

IN SEARCH OF A PROTOCOL FOR THE QUANTIFICATION OF STREAMFLOW REDUCTIONS (SFRs) DUE TO COMMERCIAL AFFORESTATION IN SOUTH AFRICA

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That the extensive land-cover changes brought about by commercial afforestation, alien plant invasions (IAPs) and dry-land sugar-cane cultivation result in reductions of downstream river flows, has been an established orthodoxy in South Africa for some time. Consequently, the concepts of “streamflow reduction” (SFR) and “streamflow reduction activities” (SFRAs) were embedded in the National Water Act (No. 36 of 1998) (NWA) as “water uses” requiring “authorisation”. The NWA identifies only afforestation as an SFRA, but the Department of Water Affairs and Forestry (DWA) are currently engaged in an evaluation of other cultivative dry-land crop production land-uses as potential candidates for declaration as SFRAs.

During the past year, an informal debate about quantification of Afforestation-related SFRs has been circulating in the water resources management (WRM) community, which displayed, variously, apparent concern, ignorance, confusion, disappointment and even frustration on the part of some individual participants. I gradually realised that many stakeholders in the water resource management domain would not necessarily have been in a position during the past few years to follow the slow unfolding of research findings and subsequent methodologies in the SFR quantification domain, or to develop an appreciation that, in the area of SFR quantification, South Africa is in a long-term research “process” and will be lacking water-tight answers in the interim.

Therefore, I felt compelled to compile this “hitch-hikers’ guide” to Afforestation-related SFR quantification in SA, in the hope that participants in the debate would appreciate that, intermittently, a long-term SFR research strategy has indeed been unfolding in SA since about 1997 and that we are not trapped in a static legacy from the past. The challenge to us in the WRM community is to find a consensus that confirms that, in the short-term, the uncertainties and gaps in our knowledge in this domain cannot be wished away, but necessitate sound and adaptive “*Protocols*” for doing wise WRM that recognise those uncertainties. The “Way Forward” section at the end of this paper outlines my understanding of these needs and opportunities, but, of course, proposals such as these are not meaningful without a historical context. Therefore, the next few sections provide such a context through an overview of the historical trajectory of SFR quantification research.

PRE-NWA HISTORY

(i) Experimental Catchments and the Empirical Van der Zel SFR Curves

The pre-history of afforestation-related SFR quantification in SA goes back to the 1930s and has as foundation the streamflow changes observed (Bosch and Hewlett, 1982) in long-term experimental catchments that had been afforested or cleared. Table 1 below presents some of the findings of the experimental catchment research, as reported by Görgens and Lee (1992)¹.

Table 1: Summary of South African Catchment Experiment Results to Determine Afforestation-Related Streamflow Reductions (Görgens and Lee, 1992)

Catchment Group	Area Range (ha)	Mid-Area Elevation (m)	MAP (mm)	Mean Streamflow Reductions (mm)
Cathedral Peak	62-190	1900-2080	1400	257
Jonkershoek	27-245	396-950	1296-2261	130-304
Westfalia	33-62	1150-1300	1597-1611	200
Mokobulaan	26	1410	1150	340
Witklip	108-159	-	1475	280 (max.)

Although the long-term catchment experiments provide indispensable data on the streamflow reduction impacts of commercial afforestation, two weaknesses detract from their ultimate value:

- + *They represent only spatially integrated impacts*, and detailed changes in particular hydrological characteristics, or of the soil moisture dynamics of the catchments, were not monitored - therefore, process understanding was not directly enhanced by them.
- + *They were located in relatively high rainfall zones* (Mean Annual Precipitation (MAP) > 1100mm), whereas about 70% of South Africa's commercial afforestation exists in MAP zones below 1000 mm (Scott *et al*, 1998). The ICFR (P Roberts, pers. com., 1998) pointed out that conditions of limited soil moisture availability under natural conditions are common in the latter areas (estimated by the ICFR by simulation modelling to be significant in more than 30% of all afforested areas). Afforestation of such areas could be expected to cause lower absolute streamflow reductions than those in Table 1.

On the grounds of such observed SFR impacts, an Afforestation Permit System (APS) was introduced in 1972 (by the predecessor to DWAF) to regulate commercial afforestation in SA. In 1972, Van der Zel (1990), a senior official responsible for the APS, used some of the catchment experiment results to develop a set of simple SFR curves for use in the APS system, based on earlier SFR curves by Nänni (1970). These so-called "Van der Zel curves" linked SFR (in mm) to natural mean annual runoff (MAR) and rotation period and became

¹ Recently, Scott *et al* (2000) conducted a detailed re-analysis of the SA catchment afforestation experimental data.

embedded in South African water resource analysis studies during the 1980s as the “standard” method for estimating SFRs due to commercial afforestation. Görgens and Lee (1992) reported that various points of criticism had been raised in the literature against the use of the Van der Zel curves in the APS. These are presented here in rephrased and augmented form:

- ◇ the Van der Zel curves were thought to be biased towards only one particular vegetation cover change, i.e. conversion of “upland KwaZulu-Natal grassland” to pines; their applicability for conversions from other indigenous species or land-uses, and/or to other commercial timber species remained untested
- ◇ the Van der Zel curves were derived from results from experimental catchments representing very different climate and soil moisture availability conditions to the more marginal conditions that exist in many afforested areas (e.g. lower rainfall, shallower soils, etc.) and therefore might be too conservative (MAR reductions too high)
- ◇ the focus on the MAR might be somewhat of an unintended red herring, as the afforestation impacts on seasonal low flows might be proportionately larger, or, at least, more devastating in terms of downstream needs
- ◇ the curves do not allow local or site-specific soils and recharge conditions to play a role
- ◇ some commentators were concerned that the curves might represent outdated site preparation (pitting) and site management (riparian zone plantings) approaches; modern site preparation may be more intensive (leading to more severe impacts), while modern site management (no riparian zone planting and tree thinning) may lead to less severe impacts
- ◇ the differences among the age-versus-water use dynamics of the different timber species are not recognised; e.g. that the impacts of eucalypts after planting tend to intensify much more rapidly than those of pines
- ◇ the curves ignore the fact that certain types of natural vegetation, such as fynbos, do not have stable water use over time, but undergo structural changes which change their water use.

