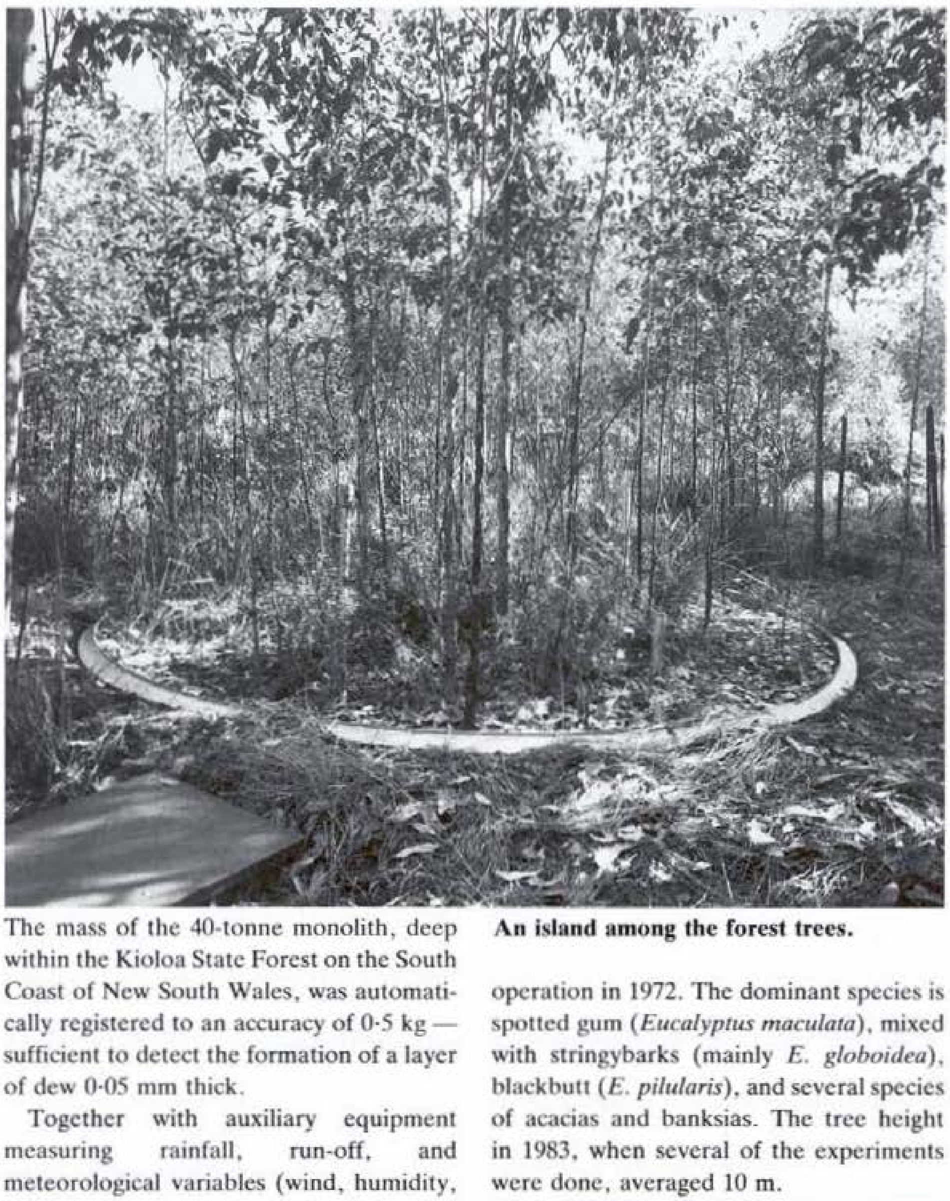
Trees catch a lot of rain

Poised on stainless steel cables, a patch of eucalypt forest containing 15 trees — one 12 m high — has been weighed continuously for months at a time by hydrologists from the CSIRO Division of Plant Industry.



An island among the forest trees.

The mass of the 40-tonne monolith, deep within the Kioloa State Forest on the South Coast of New South Wales, was automatically registered to an accuracy of 0·5 kg — sufficient to detect the formation of a layer of dew 0·05 mm thick.

