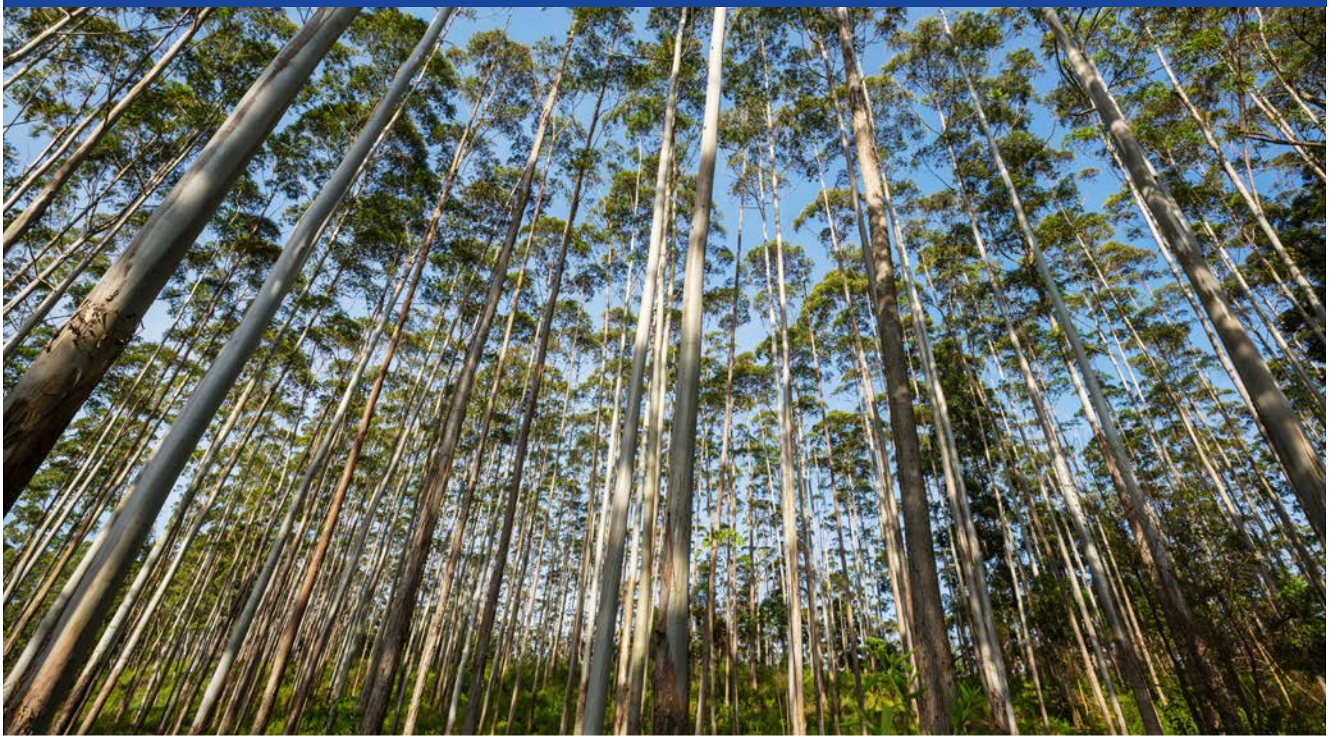
FORESTRY

Forestry and streamflow reduction – making progress in accurate assessment

Insight gained from a Water Research Commission (WRC) funded project has done much to expand knowledge about water use of different commercial forestry species and hybrids. Article by Sue Matthews.



When draft regulations on afforestation genus exchanges were published for comment in October 2015, it set the cat amongst the pigeons. The 'Genus Exchange Regulations' proposed that afforestation water users would have to apply to the responsible authority – the Department of Water and Sanitation (DWS) or relevant catchment management agency – if they planned to exchange the genus of a plantation. And should the new genus be a heavier water user than the one to be replaced, the original authorisation would be amended to reduce the number of hectares planted so that the property's water use would not increase.