The Van der Zel curves were used to calibrate the Pitman monthly model and to naturalise monthly flow sequences in the national water resources survey known as “WR90” (Midgley, *et al*, 1994)

(ii) CSIR Streamflow Reduction Curves

During 1992, Environmentek of the CSIR completely re-analysed the experimental catchment results for five different cases selected from Westfalia, Mokobulaan, Cathedral Peak and Jonkershoek (Scott and Smith, 1997). With these data, and using the paired catchment

approach, empirical SFR models (“curves”) were developed, which distinguish pines from eucalypts, “optimal” sites from “sub-optimal” sites and total flow reductions from those in low flows. These curves potentially resolve some of the aforementioned criticisms of the Van der Zel curves. “Low flows” were defined as those monthly flows in the control catchment below the 75th percentile exceedence level. This simple index was assumed to roughly identify the three driest months of an average year.

For both low flows and total flows several models were tested to express the relationship between *monthly* flows in the treated and control catchments during the calibration periods. Ultimately, log-linear models were selected to ensure homoscedasticity of the residuals. Good calibration models were obtained with no more than a few % of unexplained variance of the treated catchment flows. During 1995, the calibration exercise was repeated for *weekly* and *daily* flow volumes as a check on the influence of the time resolution on the final streamflow reduction models. Though the unexplained variances of the calibration models were now larger, the final generalised streamflow reduction curves were essentially identical to those developed from the monthly resolution flows (D Scott, pers.com., 1998).

The CSIR curves also recognised that the SFR value is dependent on the average age of the trees, and, as stated earlier, on whether or not the site is optimal or sub-optimal. Later, the “optimal site” curves became known as the “short-lag” case, while the “sub-optimal site” curves became known as the “long-lag” case, with the “lag” in question referring to the number of years after planting before the onset of the SFR impact becomes significant. Scott (pers. com., 1998) suggested that, in practice, it would be more useful to *confine the use of the long-lag curves to sub-optimal sites with MAP > 1000mm* (or MAR > 400mm). All other sites, regardless of optimality or water availability, should be allocated the short-lag curves. Early versions of the CSIR curves produced SFRs in unit terms, i.e. mm/a, but later versions expressed SFR in percentage (%) terms. Figure 1 presents examples of the CSIR curves. The CSIR curves quickly replaced the Van der Zel curves as the method prescribed by DWAF for estimation of SFR impacts in DWAF’s afforestation permit system.

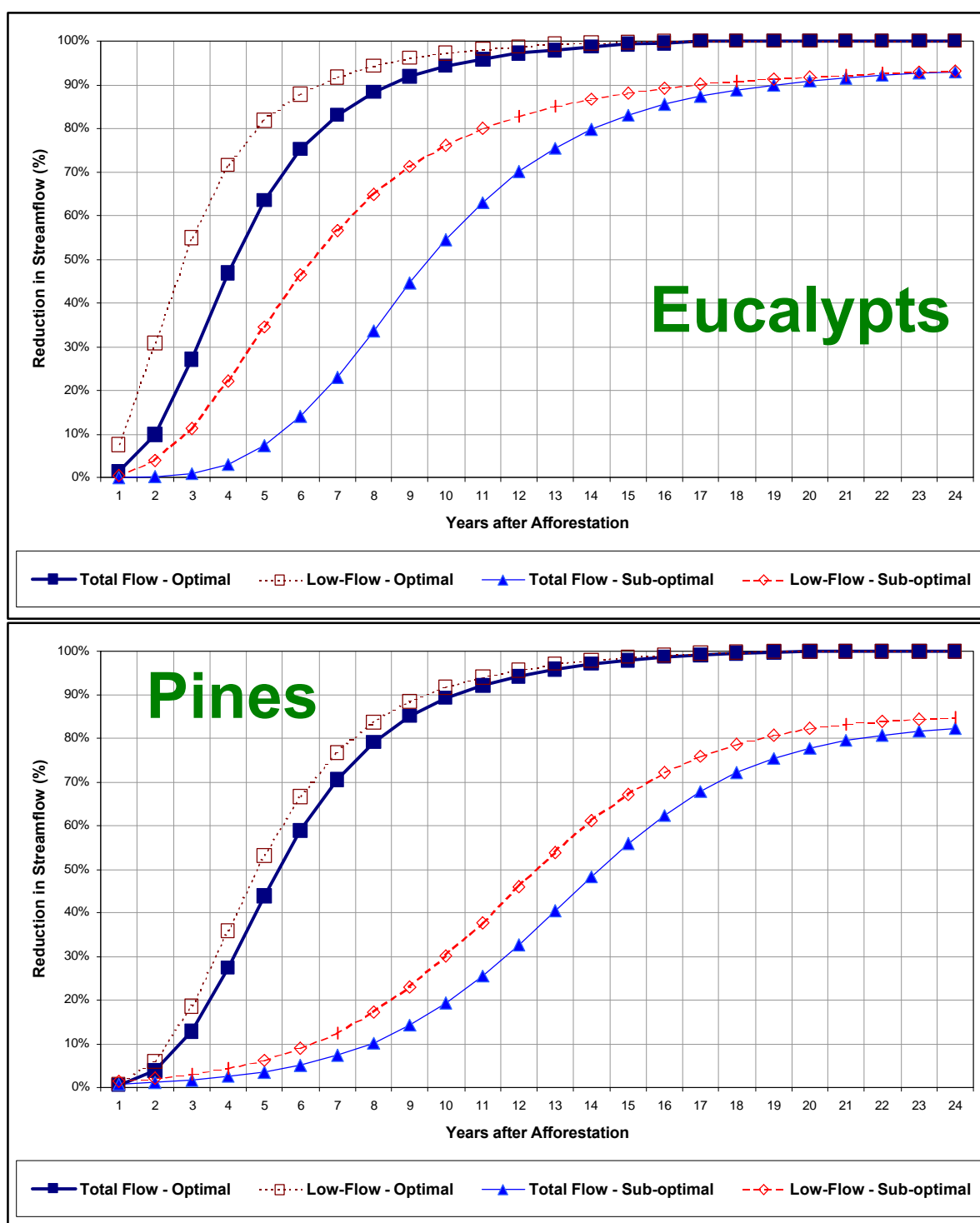


Figure 1 Generalised curves for predicting the percentage reduction in total (annual) flows and low flows as a function of age after 100% afforestation with eucalypts and pines respectively (after Scott and Smith, 1997).

In 1995 the CSIR produced the first draft of a “Handy Reference Manual” on national SFR estimates. This draft contained some serious errors and was extensively overhauled to yield a final version of the “Handy Manual” two years later (Le Maitre *et al*, 1997), while a more

recent record of the CSIR study and results was published in the journal *Water SA* (Scott *et al*, 1998). To achieve their estimates, the CSIR extracted databases of quaternary catchment boundaries, MAPs and MARs from the "WR90" series (Midgley, *et al*, 1994) and combined them with forestry areas by tree genus, timber rotation lengths in years, forestry growth potential (site optimality) and MAP of site. Such combining was achieved with a GIS to yield "uniform" blocks of forestry. For each of these blocks the CSIR SFR curves predicted total and low flow reductions as a function of rotation length, tree genus, water availability (MAP), growth potential and plantation age distribution.

