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A Joint Project on the Water Use of a Mallee Community in Late Summer

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Evapotranspiration in a mallee community proceeded at rates of less than 0.8 mm d^{-1} in late summer. Evidence was gathered by a wide range of techniques. The value of modelling from meteorological data to estimate plant productivity is discussed. It seems likely that models would be improved by including plant responses such as cavitation and storage. Airborne measurements appear to be a valuable technique to study regional scales of energy fluxes.

Estimates of water use of plant communities have made an important contribution to the development of management models for the making and implementation of decisions regarding the vegetation resources of the communities. Usually, vegetation production is expressed as a simple function of rainfall, within bounds, and data on the latter are obtained from meteorological records (Leith 1976). Within this approach, we note that a large degree of uncertainty may be associated with the rate of conversion of rainfall to biomass, or the water-use efficiency (Miller & Mooney 1976). An important concept, that of uncoupling of the canopy from environmental influences by the lowering of the canopy conductance, has been advanced as a means of comparing the conservative influence of different plant communities on their water resources (Jarvis & McNaughton 1986). There is a common assumption that there is little movement of rainfall into other parts of the hydrological cycle, and storage is usually ignored over a long time-frame.

Although we do not wish to deny the overall approach, there does appear to be a need to examine new advances in evapotranspiration measurement. These provide scope for a better scaling of direct measurements to a regional basis tenable to other models, provide for better understanding of the factors influencing the fluxes of water, and allow the characterisation of the extent of diffusion control (in stomatal and soil-vapour stages) on the overall flux of water vapour.

Thus, we describe extensive, collaborative efforts to measure energy fluxes over a mallee community. In describing our results, we also comment on particular processes in evapotranspiration that we believe are relevant to the mallee.

Instrumentation

We examined evapotranspiration(ET) rates over a two week period in mid-March 1988 in Hincks Conservation Park, a mallee community on Eyre Peninsula (33°53'S, 135°52'E), where mallee covers around 20% of the surface. A number of micrometeorological techniques were used to estimate total energy fluxes. These included a rotating Bowen ratio tower, an aerodynamic method tower, which also supported a sond which was movable vertically, a simplified aerodynamic tower, a radiometer tower, a tower measuring CO_2 assimilation rate and water vapour pressure gradients using infra-red (IR) gas analysis at two levels, and a tower sampling water vapour for analysis of stable isotope composition.

Heat pulse and porometry provided estimates of the contribution of mallee. The soil water content, and isotopic composition of liquid water in soil, plant foliage and stem, and of water vapour in the atmosphere, were examined in an attempt to confirm the daily cycle of ET.

Over wider areas, energy fluxes were examined using an aircraft as a platform for eddy correlation instrumentation (see Hacker & Schwerdtfeger 1988). The aircraft also carried an IR surface temperature meter and a video camera that has been used for ground cover partitioning in association with graphic digitizing software. Satellite images were obtained for several days, however cloudy conditions prevailed over a number of these. Measurable rainfall occurred on three days.

Vegetation and Site Survey

A survey of the mallee (*Eucalyptus socialis* and *E.leptophylla*) found that stems averaged around 26 mm in diameter (Figure 1). This suggests an average age of 13 to 15 years based on observation of growth rings, indicative of the influence of fire. The leaf area index was measured to be 0.24, over a sample of 14 stems, by leaf area meter.

The measurements were undertaken in Hincks Conservation Park in mid-March 1988. A survey observed that the dune crests were around 5 m above the surrounding land. Dunes were around 450 m away, on either side of the instrumented site, although this spacing was larger than normal. A second site on bare farmland 60 km to the north east of the mallee was also instumented for comparison with the aircraft measurements.

Sensible and Latent Heat Flux Measurements

A range of estimates of latent and sensible heat fluxes were obtained by the different methods. A major area of interest to us was to verify that the airborne eddy correlation instrumentation was providing comparable measurements to ground-based instruments, since it would then provide a convenient survey tool. We found that the airborne measurements of the heat fluxes were approximately 10-25% lower than the fluxes as measured by the Bowen Ratio method (Figure 2). The Bowen Ratio determinations employed gradient measurements of humidity by infra-red gas analysis.

