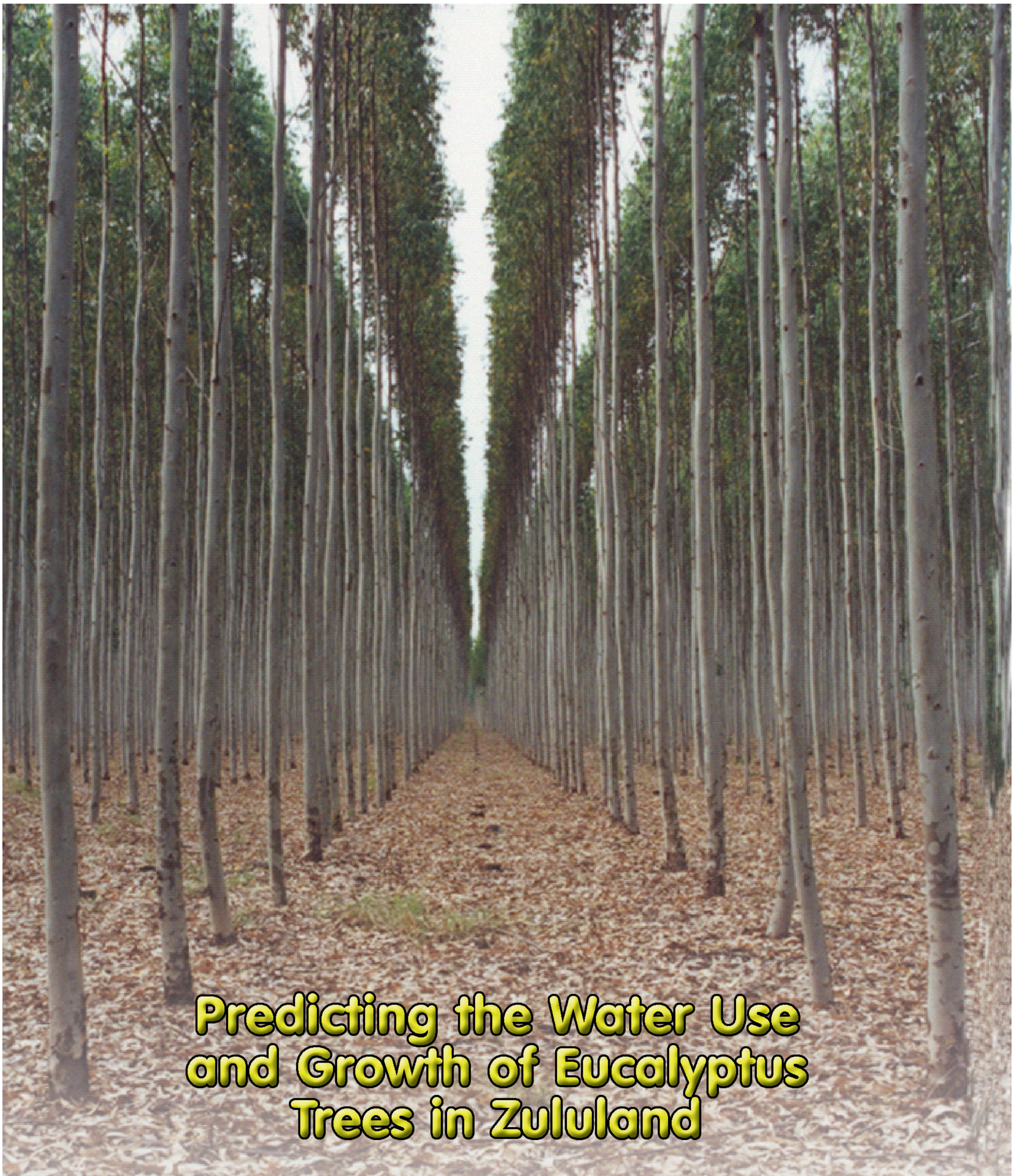


# Predicting the Water Use and Growth of Eucalyptus Trees in Zululand

***"How much water does a Eucalyptus tree use?" This question is frequently asked of the CSIR Land Use Hydrology Group in Pietermaritzburg. Providing a concise and definitive answer is very difficult, since it depends on many variables such as the species and age of trees, their planting density, the availability of soil water, and weather conditions. A similar question might be "how much does a man drink?", and we all know that this is a highly variable quantity!***

Questions on tree water use reflect the widespread and longstanding concern in South Africa over the effects of forest plantations on water availability. Our forests are necessarily concentrated in the higher rainfall areas of the country, which also provide a major proportion of the total quantity of water in our streams and rivers. Experience over the past century has shown that streamflows decline when catchments are converted from grassland or Fynbos to forest plantation. This has much to do with the fact that the seasonally dormant grasses or Fynbos are replaced by evergreen trees that maintain a high rate of transpiration throughout the year. Eucalypts are generally perceived to be particularly thirsty trees. This view may have been shaped by an earlier controversy over *Eucalyptus* plantings in India, but is supported locally by the extraordinary vigour of these trees, their known ability to extend their roots to great depths, and the speed with which they reduce stream flows and groundwater supplies.