Noteworthy adjustments made during this exercise were as follows:

- + to cater for the universal non-planting of riparian strips, all reductions from the curves were factored by 0.909, which was derived from the assumption that the active riparian zone typically amounts to 10% of a catchment's area, but its afforestation impact is at least twice that of non-riparian areas
- + wattles were assumed to have the same flow reduction curves as pines
- + a weighted mean age was calculated for each homogeneous forest block
- + for a particular genus flow reduction curves were allocated to sites (uniform forest blocks) according to the site's optimal/non-optimal classification -- except for non-optimal sites classified as "drier" (MAP < 1000mm); in such cases the short-lag curves were used instead of the long-lag curves. (Because of natural moisture limitations in such soils, plantations may have a large relative impact earlier in the rotation, while the maximum impact may approach 100%. This adjustment may have caused some over-estimation of reductions in particular cases).

The CSIR national afforestation-related SFR estimate of 1417 million m³/a amounts to a unit national SFR of 99 mm/a. This is well short of the absolute reductions observed in experimental catchments shown in Table 1, but not unjustifiably low, if it is borne in mind that a majority of the afforested areas have MARs well below those of the experimental catchments, and when the resultant range in annual total flow reductions across the country is considered:

- Pines: reductions from 106 mm on high rainfall sites with sub-optimal forestry potential, to 151 mm on high rainfall sites with optimal potential.
- Wattles: growing typically on drier sites on short rotations, range from 11 to 52 mm for sub-optimal to optimal sites respectively.
- Eucalypts: from 44 to 92 mm for sub-optimal to optimal sites respectively.

Nevertheless, Scott (pers.com., 1998) cautioned that there were compelling reasons why the CSIR estimate might actually be too low, rather than too high:

- the riparian adjustment is crude and does not apply to many plantations which do not currently have unplanted riparian reserves, or which have weed-infested reserves with high water use
- the riparian adjustment may not be applicable in “drier” catchments (>60% of all) where a high level of non-riparian planting, say, 90% coverage, has been known to consume 100% of streamflow
- the CSIR curves do not take account of the more rapid establishment of tree crops under modern site preparation practices, or in second rotations where there is no competition from native plants
- the original catchment experiments were with thinned and pruned sawlogs; unthinned pulpwood crops are likely to have a bigger impact than sawlog crops
- the curves do not take into account that, in some cases, second rotations may start off with inherited soil moisture deficits which would immediately translate into streamflow reductions.

Görgens and Tukker (1998) demonstrated the differences caused by using the Van der Zel curves as opposed to the CSIR curves in water resource evaluations in selected catchments in three different geobioclimatic regions in South Africa. The method of incorporation of the CSIR curves in the Pitman modelling paradigm was imbedded in the so-called SHELL catchment modelling software (Berg, Beuster, and Görgens, 1992; Larsen, Görgens and Little, 1995). The procedure followed was to calibrate the Pitman model for selected gauged catchments with both sets of SFR curves and then to generate naturalised 70-year long historical streamflow series at critical locations in the selected river systems. Reservoir and sub-system yields for specific assurances were then determined. The primary finding of this study was that the SFRs calculated via the two methods were often very different. Generally, as mean annual values, the “sub-optimal” CSIR flow reductions are *less than* the Van der Zel curve-based values for a 15-year rotation, while the “optimal” CSIR flow reductions are *greater than* the Van der Zel curve-based values for a 15-year rotation.

Against the background of the Görgens and Tukker (1998) findings, the team managing DWAF's Water Situation Assessment Model (WSAM) development, which is driven by yield information extracted from WR90 flow sequences, commissioned Ninham Shand in 1998 to “correct” all naturalised WR90 flow sequences for quaternary catchments with afforestation by replacing the influence of Van der Zel curve SFRs with the influence of CSIR curve SFRs. These “corrected” flows were incorporated in the WSAM background database.

(iii) Research Planning Study by Görgens and Lee (1992)

During 1992, Görgens and Lee were commissioned by the WRC to conduct an in-depth review of all research activities in the hydrological field that had a bearing on afforestation-related SFRs, as well as an evaluation of the research capacity in this field. This planning study concluded with proposals for a research programme comprising a wide range of research themes and research foci, according to the so-called FAIM logical framework, where the individual projects are interlocked throughout the following hierarchical levels: fundamental, applied, integrative and management support research.

(iv) *ACRUforest*: Agrohydrological Daily Model Customised for Afforestation

During the 1990s, the research team at the Department of Agricultural Engineering, University of Natal (now called the School for Bioresources Engineering and Environmental Hydrology [SBEEH]), under Prof R Schulze, developed a customised version of the ACRU agro-hydrological daily modelling system, known as *ACRUforest*, for use as a decision-support tool in forestry hydrology (Schulze *et al*, 1997). Before outlining this tool, it may be useful to revisit some of the basic concepts incorporated in ACRU that are relevant to its use in forest water use simulations. Figure 2 presents the conceptual elements of the basic ACRU Model.

The standard soil moisture budgeting components of the ACRU model underlie *ACRUforest*. The prime controlling parameters are the soil water retention constants - porosity, field capacity and permanent wilting point - for the two "active" soil horizons in which root development and evapotranspiration can take place. These constants are texture-class bound and their values are derived from the soil forms/series that make up all the individual soil units in a catchment. All the soil forms and series used in the SA Binomial System of Soil Classification have been classified hydrologically for use in ACRU on the basis of texture class, clay class and distribution, erosion potential and interflow potential. *A priori* determination (say, from a soils or land-type map) of the moisture retention constants of all the soil units in a catchment is therefore possible. The knowledge of these, as well as soil horizon depths (from the soils map), essentially obviates the need for calibration of these parts of the model. Another advantage of this structure is that the ACRU model simulates the soil moisture dynamics of a catchment in a semi-distributed manner, rather than in a lumped manner.

