# EXECUTIVE SUMMARY

## INTRODUCTION

Forestry is an important agricultural activity in South Africa accounting for 6.3% by value of the country's gross agricultural output in 1996/97 (FOA, 1998). This primary industry in turn supports a large forest products industry that made up 7.4% of South Africa's gross manufacturing output in 1996/97 (FOA, 1998). At the same time forestry is estimated to have a consumptive water use equivalent to 7.5% of the country's available water resources (Scott *et al.*, 1998), and forestry continues to receive much attention because of the water consumption of timber plantations. The expansion of the forest industry has been regulated since 1972 on the basis of its estimated water resource effects. The provisions of the new National Water Act will make forestry liable to pay for water use as a streamflow reduction activity, and this has placed increased attention on the quantification of the water use of timber plantations, and the accuracy with which such use can be estimated. For this reason it is important that full use is made of the information contained in the long-running catchment afforestation experiments.

The South African afforested catchment experiments were initiated over sixty years ago, with a long term vision of multiple replication of sites and species over many decades. The historical nature of the data collected, the length of record and the range of sites involved make the experiments unique and invaluable. Although most of the experimental data have already been analysed to some extent or another, there was a need to consolidate the experimental data, to re-work the data in a uniform and consistent way, and to generalise the results, particularly with respect to new information needs. We can now review this large body of data to assess the composite picture which has emerged to date with respect to the influence of forestry on streamflow.

This project for the Water Research Commission sought to:-

- Update and prepare the complete body of experimental afforestation data.
- Produce a definitive review of the South African catchment afforestation experiments based on a complete and consistent analysis of the available data.
- Consolidate our understanding of the nature of and our ability to predict streamflow reductions caused by forestry.
- Provide a definitive baseline against which modelling efforts can be tested.

## METHODS

The study looked at a series of paired catchment comparisons. This method involves the long-term monitoring of streamflow from pairs of catchments before and after a major vegetation change in one of them. The treatment effect is primarily measured against a baseline provided by the relationship between the two catchments before treatment. The method is applicable to both afforestation and clearfelling treatments. The statistical test for treatment effect is by means of the dummy variable technique of regression analysis.

Weekly streamflow volumes were used as the computational unit, which provides some smoothing when comparing different catchments, but at the same time provides for robust statistics because of the large sample numbers. The effects on both total flows and low flows were analysed separately: low flows being defined as those weeks when flow was below the 75$^{th}$ percentile exceedance level in the control catchment.

Seventeen experiments were analysed altogether, from data generated in 13 treated catchments, and comprising 12 planting experiments and five clearfelling experiments; 12 of which experiments were with pines and five with eucalypts. The research sites are at five locations across the forestry (i.e. high rainfall) zone of South Africa, namely, Jonkershoek near Stellenbosch in the Western Cape, Cathedral Peak in the Drakensberg, Mokobulaan and Witklip on the Mpumalanga escarpment and Westfalia near Tzaneen. Additional data, although incomplete, from two small catchments at Ntabamhlope near Estcourt in KwaZulu-Natal are also included.

**RESULTS**

For each successfully analysed experiment the estimated effects on total and low flows are standardised to a 10% level of planting or clearing and plotted against time in two figures. The seasonal effects are illustrated by plotting the mean flow reductions or increases for each month of the year, generated over many years while the plantations were mature. The results are also tabulated.

The initiation of flow reductions (onset of significant reductions after planting) varies widely depending on the stature of the competing native vegetation and the rate at which catchments are dominated by the plantation crop. The pine plantations in tall fynbos in the Western Cape and in high altitude grasslands in the Drakensberg usually took several years to have a clear impact on streamflow (up to 6 years). However some pine crops, e.g. Lambrechtsbos-A in Jonkershoek and Mokobulaan B in Mpumalanga had an early effect on streamflows (within 3 years). Eucalypts have an earlier impact on streamflows, within 2 to 3 years. Under drier conditions this was still true, though here (Ntabamhlope) the timber crop also had the benefit of full site preparation prior to planting.