The heat fluxes marked with a "9" in Figure 2 were measured during the passage of a sea-breeze front over the site. As advective processes play a major role under such circumstances, the difference in the measured fluxes between the Bowen Ratio method and the airborne technique is considerably bigger.

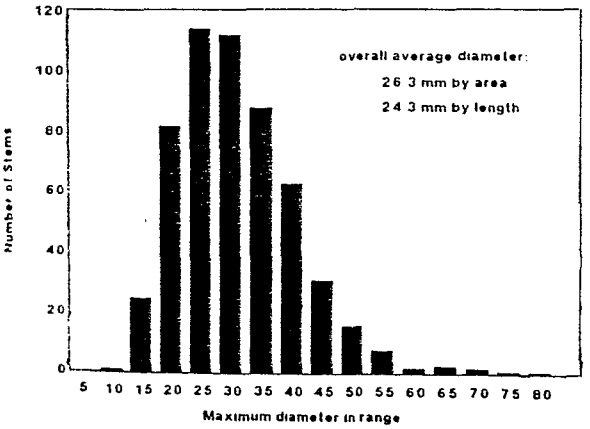

Figure 1 *Distribution of stem diameters of some 583 mallee stems at Hincks Conservation Park, over 5 mm intervals. Data from all species combined.*

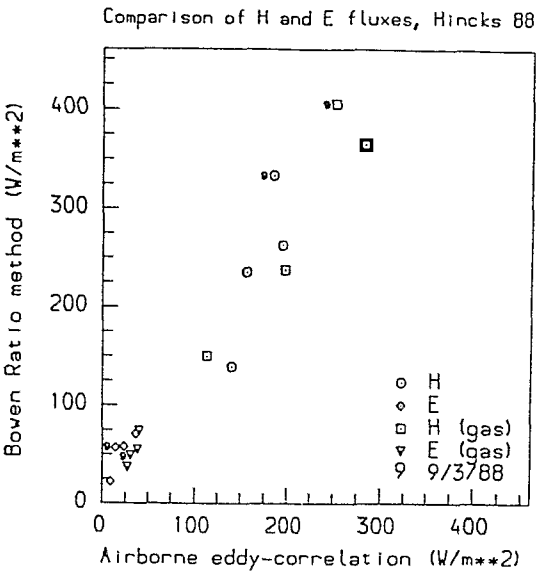

Figure 2 *Comparison of energy fluxes measured by airborne eddy correlation technique and Bowen Ratio method. The points marked with a "9" were measured during the passage of a sea-breeze front over the site.*

Examining data from the Bowen ratio and various temperature measurements (Figure 3), there was a clear correlation between the soil to air temperature difference and the sensible heat flux, suggesting that the convection of sensible heat is generated by soil heating. The data fitted a theoretical relationship advanced elsewhere (Riou & Itier 1982, Brunel 1989). A less well defined relationship was observed for canopy temperature, which was more uniform - typically no more than 5° warmer than air during daylight, whereas the soil was up to 26° warmer than the air at 2 m. Recent theoretical studies suggest that a discontinous canopy, as in the mallee, can generate circulation of air along these lines (Finnegan & Raupach 1987), rising over hot surfaces while replacement parcels move downward through cooler surfaces such as canopy.

The overnight conditions could be quite cold and dewfall was observed on some mornings. The evaporation of dew influenced the specific humidity on the morning of the 7 March (Figure 4). Overnight vapour pressure deficit at 1.5 m (Figure 4) was low and the ground temperature would have been (say) 5° lower. An inversion was observed on this morning, with the colder moist air remaining cloaking the ground until around 9 a.m. (Figure 5). Heating of air at the ground eventually dispersed this inversion.