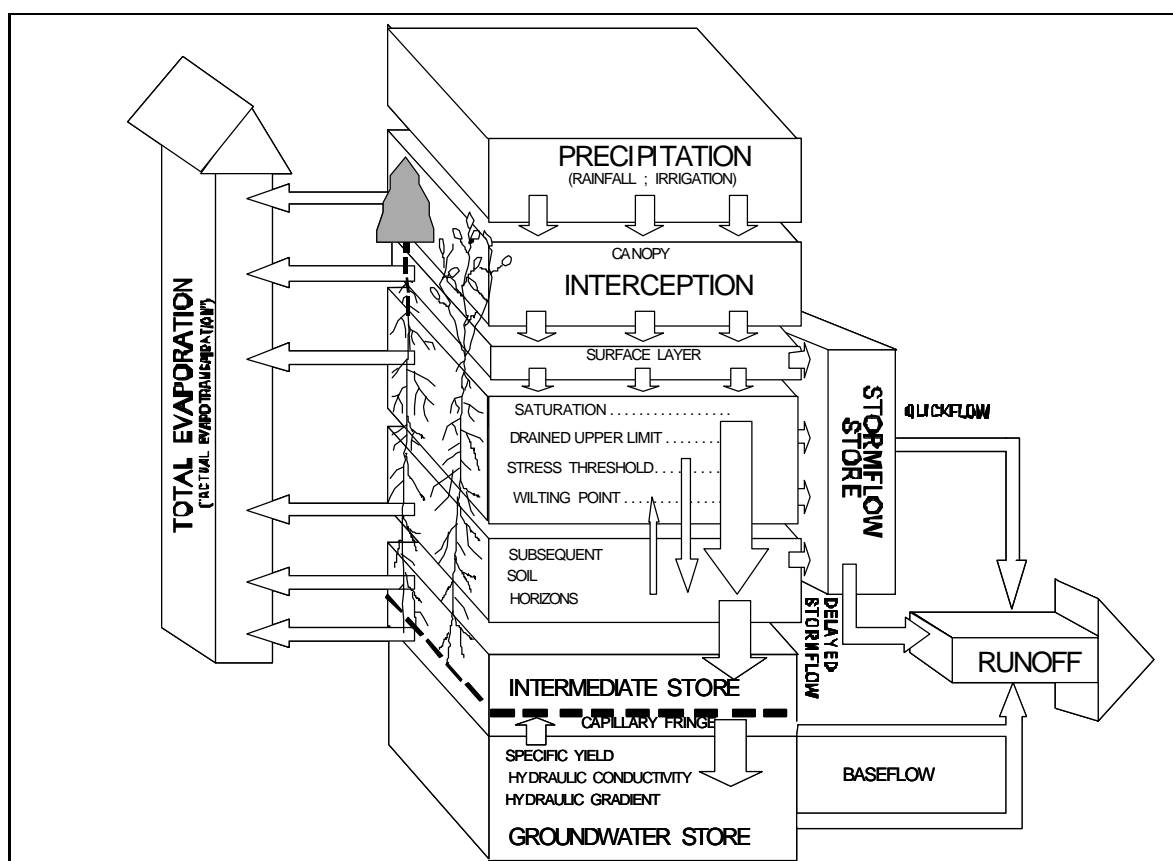


Figure 2: The conceptual elements of the ACRU Model (Schulze *et al*, 1997)

Soil moisture is abstracted for transpiration by colonising roots or under evaporation demand. “Saturated” redistribution of excess soil moisture from the top- to the subsoil horizon, and from there to an intermediate groundwater store, is governed by two response fractions of the remaining water above field capacity. These two fractions are texture class sensitive, but have only an indirect physical meaning and may require calibration. Unsaturated redistribution (up and down) takes place under a gradient based on moisture content.

Generated streamflow comprises baseflow and stormflow, with the stormflow component consisting of a quickflow response and a delayed stormflow response. The generation of stormflow is based on the premise that, after initial abstractions, the runoff produced from rainfall is a function of the soil water deficit over a critical response depth in the soil. This critical response depth may require calibration. Baseflow is released from a linear “groundwater” store, which is recharged by excess soil water content in the subsoil horizon. Both the groundwater release rate and the drainage/recharge rate from the subsoil horizon, are parameters with only indirect physical meaning and may require calibration.

The major objective of developing *ACRUforest* was to create a physically-based simulation tool that could use the vast spatial daily rainfall, climate and soils databases available in

South Africa, for rapid assessment of impacts of afforestation on a range of hydrological responses (such as baseflow, stormflow, total runoff, evapotranspiration), by accounting for the effects of *different tree genera, silvicultural management practices (including thinning), rotation lengths, percentages of area under forest and original land cover*.

ACRUforest is an interactive computer package which prompts users with simple forest hydrology-related questions. Responses to these questions lead systematically towards the completion of an ACRU input file which produces two model runs for the same period (say, 1950-1994) for one of four identified major tree growing regions (NE Cape, KZ-Natal Midlands, KZ-Natal north coast and Mpumalanga/Northern Province timber belt). The first model run represents daily conditions under a particular selected original land cover, and the second, the daily conditions under the modified afforested cover. Identification of the quaternary catchment in which the afforestation takes place, provides the model with the key to relevant pre-stored rainfall, climate, soils and natural land cover data for that particular site. A single weighted soil profile for each quaternary has been pre-processed from a national soils map. The soils input information can be overridden by provision of site-specific data.

A crucial element of the forest component of the model is that it is “driven” by *Leaf Area Index (LAI) changes over time, after planting*. LAI in turn determines water use coefficients for evapotranspiration estimates and interception storages. These relationships were derived from fieldwork, literature on tree water use and, more significantly, expert opinions obtained during four one-day workshops with SA forest hydrologists and forest company scientists. The core of this model component is a set of matrix tables combining *LAI, canopy interception, root distribution per soil horizon and root colonisation for each year after planting* (i.e. age) and for combinations of the:

- 4 tree growing regions
- 3 tree genera (pines, eucalypts and wattles)
- 2 rainfall zones (MAP>1000mm; MAP< 1000mm)
- 2 site preparation techniques (pitting vs. plough and rip).

NB: The following two points should be noted:

- It is also possible to do a site-specific analysis of afforestation-related SFRs with the standard version of ACRU by providing customised settings for the relevant model coefficients. Such an approach is described in Appendix B.
- Use of a so-called “dynamic file” allows simulation of time-changing afforestation impacts, e.g. trees growing from planting to maturity, thinning and pruning practices, etc.