Forestry companies are not that different from farmers who want to be able to change the crops they grow according to market demand and prevailing conditions, or simply to spread their risk by diversifying. The South African industry relies mainly on pines and eucalypts, and wattles to a lesser extent, but a variety of species and clonal hybrids within these three genera – ***Pinus***, ***Eucalyptus*** and ***Acacia*** – are currently in use or have been phased out over time, particularly within the past 30 years. Since 2010, there has also been widespread conversion of pine and wattle plantations to eucalypts, although pines still have a slight edge in terms of total area under production countrywide.

Pines are softwoods, used to produce high-value veneers and sawlogs, as well as coarse-fibre pulp needed to make packaging and newsprint. Eucalypts are hardwoods, grown for poles and lower-value sawlogs, but mainly for fine, short-fibre pulp. This is in great demand for making high-quality paper and various cellulose products used in everything from textiles and cigarette filters to cosmetics and plastics. Eucalypts also have the benefit of fast growth, with a rotation time of 6–15 years compared to 15–28 years for pines.

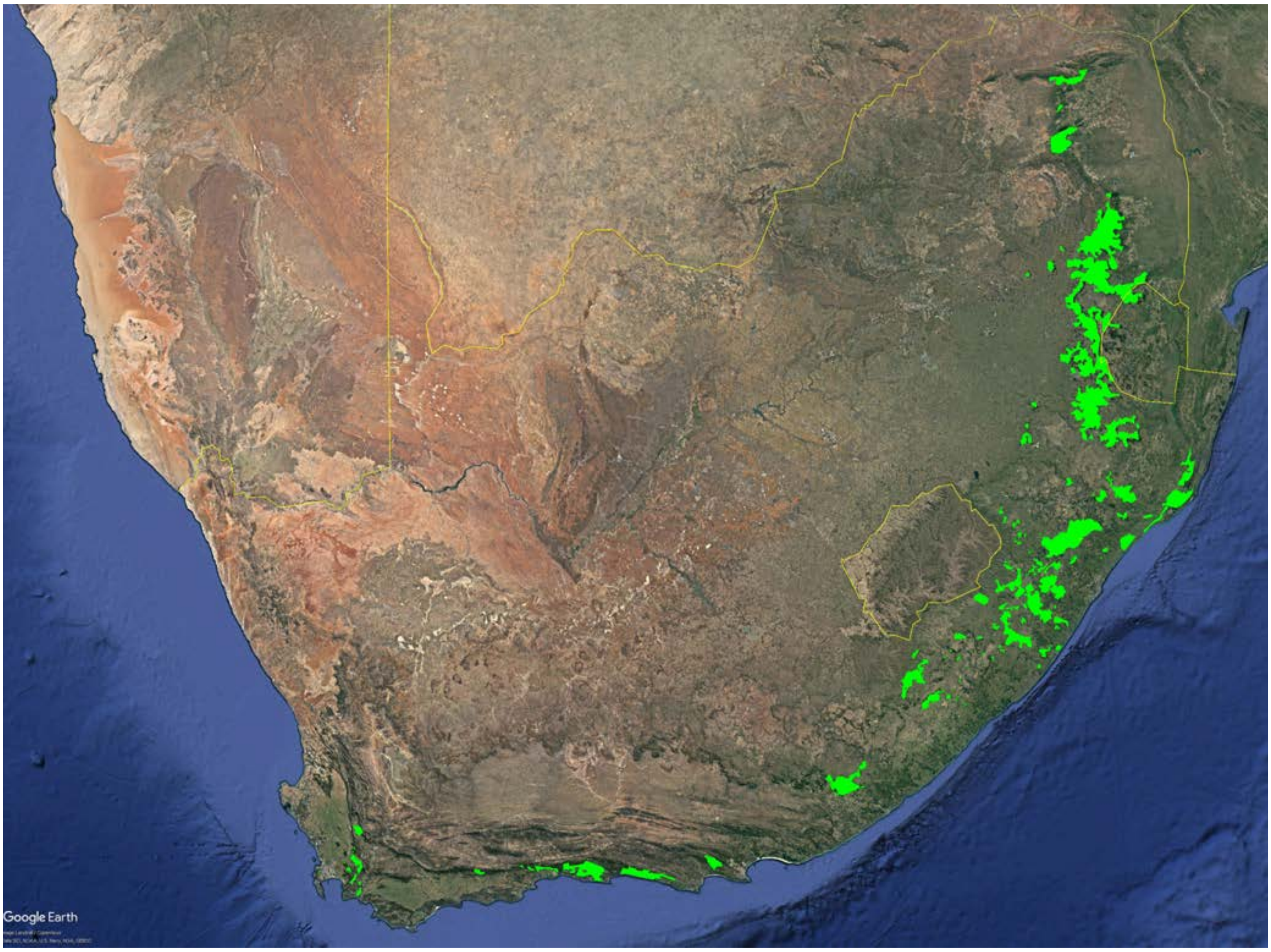
Of course, forestry trees use more water than the indigenous grasses and low shrubs they often replace, largely because they are tall and evergreen but also because – in the case of pines and eucalypts at least – they have deep root systems, able to tap into groundwater reserves. Owing to the potential impact of tree plantations on water resources, commercial forestry was declared a 'streamflow reduction activity' (SFRA) in the National Water Act of 1998, and a water use licensing system was introduced to replace the afforestation permit system.