Transpiration and Latent Flux

Sapflow measured by heat pulse was lower than the total latent flux measured by Bowen ratio. Some 75

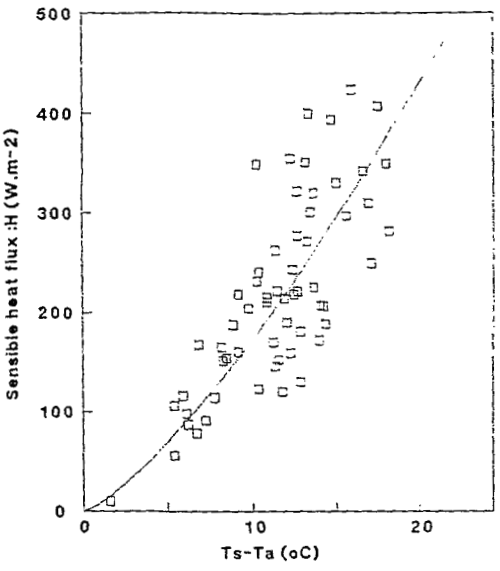

Figure 3 *Dependence of sensible heat flux on surface to air temperature difference. The fitting of a power curve to this data (Constant: 4.5, exponent: 1.5, r^2 = 0.8) is suggested by theory (see text).*

cumulative daily water uses by individual stems were obtained, over a nine day interval. Different scaling techniques were considered, after studying the relationships between sapflow and the physical dimensions of the plants (Table 1). Positive correlations between plant foliage and stem dimensions have been reported elsewhere (Espinosa Bancalari *et al.* 1987). While the relationship between foliage area and sapflow proved to have the highest correlation coefficient, and should perhaps be used to scale up the sapflow measurements to an areal contribution from the mallee for this reason, we reasoned that the large numbers of stem diameter measurements to hand (Figure 1), probably provided a better estimate of the mallee contribution. The variation between the different estimates appears to due to the size of the population measured for sapflow, which was generally larger stems, compared to the total population.

Transpiration rates measured by porometry yielded comparable estimates to the heat pulse (Figure 6). Slightly higher foliage fluxes reflect storage of water within the stem (Schulze *et al.* 1985). A lag of sapflow after the morning increase of latent flux was typical (Figures 7,8), and is also due to stem storage (Schulze *et al.* 1985).

Thus, we found that the latent fluxes (by IR gas analysis and airborne eddy correlation) were of the order of 0.4 mm d^{-1} from the community and around 0.24 mm d^{-1} from the mallee, by heat pulse. It appears

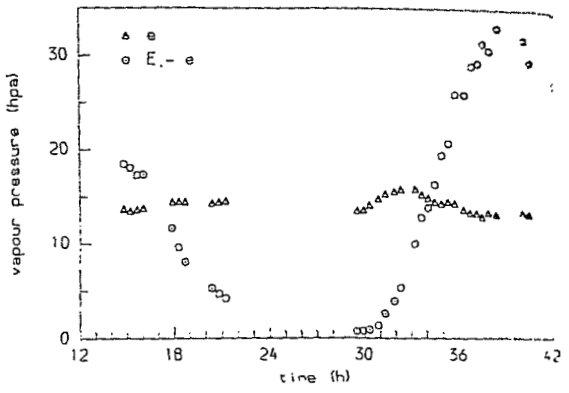

Figure 4 *Time course of atmospheric vapour pressure and vapour pressure deficit on 6 and 7 March 1988. Time is shown in hours from midday on 6 March.*

that soil moisture is still a significant water source, which is slightly suprising in light of the very dry summer experienced by this region. Comparing the ratio of sapflow to total latent fluxes with the Leaf Area Index (LAI), we note that the plants contribute more moisture than the soil on an area basis.