(iv) Review Study on Afforestation-Related SFRs (1998)

In December 1997, recognising many inconsistencies in the estimation of afforestation-related SFRs in SA WRM practice, as well as the quantification implications of the emerging NWA measures related to this domain, the then Directorate: Water Resources Planning of DWAF asked me to conduct a Review Study with the title: “*Quantification of Streamflow Reduction due to Commercial Afforestation in SA*”, with the following objectives:

- ◇ *to consolidate and present South African understanding of the impacts of commercial afforestation on runoff*
- ◇ *to assess the available methodologies for use in South African water resources analysis and planning and in the “afforestation permit system” to accommodate the impacts of commercial afforestation*
- ◇ *to quantify the implications for river system yields and low flow patterns of using specific methodologies for estimation of the impacts of commercial afforestation.*
- ◇ *to make recommendations to the DWAF regarding:*
 - + *implications for past water resources analyses of having used the “Van der Zel curves”*
 - + *an appropriate methodology for water resources analysis and for the APS system in the future*
 - + *appropriate research strategies to overcome shortcomings of available methodologies.*

The final report on this study (DWAF, 1998) details the methods and findings of the investigation, and particularly, of the consequences of using either the Van der Zel or the CSIR curves.

A crucial part of my brief was to facilitate a Workshop in June 1998 which had two objectives:

- Seeking consensus among the participants regarding the national order of magnitude, and therefore, the national significance of afforestation-related SFRs. Among the 26 participants were DWAF Water Resource (WR) and Forestry managers, WR consultants, WR researchers, WR modellers, WRC reps, Forestry Industry reps, Forestry Industry consultants, a Sugar Industry rep, a senior academic in Botany and myself.
- Outlining a framework and criteria for directed research that would guide the alignment of the various afforestation-related SFR quantification methodologies.

The range of national estimates of SFR due to afforestation considered by the Workshop is depicted in Table 2:

Table 2: National Afforestation-Related SFR Estimates before 1999

Study	Demand Scenario	Afforestation-Related Streamflow Reduction (million m ³ /a)	Afforestation-Related Streamflow Reduction (mm/a)
DWA (1986)	1990~	1427	114
Van der Zel (1996)	1995	396	28
ICFR (1997)	1997~	594	38
CSIR (1998)	1993 & 1996	1417	99
LHA (1998a)	1997~	500	35
LHA (1998b)	1997~	700 - 800	49 - 56

After extensive debate, the participants accepted that “sufficient consensus” was being reached that the estimates achieved by the CSIR (1998) study (the so-called *Handy Reference Manual*), in which the CSIR SFR curves had been applied to all afforested areas in the RSA, were indeed the most acceptable at that stage. The following points outline the Workshop outcomes:

Workshop Resolutions:

- ⇒ The CSIR’s national streamflow reduction estimate, equivalent to 99 mm/a in unit terms, is accepted as the most reasonable quantification available.
- ⇒ The streamflow reduction quantification methodology used in the Afforestation Permit System (APS) must have the following attributes:
 - + *unambiguous*; i.e. the same answer every time, regardless of the user
 - + *transparent*; i.e. validatable assumptions
 - + *unbiased*; i.e. consistently accurate, not precise
 - + *dynamic*; i.e. easily accommodate new scientific understanding, catchment changes and new social aspects
 - + *easy to use*.
- ⇒ In principle, the approach used for the CSIR curves meets most of the above desired attributes, but they represent too limited a range of afforestation situations.
- ⇒ The *ACRUforest* approach holds potential for extrapolation of the range of afforestation situations.

- ⇒ Both a long-term and a short-term strategy for the quantification of streamflow reductions need to be agreed.
- ⇒ The long-term strategy should be a joint venture between the CSIR and *ACRU* research teams to ensure that the best of both approaches is captured.
- ⇒ The short-term strategy should be to use the current CSIR curves in the APS.
- ⇒ A Continuation Task Team to formulate the details of the long-term strategy would be identified jointly by Mr J van Rooyen (Project Planning) and Mr M Warren (Water Utilisation) of DWAF.

Workshop Research Recommendations:

The Workshop recommended a research process with the following components:

- The *ACRUforest* model should be used to “interpolate” between/ “extrapolate” from the current CSIR curves to yield a range of streamflow reduction tables that could be applied in all afforested regions of South Africa.
- Such tables should have a pragmatic range of input variables, such as tree genera, site suitability index, rotation length, natural MAR, bio-climatic region, and, perhaps, topographic position.
- The tables should include impacts on both total flow and low flow.
- Preceding the development of the tables, the *ACRUforest* model should be verified independently on a wide range of catchment afforestation experiments and improved if necessary.
- The research process should be completed within two years.

POST-NWA RESEARCH

(i) National SFR Tables for Commercial Afforestation (2002)

Management and Administration

The June 1998 Workshop resulted in a joint 2-year research project between the CSIR and the School for Bioresources Engineering and Environmental Hydrology (SBEEH) of UN that started on 1 April 1999, with objectives modelled on the Workshop recommendations presented above and jointly funded by DWAF and the WRC. My own role in this project was described as “strategic coordination and delivery focusing by an independent third party”. During the first year of the study, Mike Warren of DWAF was the “Research Manager” and

during the second year, the late Hugo Maaren of the WRC. The Steering Committee comprised the following:

Hugo Maaren – WRC; Steve Mitchell – WRC; Mike Warren – DWAF; Peter Roberts – Forestry Industry consultant; Jan Bosch – CSIR rep; Erik Schmidt – SA Sugar Experimental Station; Ms A Roelofsen – BEEH UN representative.

I chaired three meetings during the first year and Hugo Maaren chaired three more meetings during the second year. Minutes were kept of all the meetings and progress reports were submitted. While the draft final report was being finalised, two more meetings, including some Steering Committee members, took place at DWAF to brief Forestry Industry representatives and Mr Piet Pretorius of DWAF and to ensure that the format of reporting met the requirements of both parties. The final work on the project was concluded in mid-2001. During the period June 2000 – June 2001, as the research threw up challenge after challenge, robust e-mail debates were conducted among team and SC members, as well as advisers such as Dr Peter Dye and Jan Bosch, regarding many aspects of the project.

Research Methodology

The details and outcomes of the 2-year Project are fully reported in the WRC Report TT 173/02: *“Estimation of Streamflow Reductions Resulting from Commercial Afforestation in South Africa”*, April 2002, by M Gush, D Scott, G Jewitt, R Schulze, T Lumsden, L Hallows, A Görgens. The methodology comprised verifying the ACRU daily agrohydrological model on data from ten different afforestation-related field experiments/ catchment data sets and using the lessons so learnt to extrapolate the ACRU model to all 843 QCs with afforestation potential. Figure 3 indicates the locations of the field experiments, while Figures 4 and 5 present the outcomes of two of the verifications, as illustrations, when compared with the CSIR’s detailed regression analysis (treated catchment versus control catchment) of the experiments’ SFR impacts. In general the ACRU verifications were acceptable for total flow impacts but not convincing for low flow impacts.