Once reductions are significant they generally become larger quite quickly, reaching peak or near peak reductions fairly early in the rotation. Peak reductions under pine are reached around 15 years of age and at least 5 years earlier under eucalypts. At the drier Ntabamhlope site flows ceased completely in the fourth year after planting, which was also a dry hydrological year. It seems to be generally true that dry conditions will accelerate the desiccation of the catchment after planting.

Peak reductions per year (mean over 5 consecutive years) range widely under pines from 17 to 67 mm/10% and from 37 to 41 mm/10% planted under eucalypts. The absolute reductions at Ntabamhlope have only been measured for a few years but would be much smaller than the figures for other eucalypt plantings. Peak absolute reductions relative to expected flows occur at variable stages within the rotation depending on site specific conditions. Relative reductions, also over a five year window, have a narrower peak, from 6.6 to 10%/10% under pines to 9.8 to 10%/10% planted under eucalypts.

A new finding from this up-to-date analysis is that flow reductions are definitely diminished towards the end of longer timber rotations, and this is true of both pines and at least one eucalypt experiment. Obviously this trend is clearest in the longer term experiments. The diminution of final flow reductions (mean over last 5 years measured) compared to the highest 5 year mean reductions ranges from zero (no change over time, usually in short term experiments) to 60% and 50% less, for absolute and relative measures respectively. The single eucalypt experiment in which this trend was observed was confounded by a partial clearing (~10% cleared along the stream) prior to the restoration of streamflows. However, the small area that was cleared is not likely to account for the large change in flow reductions (48%).

## DISCUSSION

### Understanding the drivers of afforestation effects

The most important determinant of the flow reductions is water availability. Wet catchments with a high water availability have the highest flow reductions. This is probably because water demand is generally greater than supply in South African conditions (situations where supply is unlimited are rare in this country). Good examples of this point are Cathedral Peak II and Tierkloof where 5-year mean estimated peak reductions were 67 and 54 mm/10%, respectively. From this it also follows that wet years are those in which the highest reductions are measured. This point is illustrated by Mokobulaan A & B that were both dry for the latter half of the rotations but because of differences in rainfall the estimated 5-year mean maxima were 41 and 17 mm/10% respectively.

Conversely, low water availability can lead to bigger relative reductions, earlier in the rotation, e.g. Mokobulaan B under pine reached a 100% reduction in 12 years under a dry cycle and the dry Ntabamhlope catchments, planted to a hardy eucalypt, reached 100% reductions in the fourth year of the rotation.

### Fit of the CSIR empirical models

The empirical curves developed by the CSIR are currently used to estimate the probable impact of afforestation schemes. The additional experiments analysed in this study offer an opportunity to verify these models. It is clear from the study that the general empirical models provide only an average and long-term estimate of the reductions caused by afforestation. Age is far from being a complete predictor of streamflow reductions as indicated by the large year by year variation in effects on flow.

There is a substantial variation in the key components; time to initiation of flow reductions after planting, size of reductions in individual years, and size of effects in the later years of long rotations.

In broad terms the results show that the curves often underestimate the early effects of afforestation, especially for the longer rotation pine experiments in Jonkershoek and the eucalypt crops at the drier Ntabamhlope site. Furthermore, the curves are asymptotic, remaining at a maximum for the latter part of a rotation. This shape seems to be realistic for short rotation crops and in drier areas, where water demand will usually exceed supply for the duration of the rotation. For the longer rotation crops (probably over 15 and 20 years for eucalypts and pines respectively) on more humid sites the flow reduction curves will need to be modified to replicate the shape of a growth curve, to give a gradually declining influence of the trees on streamflow.

**Understanding the long rotation reversals in effects**

This study has established for South African plantation forestry conditions that flow reductions are not sustained at an asymptote indefinitely. As plantations mature so they have a diminished effect on streamflows than earlier in the rotation. The timing of these decreases is not adequately understood at this stage. The pattern of streamflow effects in the catchments resembles the pattern, though with different time scales, of the measured transpiration cycle of young *Eucalyptus grandis* stands in Mpumalanga, of the response in streamflow to fire in, and regrowth of, mountain ash (*Eucalyptus regnans*) forest in Australia and over-mature fynbos in the Western Cape, and the regrowth of mature indigenous scrub forest at Tzaneen, Northern Province.