Sapflow fitting to Environmental Parameters

Brief fluctuations in evaporation, apparently due to the passage of cloud cover, were in correspondence with the heat pulse and Bowen ratio traces, particularly in the afternoons (Figures 7,8). Multiple regression analysis of cumulative daily sapflows against all measured plant dimensions (Table 1) and environmental parameters (net radiation, vapour pressure deficit, temperature, wind speed; all integrated over a daily basis to day-degrees) obtained an r^2 of 0.92, n = 75. This was dominated by the plant dimensions. Variation of actual sapflow at individual sensors within trees over single days (on just environmental parameters) was dominated by net

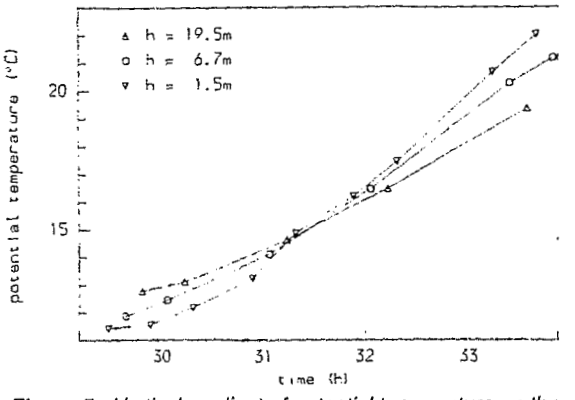

Figure 5 *Vertical gradient of potential temperature on the morning of 7 March. Note the increase in vapour pressure with evaporation on this morning (Figure 4) and the presence of an inversion maintaining this cool air near the surface. Time as in Figure 4.*

Table 1 *Regressions of Sap Flow Rates Against Stem Dimensions*, and Leaf Area.*

Relation Form	r^2	A+	B
Flow = A (Leaf Area) + B	0.713	288	42
Flow = A (Sapwood Area) + B	0.730	57.4	108
Flow = A (Diameter) + B	0.639	366	-952
Flow = A (Basal Area) + B	0.671	52.1	-171

*number of stems = 14

+Units of l d^{-1} for flow, leaf area in m^2, basal area and sapwood area in cm^2, diameter in cm

radiation and temperature, with r^2 values averaging 0.83 ± 0.13 (200) (Correll 1989), despite vapour pressure deficit not being considered in this fitting, because of inadequate detail of the data. This leads us to support the observation that prediction of both daily water use and instantaneous flow rates can be made fairly accurately based on measurements made external to the stem (Edwards & Warwick 1984).

The residuals present in these regressions may be due to random variation or processes apart from the environment and the measured plant dimensions. Trees are very susceptible to embolism or cavitation of the xylem vessels when the xylem water column is under great tension due to transpiration and low water availability in the soil (Milburn & Johnson 1966). Cavitation probably leads to oscillating behaviour in the sapflow rate. Sheriff (1973) provides a model of water storage and hydraulic resistance within the stem that explains such effects. While we did not directly observe cavitation, oscillation of the sapflow was noted, even on clear days when there were steady levels of radiation. This oscillation was occasionally found to be related to the wind speed (Correll 1989), and cavitation is known to be induced by mechanical shock (Sperry & Tyree 1988).

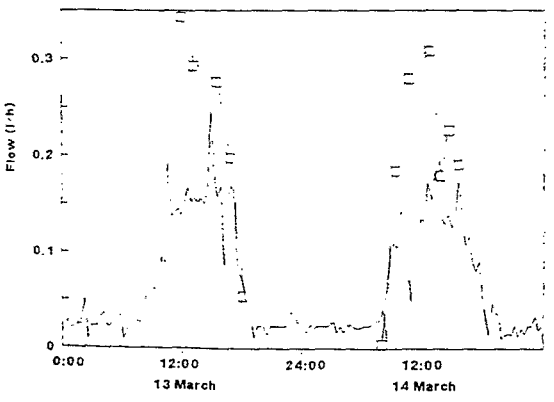

Figure 6 *Daily course of heat pulse sapflow and porometry measurements on a single tree on 13 and 14 March 1988. Porometry values are the means of 6 individual measurements, with a standard deviation of 0.07 l h^{-1}. The tree was subsequently sampled for leaf area.*

Stable Isotope Studies

The principles of the physical changes of isotopic composition of water during evaporation are well established (Craig & Gordon 1965, Walker *et al.* 1989). The isotopic compositions of foliar water and soil surface water were enriched over adjacent stem and deeper soil water respectively, characteristic of water of an evaporating compartment (Figure 9). The ^2H and ^{18}O compositions of water were correlated in linearly, with minor changes in slope due to changing conditions. Foliar water compositions fitted the steady state model of leaf water fractionation (Walker *et al.* 1989). The foliar water composition varied over the day, being highest in the late afternoon, responding to the drop in relative humidity (not shown). Fitting the stable isotope data to the transport model of Merlivat and Coantic (1975) demonstrated that vapour diffusion in the foliage and soil surface controlled the rate of evapotranspiration (Figure 9, Walker & Brunel, pers. comm.).