The SFRs were estimated relative to the dominant Acocks vegetation type in each QC, but a constant soil texture class was used nationally, namely a sandy-clay-loam. This texture was regarded as the modal value nationally. One typical “average” age was selected for each genus, which is believed to be representative of rotation practices nationally, i.e., for pines – 7 years, eucalypts – 4 years, and wattles - 4 years (averages all).

For the derivation of the ACRU-based SFR tables described earlier, Gush et al (2002) used an upgraded version of *ACRUforest*, while the verification stage of their study required use of dynamic files to portray the time-varying changes of plantings, thinning and pruning, fires and

fellings in the experimental catchments under consideration. A particular strength of the ACRU approach, compared with the monthly modelling approach where the CSIR curves are incorporated during Pitman model runs, is that the ACRU-based SFR effects are derived from actual soil water budgeting, which means that delayed SFR effects may be simulated.

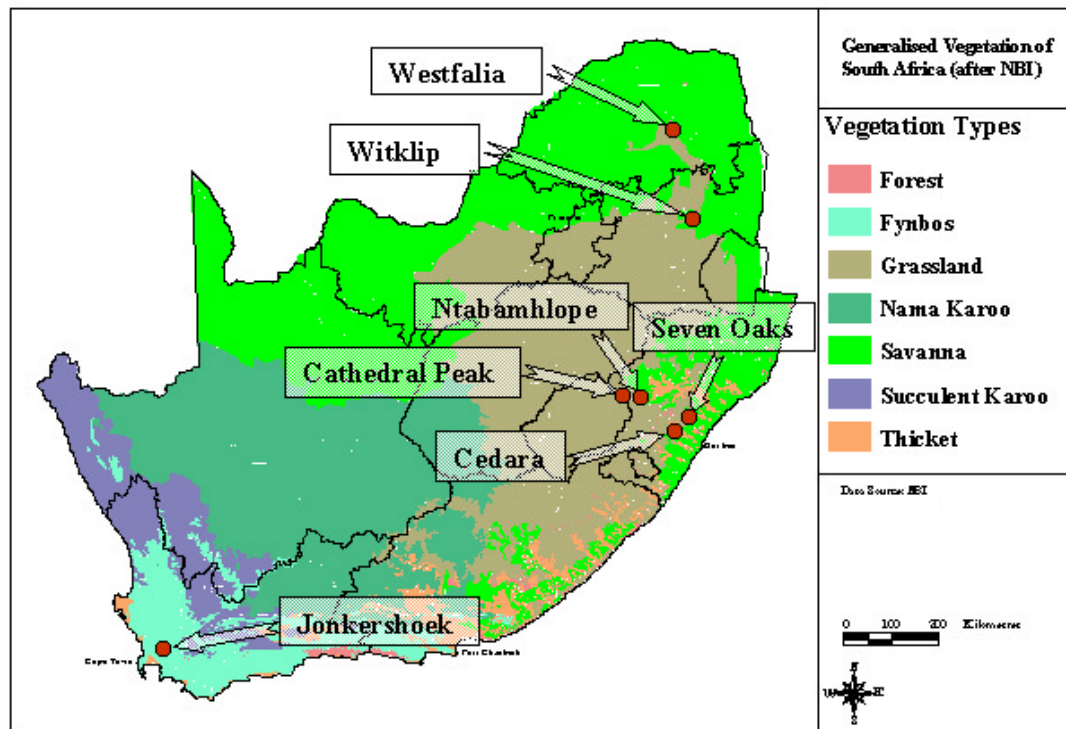


Figure 3 Map of South Africa illustrating the generalised vegetation types / biomes for the country (after Low and Rebelo, 1996). The locations of the experimental catchments referred to in the text are indicated.

Research Outcomes

A set of QC-based Tables of *median and mean long-term annual SFRs* for three different tree genera (pines, eucalypts and wattles), three soil depth classes and both low flow and total flow impacts formed a crucial part of the “Gush” Report and research output. Appendix A presents an example of the ACRU-based SFR tables for median values.

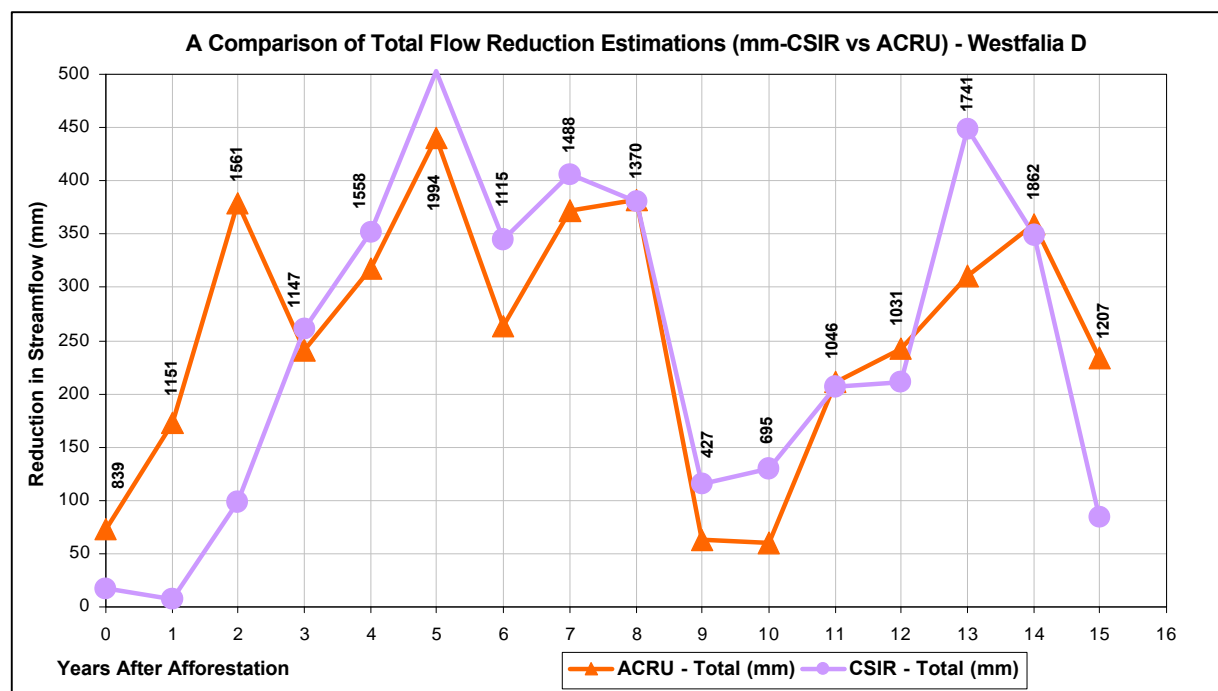


Figure 4 A comparison of ACRU-simulated total streamflow reductions (mm) against those calculated by regression by Scott *et al.* (2000) for the afforested Westfalia catchment D. Annual precipitation totals are included as labels.