The results support a hypothesis that the catchment is a large reservoir formed of deeply weathered soil and therefore acts as a buffer for short-term changes in components of the hydrological cycle. Large increases in evaporative losses, such as occur after the establishment of fast growing plantations into grassland, draw on the reservoir of the catchment as well as current year rainfall. The effects of afforestation on streamflow therefore become lagged. In other words, changes in storage of water within the catchment vary from year to year and are important in smoothing the response in streamflow to change in vegetation. Once evaporative losses decline such as occurs with maturing trees or after clearfelling or fire, the catchment reservoir must first be recharged before full streamflow recovery will be recorded.

## CONCLUSIONS

There is large variability in the results of these experiments: both natural variability caused by site and species differences and climatic variation and the sequence of climatic events. The responses in two similar catchments to specific climatic events or the inability of the statistical models to replicate a seasonally specific response provides a source of statistical variability. Streamflow response is an integral of all hydrological processes, and streamflow generation is a complex process and probably unique for each catchment - hence this is a source of variation that is not, and is likely to remain, inadequately understood.

Consequently,

1. There is a need for long periods of data in order that one can develop a full

picture of land use effects through the natural variations that obscure the picture.

2. Also, for the above reasons, replication is vital. A single catchment cannot provide proper insight, nor can a single climatic sequence provide an understanding of how a response will vary under different rainfall cycle. Replication therefore involves different species, sites and timing.

The initial onset of flow reductions has been underestimated for the bulk of pine plantations. Whereas a long lag before flow reductions become significant has become the general expectation, many of the additional experiments analysed here show that flow reductions can be important from an earlier stage in the rotation. As most forestry in South Africa is now in second or higher rotations and there is much less competing vegetation at the time of replanting, long lags prior to there being significant effects on streamflow are probably most unlikely.

Over longer rotations, there is a negative relationship between plantation age and streamflow reductions. This means that during the later stages of a long sawlog rotation some degree of replenishment of soil water stores occurs, to counter-balance net losses from storage in the early part of the rotation. The implication of this finding is that the hydrological effects of long rotation crops has probably been over-estimated in the past, and the hydrological effects of short rotation crops, such as eucalypt pulp and mining timber, has been under-estimated (because of a lag between evaporation and streamflow response).

**RECOMMENDATIONS**

The project has produced a large series of secondary data sets; the estimated flow reductions or increases over time following afforestation or clearfelling respectively. An aspect that can be readily researched from this base is the relationship between flow reductions and rainfall year (or general catchment wetness), i.e. the effects of forestry in wet and dry years and through wet and dry cycles. There is considerable speculation over this relationship which is of particular relevance for the estimation of supply to run-of-river water users and calculations of the reserve. It is also important to establish the nature of this relationship in order to establish a proper baseline against which the realism of modelling efforts can be tested.

The current project has not investigated the environmental variables that might add explanation to observed variation in forestry effects between different catchments and different years. Amongst the environmental drivers, for example, that might be tested for an influence on observed effects are rainfall, temperature, soil depth or tree rooting.

The major part of the current project went into data preparation, and relatively little time was spent on analysis. However, now that all the data has been prepared, and especially as the secondary data (i.e. observed effects) are available, there are several additional aspects that may be studied at relatively little extra cost. These are listed in brief below.

- Clarify the effects of forestry by further analysis, specifically characterising the onset and extent of the diminished effects late in the rotation, and determine the influence within each catchment of annual rainfall characteristics.

- Relate the secondary results to broader environmental determinants, for example relating observed effects to Et, rainfall or temperature, to soil depth or tree rooting.

- Investigation of patterns in the flow duration curves through the forestry rotations.

- Refinement of the empirical flow reduction models to incorporate the increased understanding developed through the additional analyses accomplished by this project.

- Setting up generalised limits to the effects of forestry within various climatic conditions for different types of forestry, as a basis for checking the results of deterministic modelling efforts.