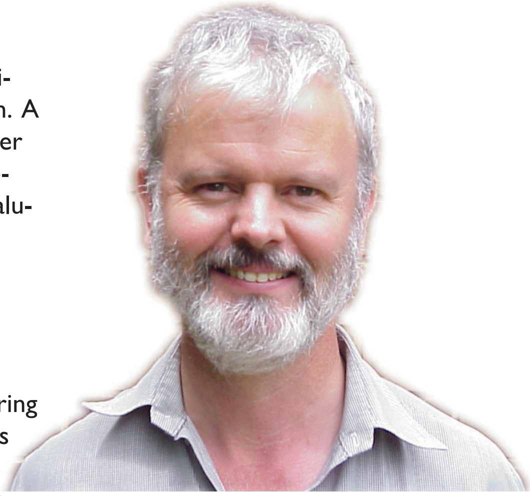
Given the wide variety of tree species and growing conditions in South Africa, it is important to get better information on the impacts of forest plantations on water resources. However, it is also important to take into account the productivity of forest plantations, and the overall economic and productive efficiency of water use. Forest plantations are efficient producers of biomass, and sustain an enormous wood products industry. Water used by forest plantations may be more efficient than for some other land-use or industrial purpose further downstream. Catchment Management Agencies will be tasked in future with regulating water resources in 19 different Water Management Areas around the country. Efficiency of water use will become an increasingly important criterion in deciding on optimum catchment water allocation. A clear picture of growth **and** water use of forest plantations is therefore required to assist in this evaluation.

## MEASURING TRANSPIRATION

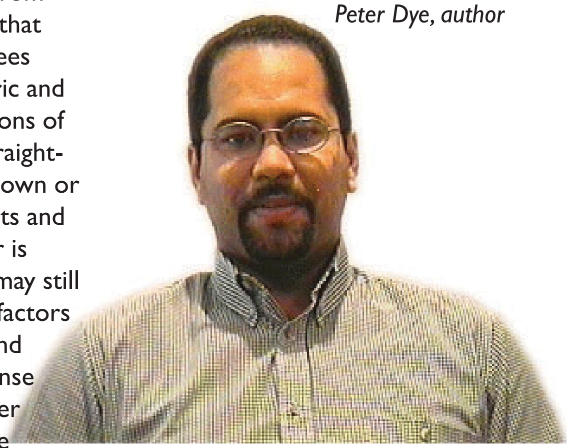
How does one set about measuring transpiration and growth in trees and forests? The answer is with great difficulty! Evaporation from leaves is an invisible process that varies continuously as the trees adapt to changing atmospheric and soil conditions. Even predictions of tree growth rates are not straightforward. Growth may slow down or stop during and after droughts and dry periods. When soil water is ample for the trees, growth may still be strongly affected by such factors as soil fertility, tree density and weather conditions. In response to these complexities, forester researchers resort to the use of computer models that keep track of changing growing conditions, often on a daily or monthly basis.

## PC MODEL

One recently developed model (3-PG; Physiological Principles of Predicting Growth) appears to have struck the right balance between simplicity and realism, and shows great promise as a useful PC-based tool for predicting water use and growth in South African forest plantations. A recently completed Water Research Commission report (K5/1194) describes a project in which the 3-PG model was evaluated on 12 diverse clonal *Eucalyptus* stands on Mondi Forest estates in the Kwambonambi and Hluhluwe districts of Zululand. The purpose of the project was to test the practicality of setting up 3-PG for a range of tree stands over a short space of time, and also to evaluate the accu-



*Peter Dye, author*



*Shayne Jacobs, author*

*Dave Drew (author) measuring the leaf area of Eucalyptus stands with an instrument which measures light interception beneath the tree canopy*

## MEASURING SAP FLOW IN TREES

*The heat pulse technique was used to measure the flow of sap in the sapwood of the tree*

Plants need to take up soil water and transport it to the leaves where it is transpired through microscopic pores called stomata. In trees, this transport of water (sap) occurs in the outer, sapwood part of the stem. The older, inner part of the stem is called heartwood, and is blocked by resin-like substances that prevent the flow of water. The heat pulse velocity method allows one to measure the rate of sap movement in the sapwood. A metal probe is inserted into the wood and electronically regulated to briefly heat up at specified intervals during the day. This heat is absorbed by the wood and sap close to the probe. A second type of heat-sensing probe is implanted a fixed distance above the heater probe. An attached data logger then records the time it takes for the pulse of heat to be transported by the moving sap over the known distance to the sensor probe. The faster the rate of water use by the trees, the quicker the sap flow and the shorter the time it takes for the pulse of heat to be registered by the sensor probes. Various other sapwood characteristics are taken into account to permit calculation of the total flow of water through the tree.

racy of the model predictions. An important additional objective was to test the usefulness of satellite remote-sensing data in spatial applications of 3-PG. Efforts were focussed on predicting the total leaf area of forest stands, since this is a very important feature of forests that influences the rate of growth, and transpiration of water.