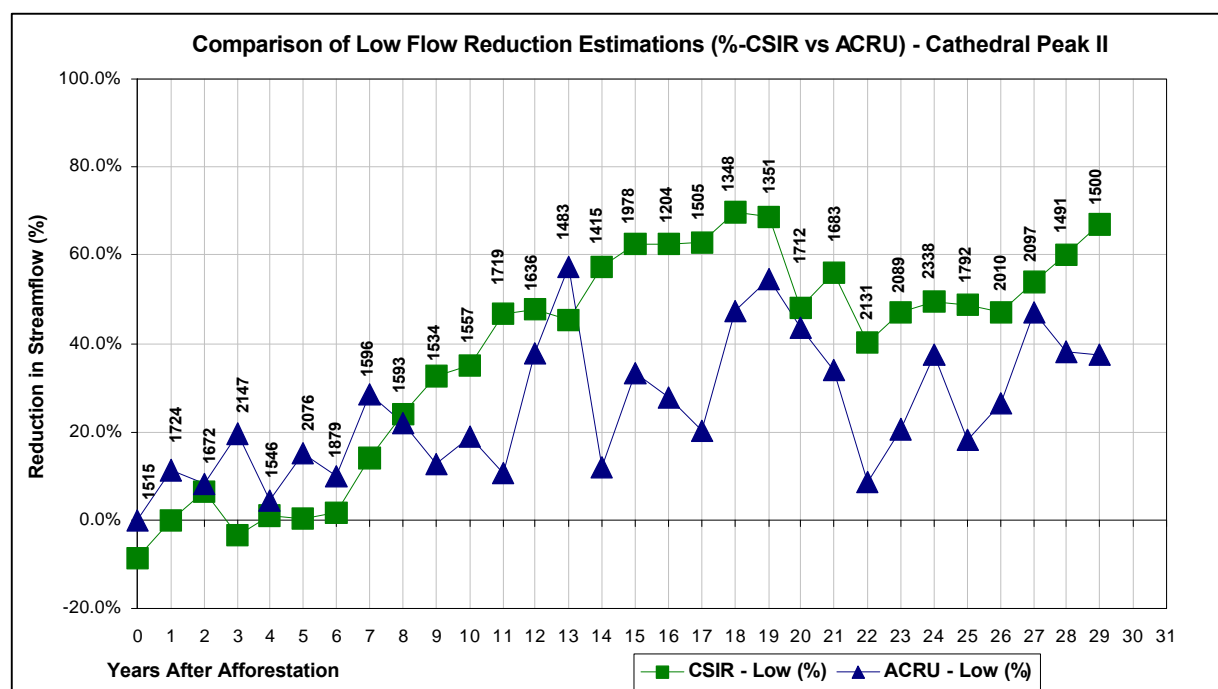


Figure 5 A comparison of ACRU-simulated low flow reductions (%) against those calculated by Scott *et al.* (2000) for the afforested Cathedral Peak catchment II.

Recently, some heat has been generated in the WRM community because in some cases the median annual SFR values in the Gush Tables as published in the aforementioned WRC Report appeared to be much lower than mean values for equivalent QCs in the CSIR study of the mid-1990s. Table 3 provides a bird's-eye view of the national median and mean annual SFR outcomes (in mm) of the Gush Study (the mean values are reported in Mark Gush's MSc Thesis.)

Table 3: National median and mean annual SFR statistics

All QCs	Area (km ²)	MAP (mm)	"Natural" MAR– medium soil depth (mm)	Eucalypt SFR medium soil depth (mm/a)	Pine SFR medium soil depth (mm/a)	Wattle SFR medium soil depth (mm/a)
Median - Max	2587	1813	1179	232	200	180
Median - Min	55	647	14	14	11	10
Median - Average	354	840	124	74	57	57
Mean - Max	2587	1813	1179	204	169	140
Mean - Min	55	647	14	22	16	16
Mean - Average	354	840	124	73	57	55

One is tempted to want to compare the averages of the median and mean annual SFRs with the 1998 national average of 99 mm/a given in Table 2 above. However, such a comparison is meaningless because the two sets of values represent very different statistical entities. But the following points of interest may help to create some perspective:

- The 99 mm/a was a weighted average calculated from all current afforested land in the RSA in the mid-90s, where as the Gush values shown above are simple averages of 843 annual median or mean values for generalised QC conditions and characteristics.
- The 99 mm/a had been estimated by applying the CSIR SFR curve proportions to the natural QC MARs of the WR90 study for about 600 QCs with current afforestation, very few of which had the relatively low MAPs included here (all QCs with MAP>650mm). Therefore, the Gush QC sample is considerably more bulky on the low MAP end of the range.

- About 13% of the QC sample here had MAPs >1000mm, but in the CSIR study 30% of the afforested areas had MAPs>1000mm. (Lower MAPs imply lower absolute MARs (in mm), which, in turn, imply lower absolute SFRs (in mm), in general.)
- The CSIR SFR-curves were developed from the results of five sets of catchment experiments, all with MAPs above 1100mm and relatively deep soils. Their applicability to the 70% of SA's afforested areas with MAPs<1000mm, often on shallow soils, was regularly questioned.
- The natural QC MARs produced by ACRU for medium soil depths are on average about 25% lower than those of the WR90 series, indicating, inter alia, higher baseline (natural) evapotranspiration loss from the catchment. Inevitably, this difference should also be reflected in lower average ACRU-based SFRs (in mm) compared with WR90-based SFRs. Also, had the original CSIR curve-based proportions been applied to the ACRU naturalised flows, the outcomes would have been markedly lower SFR values in the forementioned 25% of QCs.
- Concern has been expressed that the high (>150mm/a) SFR values observed in the catchment experiments (mostly deep soils) have not been captured by the Gush Table, but a simple check reveals that about 50 (6%) eucalypt QC cases and about 9 (1%) pine QC cases for deep soils show annual median SFR values > 150mm (also, keep in mind that 50% of the years modelled had SFRs larger than 150mm for each of these cases!).
- The concern about potential under-estimation in the Gush study can further be evaluated by comparing the maximum and minimum values of the CSIR curve-based total flow SFRs with the equivalent extremes in the Gush Tables, as in the next Table. The Gush maxima for medium depth soils far exceed those of the CSIR study.