Together with auxiliary equipment measuring rainfall, run-off, and meteorological variables (wind, humidity, radiation, and temperature), the set of scales, or lysimeter, was used by CSIRO scientists from 1979 to 1985 to learn more about the cycling of water in native forest and, in particular, its water use.

With forests being subjected to growing demands for use as water catchment, for conservation and recreation, and for the timber industry, knowledge of their hydrological balance is becoming increasingly important for sound management.

To construct the lysimeter, the team dug a 2-metre-deep circular trench nearly 4 m in diameter around a typical piece of forest — a community of young eucalypts regenerating since a clear-fell and burn operation in 1972. The dominant species is spotted gum (*Eucalyptus maculata*), mixed with stringybarks (mainly *E. globoidea*), blackbutt (*E. pilularis*), and several species of acacias and banksias. The tree height in 1983, when several of the experiments were done, averaged 10 m.

Water evaporates from the foliage even during rain.

Care was taken to minimise disturbance to the site, and to preserve the ground flora of grasses, sedges, and ferns while the plot was encircled with galvanised iron. Steel base plates were then forced beneath the living assemblage at a depth of 1·5 m and welded together. Formed into a giant pot this way, the whole construction was then jacked up, a concrete base formed underneath it, and the whole lot supported by cables. Metered collectors, at the surface and underneath, recorded outflow from percolation and run-off.

By constantly monitoring the weight of the lysimeter, Mr Frank Dunin and Divisional colleagues, together with Dr Emmett O'Loughlin of the Division of Water Resources Research, wanted to calculate the water use of typical eucalypt forest. They are also seeking a precise scientific description of evapotranspiration, a term referring to the combined effect of physical evaporation and biological transpiration. Within eucalypt forest, the largest loss of water from the system occurs by evapotranspiration.

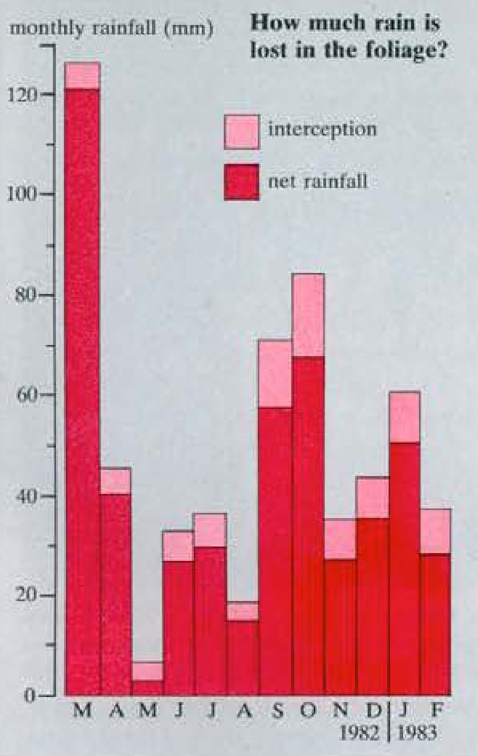
Until the lysimeter was built, scientists had to use estimates of evapotranspiration rates based on standard meteorological observations, or resort to intensive micrometeorological studies. These latter techniques could only supply information over short periods and, as the underlying principles have been devised for uniform vegetation (like a crop) on a flat landscape, their application to hilly terrain with irregular forest vegetation can be questionable.

The lysimeter enabled the scientists to measure water loss precisely. However, it did create a difficulty in knowing the extent to which the site chosen was representative of the entire forest. Encouragingly, early experiments showed excellent agreement (over time scales of hours to weeks) between evaporation as indicated by humidity and soil moisture measurements and that given by the lysimeter.

One finding from the lysimeter is that the evaporation from the forest, averaged over a long term, is only about 60% of the amount that measured available radiant energy could produce. The difference must be due to heat lost by convection.

While measured rates of transpiration vary widely, the scientists have found that their changes with time are influenced by a parameter called the leaf-area index (LAI) — the ratio of the total area of leaves on a tree to the area of ground the tree occupies. Under conditions of extreme water stress, trees conserve water by dropping their leaves, lowering the LAI.