The presence of the soil evaporating front, identified by the maximum enrichment of the soil water (Barnes & Allison 1988), in the top soil sample interval (0-0.1 m) supports the suggestion that significant soil evaporation was occurring. Soil water content was over 6 % by weight in the next (0.1-0.2) interval, which also supports this. Such high levels of water in the upper

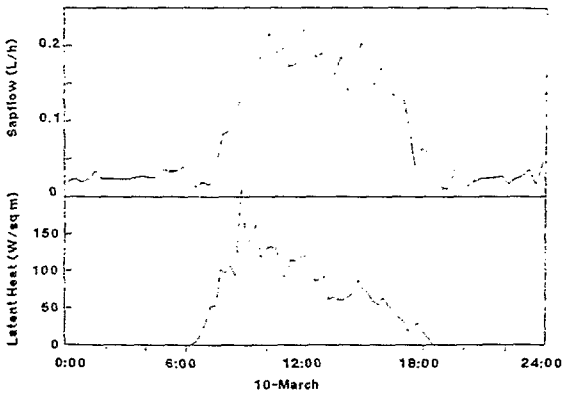

Figure 7 *Daily course of heat pulse sapflow on a single tree and latent heat flux, determined by Bowen ratio, on 10 March. Note the lag of sapflow behind the overall latent flux due to plant storage.*

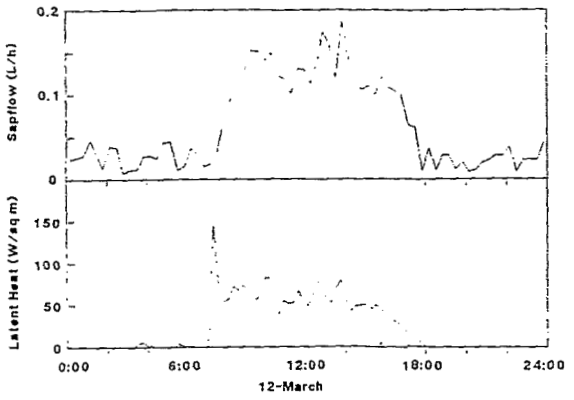

Figure 8 *Daily course of heat pulse sapflow on a single tree and latent heat flux, determined by Bowen ratio, on 12 March. Note the corresponding peaks of latent heat flux and sapflow in the afternoon.*

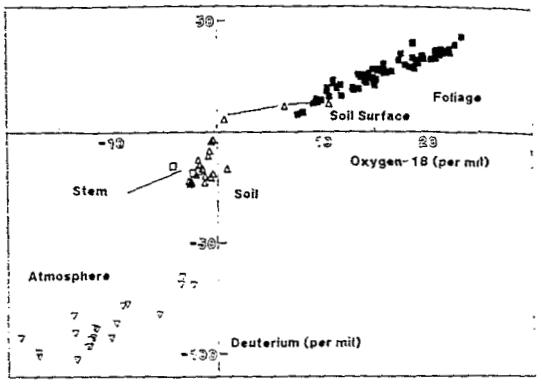

Figure 9 *Corresponding deuterium and oxygen-18 compositions of water samples obtained from foliage, stem, soil and atmosphere. All data are expressed relative to an international standard, V-SMOW, which is obtained from ocean water (Barnes & Allison 1988). Modelling of the water transport is described in a paper in preparation (Walker & Brunel).*

soil may result from the efflux of moisture from the root systems of the deep-rooted mallee into the upper soil, as has been observed in *Artemisia tridentata* (Richards & Caldwell 1987). This water flow is termed 'hydraulic lift' by these authors.