The licensing system includes an assessment of the likely reduction in streamflow using a procedure that was developed in WRC-funded projects by Gush et al. (2002) and Jewitt et al. (2009) – more on these later – but is based on water use estimates for only one species in each genus, namely ***Eucalyptus grandis***, ***Pinus patula*** and ***Acacia mearnsii***. The available information suggested that ***E. grandis*** had higher water use than ***P. patula***, but the growing conditions during some of the early experimental studies were not reflective of forestry practices.

Besides, what about all the other species and clonal hybrids in commercial plantations? Might a eucalypt hybrid developed for its resistance to drought use less water over its lifetime than a pine species or hybrid? Or could a pine species with particularly fast growth prove to be as 'thirsty' as ***E. grandis***, which has in any case been overtaken by ***E. dunnii*** in terms of hectares planted. And how does water use compare over two or three decades, given the different rotation cycles of pines and eucalypts?

It was recognised that better information was required, so DWS put the Genus Exchange Regulations on hold and subsequently commissioned the WRC project by Clulow et al. (2023), 'The expansion of knowledge on evapotranspiration and streamflow reduction of different clones/hybrids to improve the water use estimation of SFRA species (i.e. ***Pinus***, ***Eucalyptus*** and wattle species)'.

In November 2019, however, Forestry South Africa (FSA) lodged a court application on behalf of its members around the interpretation of the National Water Act's 'existing lawful water use', as well as the definitions of 'streamflow reduction activity' and 'water use' in relation to genus exchange. The Judgment delivered in August 2021 went in favour of FSA on the genus exchange issue but not on the existing lawful water use matter. Since FSA appealed the latter and DWS the former, the case is set



All photographs supplied

Commercial forestry occupies almost 1.2 million hectares of South Africa's land area, with plantations being concentrated in KwaZulu-Natal and Mpumalanga.

A satellite view of three of the project's study sites, situated about 70 km north-east of Pietermaritzburg. The middle site is the Two Streams Research Catchment, where the impact of the Eucalyptus dunni plantation on groundwater and streamflow was monitored using four boreholes (B) and a streamflow recorder (SFR). Instrumentation on a tower (T) within the plantation allowed for energy flux and total evaporation measurements, while an automatic weather station (AWS) provided data on climatological variables. The other two sites, 4 km apart, were plantations of Pinus elliottii and the eucalypt hybrid E. grandis x E. nitens.

to be heard by a panel of five judges at the Supreme Court of Appeal on 24 August 2023. Until then, an exchange of genus or species does not constitute a water use as envisaged in section 21 of the Act, exchanges may take place without the need for authorisation, and the responsible authority is not entitled to insist that the area of land planted be reduced.