The research has shown that, for most of the time, a tree with a full canopy has an LAI greater than 3. Under these conditions, the rate of evapotranspiration is largely determined by the atmosphere and soil dryness (the atmosphere imposes a demand, and a reservoir of soil moisture supplies water to the trees to meet this demand). A mathematical model to incorporate these factors — devised by Mr



Lysimeter data from Kioloa showed that, over a year, 15% of the rainfall can be lost before it hits the ground. This is about the same quantity that finds its way into streams.

Dunin and his colleague Dr Alan Aston — accounted for 86% of the variability in daily evapotranspiration rate.

Evaporation during rain

But when it's raining things become much more complicated. Developing an understanding of what happens to rain-water in a forested catchment, and hence how much will find its way to reservoirs, is vital to water supply managers.

When it rains, trees catch some of the water, stopping it reaching the ground. However, measurements of the 'interception losses' in eucalypt forests have indicated that a tree canopy typically holds only 0·3–0·5 mm of rain.

While that hardly seems worth worrying about, hydrologically speaking, Mr Dunin's lysimeter has shown that the amount of water lost from interception can be very considerable, roughly matching the quantity ending up as stream flow — that is, for a wide range of eastern Australian eucalypt communities, somewhere between 10% and 20% of annual precipitation. Ignoring interception will give us very wrong answers for catchment run-off.

Experiments with the lysimeter revealed the reason for the apparent paradox. While a one-time interception of 0·5 mm is all but negligible, rainfall is hardly ever continuous. Whenever a spell in rainfall occurs, water evaporates from the wet foliage, leaving it ready to acquire more moisture. Frequent repetition of this process can account for a lot of water: the evaporation of water held on the canopy in the post-rainfall period can account for about one-third of annual interception.

Even more surprisingly, the lysimeter has demonstrated that water evaporates from the foliage even during rain! Mr Dunin and Dr O'Loughlin have found the evaporation rate can reach nearly 1 mm per hour — as much as may be transpired by an irrigated crop at the height of summer. More commonly, though, the figure is 0·1–0·2 mm per hour.

This means that the interception loss rate from a eucalypt during rain may be as much as three times the rate of loss due to transpiration under the same conditions but with a dry canopy. Over a year, about two-thirds of the total interception loss can be accounted for as evaporation during rain.

These results give a whole new dimension to hydrology, and have caused hydrologists to go back over their old data looking for ways to allow for large interception losses. One implication is that differences between species in the water-storage capacity of forest foliage will have a substantial impact on catchment run-off. Pine trees typically intercept 0·8 mm of water whenever it rains — more than twice the amount usually caught by eucalypts. Under the conditions encountered at Kioloa, that would mean that about one-third of the total rainfall would be lost from interception.

What happens if grassland replaces the forest? Although it is much 'leafier' than trees (clover pasture has a LAI of about 8, whereas eucalypt forest frequently has a LAI close to 2), it still may have only half the interception loss of forest. The reason is that forest is aerodynamically 'rougher' and so evaporation during rainfall is considerably greater. With short grassland vegetation, such losses are hardly detectable.

On the other hand, grass transpires water more freely than trees; Mr Dunin has measured a figure of 7 mm per day in the Kioloa forest, compared with 13 mm per day for wheat growing at Griffith, N.S.W.

On an annual basis, though, forest is likely to consume more water, because tree roots penetrate deep down into the soil, and continue to extract moisture all year round. Shallow-rooted grasses, in comparison, dry off as soon as their near-surface water supply is exhausted.