Airborne Meteorology as a Study Technique

Satellite images of Eyre peninsula were obtained on a number of days during the study. The surface temperatures measured from the aircraft and satellite showed comparable profiles over an initially studied flightpath (Figure 10). Aircraft surface temperature measurements and those taken on the ground were also directly comparable. It seems reasonable to advance the aircraft as an appropriate technique for obtaining higher definition of surface measurements to establish the accuracy of wider remote sensing studies and to survey small features in particular problem areas. The assessment of energy fluxes detected by the aircraft eddy correlation instrumentation in relation to surface features is proceeding with the development of an image analysis procedures for video recordings taken simultaneously during a flight.

Concluding Remarks

The water use of mallee during late summer, when it has a flush of new growth, has been extensively studied using a wide range of meteorological techniques. We suggest that total latent fluxes from the landscape were around 0.4 mm d^{-1} with around 0.24 mm d^{-1} coming directly from the mallee. Further field study is in preparation.

The summer growth of mallee has been commented on by Specht and others, perhaps because of the great contrast between the luxuriant health of the new mallee foliage while, all around, smaller vegetation is struggling in a state of near-desiccation or summer dormancy as seed. This growth has led researchers to consider that mallee trees have access to deep water reserves. It is clear from soil studies, cited elsewhere in this volume, that recharge rates are, on average, very much lower under mallee in comparison to pasture or cereals, which supports this suggestion. However, in light of our results, we ask what is known of the ability of mallee to remobilise and assimilate nutrients from elsewhere in the plant to possibly bring about the late summer growth?

Part of the uncertainty associated with the development and use of models of water use in plant communities lies in the whether the proposed model adequately matches the major fluxes occurring in the real system. In the current paper, we have discussed the possible roles of dewfall, inversions, cavitation, storage and hydraulic lift in modifying day-to-day water fluxes from the land surface. In respect to cavitation and storage, we suggest that part of the residual variation observed in the regression of sapflow over environmental parameters may be related to these processes. Is this important from a management point of view? It is probable that effective water use by native plant communities probably had the salts resident in the subsoils of semi-arid regions 'under control', a perception that is reflected by recharge modeling. When extensive clearing occurred, resultant changes in patterns and quantities of water withdrawal have resulted in salinisation. While the effective removal of water from depth is a clearly recognised contribution to controlling salt movement, and is widely assumed in deep-rooted mallee, the cavitation and hydraulic lift processes could release further water to the shallow part of the profile which may

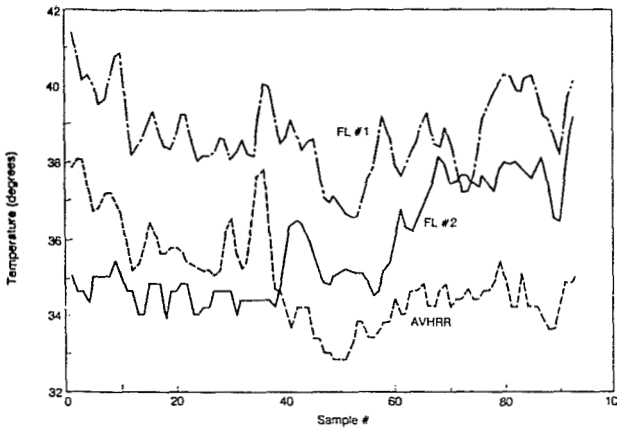

Figure 10 *Comparison of surface temperature measurements made from satellite and aircraft over a 60 km transect from over mallee to over fallow farmland, 6 March 1988. Aircraft flight time was around one hour earlier than satellite overflight, accounting for the overall difference between traces.*

be even more advantageous, since it avoids the lifting of salt in soil evaporation and transpiration of shallow-rooted understorey plants. While we can only suggest these processes rather than quantify them, we have no clear idea how effective at managing salt the native mallee communities really are.

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the Mallee Lands
A CONSERVATION PERSPECTIVE

Editors J.C. Noble, P.J. Joss, & G.K. Jones