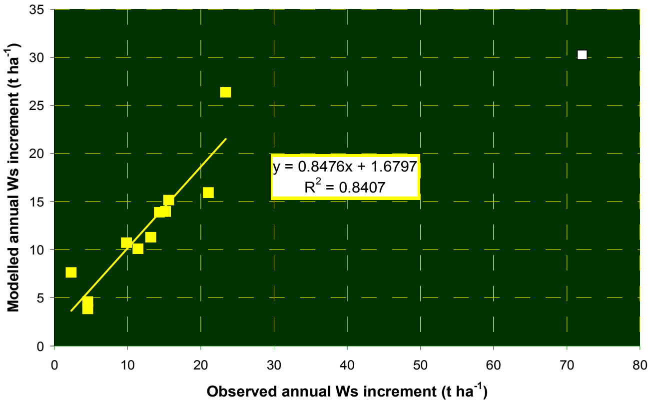
Over a 12-month measurement period, the research team recorded various properties of the soil, trees and weather conditions in each stand. Changes in stem, branch and leaf biomass were calculated from measurements of tree diameters and heights, as well as from field measurements of stem, branch and leaf mass of a sample of harvested trees. The leaf area of the whole stand was estimated using an instrument that compares sunlight measured above and below the forest canopy. The loss of old leaves from the canopy was recorded in collection trays sited in random positions on the forest floor. Tree transpiration rates were measured with the heat pulse velocity technique, which provides information on the flow of sap through the sapwood portion of the tree trunk. The availability of soil water to the trees was estimated at intervals during the dry winter months. The tree physiological technique used for this purpose requires measurements to be performed on leaves before dawn, when the trees have had an entire night to reach equilibrium with the water content of the soil. Two weather stations and several additional rain gauges were used to gather information on those weather conditions that have an effect on transpiration rates.

All available field information was used to set up the model to predict monthly growth and water use for each stand. The modelled annual growth increment was then compared to the measured growth difference after 12 months, while the modelled monthly water use rates were compared to observed sap flow measurements.

## RESULTS

3-PG yielded good predictions for 11 of the 12 stands of trees. The one exception was a stand of trees that showed an exceptionally high growth rate and also very high leaf areas. These trees were known to have easy access to a shallow water table, and may therefore have adapted physiologically to this situation.

Landsat imagery was purchased for two periods that coincided with leaf harvesting in the field. The




*The agreement between observed and model predicted growth increment in the twelve Eucalyptus stands*

*Landsat imagery of the Hluhluwe district showing the location of six Eucalyptus stands*

exact position of the experimental stands was located on these images. The spectral properties recorded at these precise points were then analysed and correlated to the observed measurements of leaf area. These correlations proved to be disappointingly poor, indicating that we need to continue estimating leaf areas at ground level for the foreseeable future.

The project was successful in demonstrating that the 3-PG model can be set up relatively easily to produce realistic predictions of growth and water use in a wide range of tree stands. A current project funded by the Innovation Fund is extending the use of the 3-PG model to all the major forestry species in South Africa, and aims at providing the forestry industry with useful decision support tools to improve predictions of tree growth and water use throughout the forestry regions of South Africa.

## HOW CAN ONE DETERMINE IF A TREE IS WATER-STRESSED?

*The Scholander pressure chamber*

One method involves measurement of the water tension within the conducting plant tissue using a device called a Scholander pressure chamber. As trees transpire during daylight hours, the water within the conducting cells of the roots, stem and branches comes under tension, behaving somewhat like a stretched rubber band. During the night when transpiration stops, the tree continues to absorb soil water and is therefore able to release this tension. If there is insufficient soil water for this equilibration process, then the tension may be only partly relieved. One can measure how complete this equilibrium process has been by cutting a leaf from the tree just before dawn. If the sap is still under tension, it withdraws away from the cut surface back into the leaf tissue. By applying a counter pressure to the leaf suspended in a sealed pressure chamber with the stalk protruding through a rubber bung, one can measure how much pressure is required to push the sap out again to the cut surface. The greater the shortage of soil water, the greater the required pressure to counteract the sap tension in the leaf. Some problems encountered in our use of this technique included:

- Getting out of bed early enough in the morning!
- Finding sites in the pre-dawn darkness. It is often difficult to navigate around forestry estates even during the daytime.
- Obtaining leaves from tall Eucalyptus canopies. We resorted to using a catapult to knock down leaves. Finding these leaves required following their descent to the ground with torches!