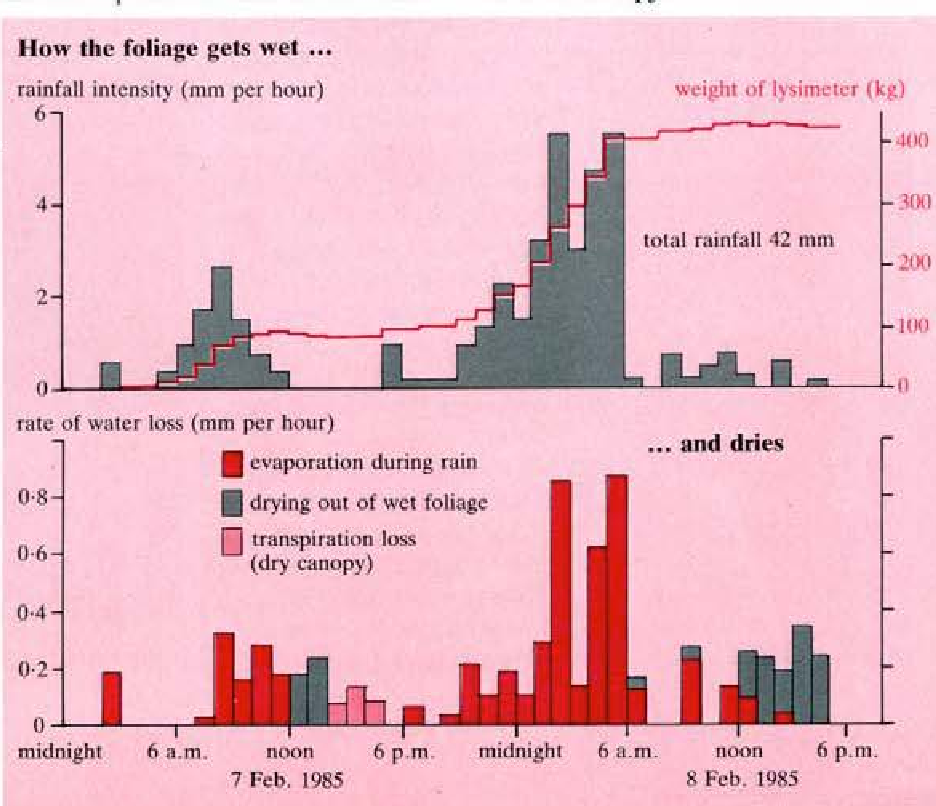
Tree in a tent

Two interesting experiments undertaken with the lysimeter involved enclosing the trees growing in it with a 12-m-high tent of transparent plastic film.

In the first, Mr Dunin and Dr Eric Greenwood of the Perth laboratory of the Division of Water Resources Research confirmed that evaporation from the enclosed lysimeter was generally the same as that from the surrounding forest — a result to be welcomed by many plant physiologists who depend on the plant-enclosure technique for much of their data.

Windy conditions can increase evaporation, and so can blowing air over foliage with ventilating fans in an enclosure experiment. The two scientists have devised a theoretical treatment that permits

Scientists had no idea that so much water was lost by evaporation during rain. The loss was calculated by comparing the lysimeter response with readings from gauges measuring rainfall above and below the tree canopy.



Constructing the lysimeter.

Wrapped in plastic to allow measurements of carbon dioxide and water use.

experimentalists to adjust the findings of enclosure experiments to take account of ventilation.

In the second tent experiment, the trees' rate of photosynthesis and the efficiency of photosynthesis, in terms of water use, were gauged by measuring the concentration of carbon dioxide and water vapour in air drawn through the tent. This study was done by Dr Chin Wong of the Australian National University and Mr Dunin. They found that, at normal carbon dioxide concentrations, the rate at which trees assimilated carbon dioxide reached a maximum at about half the light intensity of full sunlight. When they artificially increased the carbon dioxide levels, the trees, at all light levels, photosynthesised more rapidly, and the maximum rate achievable shifted to higher light intensities.

When the normal carbon dioxide level of the air was doubled (as may be done to our atmosphere some time next century by industrial emissions), the rate of photosynthesis increased by 50%. At the same time, the transpiration rate fell by about one-third, showing that the trees were operating much more efficiently.

We should not assume that the same outcome will follow a doubling of the atmosphere's carbon dioxide content. Quite possibly trees will react to long-term enhancement: for example, average LAI or shoot : root ratios may change, as may other aspects of the trees' physiology.

Nevertheless, the results could be taken as an indication that higher carbon dioxide levels will mean lower water use. Hydrologically, this would be reflected in greater run-off.

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More about the topic

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