leaf area present in this species.

Water use in the ash trees was found to be highly skewed; the 14 largest trees in the plot of 164 individuals transpired almost 28% of the water while the 90 smallest individuals transpired only 22%. This finding emphasises the need to sample a spectrum of tree sizes when attempting to estimate plot water use.

Strong correlations were observed between tree dbh, sapwood area, leaf area and tree water use in the ash trees. Perhaps one of the most significant findings of the study was that ash dbh could explain 93% of the variation in ash leaf area, 96% of the variation in ash sapwood area and 88% of the variation in mean daily ash tree water use.

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