Main findings of the project

Regardless of the outcome of the appeal, the WRC project has done much to expand knowledge about water use of different species and hybrids. The project report is split into two volumes, the first of which, 'Improved water use estimation of SFRA species', focuses on field-based studies. These studies were mainly conducted in and around the Two Streams Research Catchment, in the Seven Oaks area some 70 km north-east of Pietermaritzburg. The catchment has been used for a number of hydrological studies since 1999, but it has always been planted to ***A. mearnsii***. In March 2018, following the harvesting of the wattle rotation, a genus exchange was undertaken by planting ***E. dunnii*** in its place. Once the crop was 18 months old, measurements of hydrological processes began, and were continued for two years. The findings were compared with those from a two-year-old ***A. mearnsii*** crop and a mature, six-year-old ***A. mearnsii*** crop, using historical data from the earlier studies at the site. This showed that total water use for the young ***E. dunnii*** was much the same as that of ***A. mearnsii*** of the same age, but about 12% more than for the mature ***A. mearnsii***.

Higher water use by young crops suggests that rotation time needs to be taken into account when considering the implications for stream flow reduction. The project team therefore recommends that measurements continue for the full ***E. dunnii*** rotation to allow for comparison with the historical ***A. mearnsii*** rotation, but they point out that both species could have a negative impact on stream flow and groundwater reserves. "These findings were supported by a reduction in stream flow when the catchment was afforested by either ***E. dunnii*** or ***A. mearnsii***, while the stream flow increased when the catchment was cleared," they note.

Two other plantations adjacent to the Two Streams catchment presented the opportunity to compare ***P. elliottii*** – the second most planted pine species in South Africa – with the eucalypt hybrid ***E. grandis x E. nitens (GN)***. The pine plantation was 20 years old and the eucalypt one eight years old, but the two were at a similar stage of development given the species' different growth and rotation rates, and both were planted at a spacing of 2 x 3 m. Although the sites lacked the boreholes and stream flow gauge of the Two Streams catchment, transpiration by four trees at each site was measured over two years and evapotranspiration estimated to compare the species' water use. Surprisingly, ***P. elliottii*** outstripped ***GN*** in this regard during the first year of the study, using significantly more water, but the difference levelled out over the second year. The lower-than-expected water use by ***GN*** was attributed to water stress, because although the two plantations were only 4 km apart, their soils had different textures and those at the ***GN*** site were generally drier.

The genus exchange ratio between ***GN*** and ***P. elliottii*** averaged 0.92 over the two years, but the project team recommends that the same measurements be conducted at several forestry sites to include different soil and climatic conditions. "Based on these results, a conclusion was drawn that conversion from ***P. elliottii*** to ***GN*** in water-stressed sites and where groundwater resources are too deep for access by trees may not affect groundwater resources," they report. "However, during the wet season, trees may deplete the recharged soil profile soil water content, which may lead to stream flow reduction in the long term."

A fourth study site was identified at KwaMbonambi in northern Zululand. It was planted with nine-year-old ***E. grandis*** x ***E. urophylla*** (***GU***), the dominant commercial forestry tree in this humid, subtropical region. Transpiration measurements on four trees for a two-year period revealed that water use was in the same range determined by previous studies on ***E. grandis*** and ***E. urophylla*** within the region and at other subtropical sites internationally. The project team notes that despite the very low soil water content and paucity of rainfall during the study period, the trees showed no sign of water stress, suggesting that they were able to access deeper groundwater reserves. This implies that ***GU*** plantations would likely cause a reduction in stream flow, especially during low-flow conditions during the dry season.

As much as these field-studies have provided water-use information for a few species and hybrids that was not previously available, it would clearly be impractical to conduct similar studies on all the other species and hybrids planted by the forestry industry countrywide. Yet some means of taking this tree diversity into account in the water use licensing system would be beneficial, particularly if the Genus Exchange Regulations become legally binding. The second volume of the research report, titled 'SFRA Assessment Utility', provides a method to do so.

The SFRA Assessment Utility is the software tool developed by Jewitt et al. in 2009, although it has been modified and improved over the years. Like the 2002 'Gush Tables' containing estimates of stream flow reduction resulting from afforestation, it is based on outputs from the ACRU hydrological model. But while the Gush Tables were for quaternary catchments, the SFRA Assessment Utility made use of a database on the soils and climate of quinary catchments for the modelling, allowing for estimates of stream flow reduction at a finer scale. Both systems relied on the Acocks Veld Types for the indigenous vegetation that would have existed in the catchment under natural conditions, with simulations of stream flow under this reference land-cover providing baselines against which reductions could be assessed.

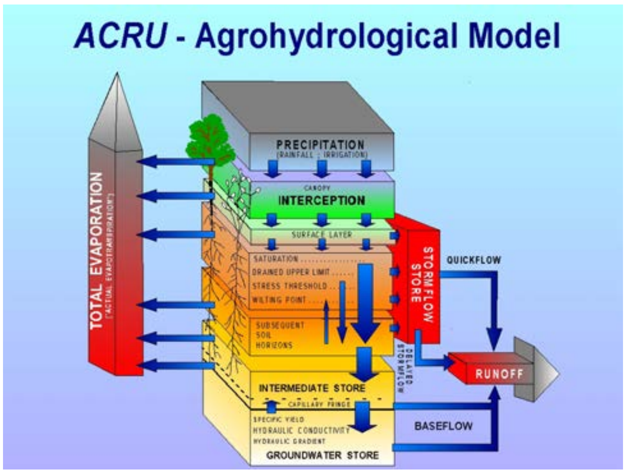
Acocks mapped South Africa's vegetation according to its grazing potential, identifying 70 different 'veld types' in the 1950s. Today, the National Vegetation Map and accompanying database developed by the South African National Biodiversity Institute (SANBI) is the accepted reference land-cover. It has been updated a few times since the first iteration in 2006, and now contains more than 450 different vegetation types. A recent WRC-funded project by Toucher et al. (2020) grouped them on the basis of their hydrological similarity to produce 128 CWRR clusters – so-named because the project was conducted by the Centre for Water Resources Research at the University of KwaZulu-Natal. The vegetation and water use parameters required by the ACRU model were then derived for each cluster in order to develop a new hydrological baseline.

This was used in the current project as the baseline against which the impacts of commercial afforestation could be assessed. Improvements to the climate and soils databases for the quinary catchments were also incorporated into the ACRU model runs. Evapotranspiration is a key variable in the model, estimated using the Food and Agricultural Organization (FAO) method of multiplying the reference evapotranspiration by the crop coefficient (K_c), which is the ratio of actual crop evapotranspiration to reference crop evapotranspiration. One way of obtaining the K_c values for different crops is to derive them from the Leaf Area Index (LAI), a canopy parameter defined as the total single-sided leaf area per unit ground area.

Although LAI can be determined from field-based measurements, it's not without its challenges, as the project team quickly discovered. Their plant canopy analyser needed just the right light conditions – diffuse early morning or late afternoon light with no cloud cover – for accurate measurements, and the weather invariably didn't play along on scheduled field trips. So they turned instead to remotely sensed LAI estimates, and after testing a few satellite products and methodologies settled on the MODIS LAI product. Using data from daily evapotranspiration measurements conducted on ***A. mearnsii*** and ***E. dunnii*** at the Two Streams Research Catchment, the team derived a monthly time-series of K_c and then developed a generic K_c-LAI model, which made it possible to obtain K_c estimates from MODIS LAI values at other sites with different tree species.

Accordingly, 15 sites in KwaZulu-Natal and Mpumalanga containing the major commercial forestry tree species and hybrids were identified, and the monthly averaged K_c values derived. They are for four pine and seven eucalypt species and hybrids as well as ***A. mearnsii***, but for ***P. patula***, ***E. grandis*** and ***E. grandis*** x ***E. nitens*** the K_c value was derived for two different climate zones.

With these K_c values and other required input parameters, the ACRU model was used to simulate mean monthly and annual runoff response for each of the species and hybrids (assuming that the entire quinary catchment was a plantation), as well as the baseline conditions. If the difference in mean annual runoff under forestry was more than 10% of the baseline, the catchment



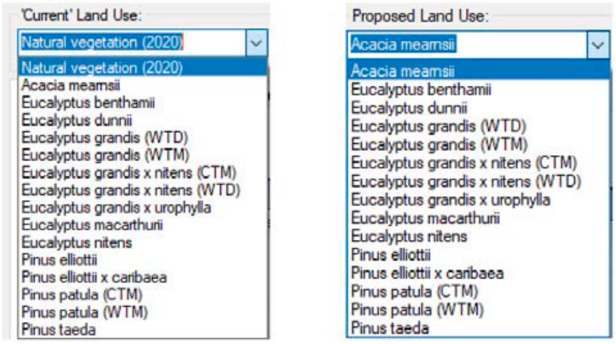
The ACRU model, used for assessments of streamflow reduction, has its origins in research conducted in the 1970s by Roland Schulze, who developed it further and produced an accompanying handbook as part of a WRC-funded project completed in 1995. Since then, it has been improved and revised to incorporate new information. The model simulates the components and processes of the hydrological cycle affecting the daily soil water budget. More detail can be found at https://cwrr.ukzn.ac.za/resources/acru/.

was flagged as a potential candidate for a stream flow reduction assessment. Mapping the results showed that all the pine and eucalypt species and hybrids were estimated to reduce mean annual runoff by more than 10% in KwaZulu-Natal, Mpumalanga and Limpopo – the provinces where they are mainly grown – while ***A. mearnsii*** resulted in the lowest proportion of flagged catchments.

The outputs of the ACRU model runs are contained in the updated SFRA Assessment Utility, now referred to as the Genus Assessment Utility. This allows users to select the current and proposed land use (forestry species or hybrid), followed by the desired output variable (such as runoff simulated by the ACRU model), the quinary sub-catchment to be assessed, and the start month of the hydrological year. The Utility then displays monthly time series in the form of data tables and graphs for the current and proposed land uses, as well as the calculated difference and accompanying statistics.

The project team gives a few suggestions in the report to improve the accuracy of modelled results, as well as more general recommendations. They point out, for example, that it's not ideal that the development and validation of the model for determining K_c values from LAI relied on evapotranspiration measurements from only two species grown at the same site, but the method is documented and repeatable, so water use parameters can be refined as more data becomes available. They add that greater access to the commercial forestry industry's compartment database would be helpful in expanding the sites for which LAI records are obtained. It remains to be seen whether the industry will be willing, once judgement is handed down in the upcoming appeal.

To download the two volumes of ***The expansion of knowledge on evapotranspiration and streamflow reduction of different clones/hybrids to improve the water use estimation of SFRA species*** (i.e. ***Pinus***, ***Eucalyptus*** and wattle species) Visit: https://bit.ly/3JHj9mn (Volume 1) and https://bit.ly/3JJyRxi (Volume 2)



The Genus Assessment Utility is a software tool that allows users to view, extract and make comparisons of different ACRU model simulations for a range of species and hybrids. WTD = Warm temperate dry, WTM = warm temperate moist, CTM = cool temperate moist.

THE WATER WHEEL

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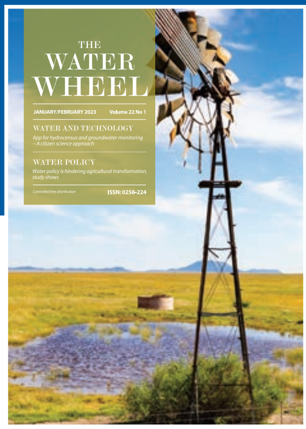

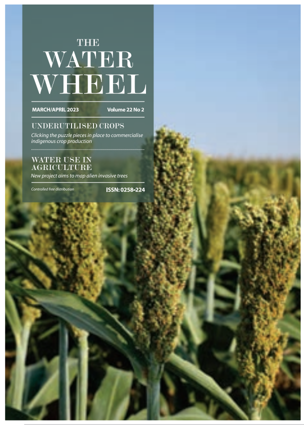

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