Table 4: Comparison of National SFR Table extremes with those of the CSIR Handy Manual study

Study	Eucalypt SFR (mm/a)	Pine SFR (mm/a)	Wattle SFR (mm/a)
CSIR (annual mean)	44 - 92	106 - 151	11 - 52
Gush (annual median) (medium depth soils)	14 - 232	11 - 200	10 - 180

Table 5 casts some light on the question of how the Gush SFRs as percentage of the MAR (for total flow, medium-depth soils and expressed as national averages) compare in a direct way with the CSIR SFR-curve proportions:

Table 5 Comparison of SFR proportions between Gush and CSIR studies

	Eucalypts	Pines	Wattles
	SFR %	SFR %	SFR %
Average Age (years)	4	7	4
CSIR Curves	47	71	27
Gush Medians	70	57	57

Table 5 illustrates a general trend that, for identical rotation periods, the Gush ACRU-based median proportional SFRs (for both total flow and low flow) are larger than those from the CSIR curves for eucalypts and wattles, but smaller than the CSIR-based values for pines.

Verification and Confidence Limits

In general, the magnitude of the averaged SFRs observed in the catchment experiments could be reproduced by the ACRU model, but the detailed time series verification of the ACRU model against the catchment experiment results was very uneven. In two cases the verification was good, in another four it was acceptable and in the remaining four it was poor to varying degrees. Some of these verifications were undermined by poor data which could not be rehabilitated. The verification outcomes were brutally scrutinised by Dr Dave Scott and myself, both of whom were at an arm's length from the modelling work, and we contributed a 17 page uncertainty/confidence analysis which should inform the use of the median annual SFR Tables. (It is unlikely that any catchment model verification in SA has ever been subjected to such an uncompromising analysis!) Table 6 provides a glimpse of some of the Confidence Bands (for total flow) that we recommend when the Gush SFRs are used, while Figure 6 summarises the full set of Bands:

Table 6: Examples of Confidence Bands proposed for use with National SFR Table Values

Confidence Bands (%) for Proportional SFRs			
<i>Genus</i>	<i>Humid</i>	<i>Sub-Humid</i>	<i>Marginal</i>
Pines	25	45	60
Eucalypts	25	50	80
Wattle	50	50	100
Confidence Bands (%) for Absolute SFRs			
Pines	40	60	100
Eucalypts	40	60	100
Wattles	60	80	120

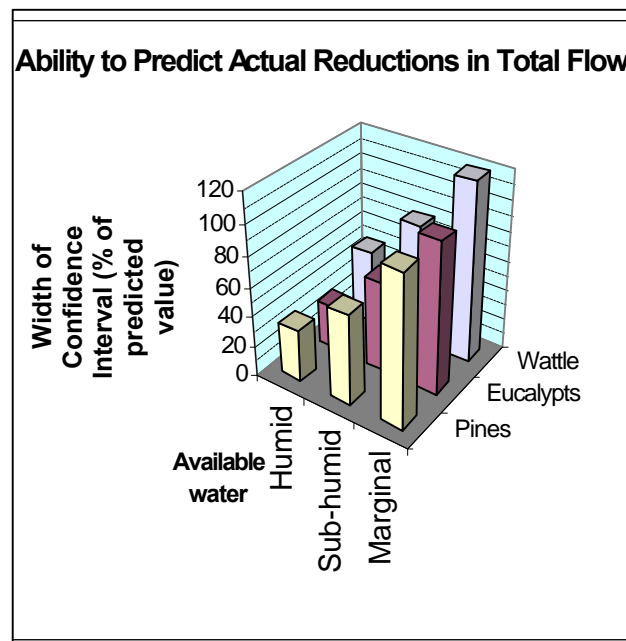


Figure 6: Approximate confidence limits on predictions of actual total flow reductions by genus and water availability regime for the new SFR factors for forestry, derived from ACRU modelling.

The implication is that the user must expect the true SFR value to lie within the indicated band around the Gush Table value, e.g. under sub-humid conditions the total flow SFR in mm for Eucalypts might be up to 30% larger or 30% smaller than the Gush Table value.

Regarding concerns in the WRM community that the Gush Tables in fact implies a national SFR picture significantly lower than the 1998 CSIR study, I must state that “the jury is still out”. If the Gush annual medians are applied with adequate recognition of the Confidence Bands, then it is possible that the national SFR picture might look more alarming than it did after the 1998 CSIR study. Conservatism will require that the upper limit of the Bands be used, and, given that roughly 13% of the QCs are classifiable as Humid, 31% as Sub-Humid and 56% as Marginal, then the national mean upper limit annual median SFRs can be coarsely approximated as follows:

Table 7: National Mean Upper Limit Annual Median SFRs for Total Flow

Pines on Medium Depth Soils = $57 \times [0.13 \times 120 + 0.31 \times 130 + 0.56 \times 150] / 100 = 80\text{mm}$

Eucalypts on Medium Depth Soils = $74 \times [0.13 \times 120 + 0.31 \times 130 + 0.56 \times 150] / 100 = 104\text{mm}$

Wattles on Medium Depth Soils = $57 \times [0.13 \times 130 + 0.31 \times 140 + 0.56 \times 160] / 100 = 85\text{mm}$

Footnote: Do Stakeholders have Alternatives to the Gush National SFR Tables?

The National SFR Tables produced by Gush et al (2002) were aimed at regional or large-scale decision-making regarding SFRs. Of course, if a stakeholder needs to dispute a particular decision at such a coarse scale, then a fine-scaled or site-specific investigation of SFRs can be performed via the ACRU or another suitable model, but with the added burden of assembling soils, land-cover, land-use and meteorological data that are specific to the site in question.

(ii) Guidelines for dealing with scale and resolution in the quantification of SFRs (aforestation and invasive alien plants (IAPs)) in WR Evaluations (currently in progress)

During 2000 the late Hugo Maaren of the WRC organised a Workshop at which a prioritisation was made of the most urgent landuse-impact-related research needs. This Joint University of Stellenbosch/Ninham Shand project (Researcher: Tembi Dzvukamanja), which started in April 2001, was borne out of this prioritisation and has the following objectives:

- Illustrate the differences that the competing quantification methodologies for SFRs due to plantations and IAPs cause in water resource evaluations for representative SA river systems, for different spatial scales and time resolutions.
- Develop a Framework with Guidelines for dealing with SFRs in WR evaluations.

Tembi has configured the daily ACRU model and the SHELL version of the Pitman monthly model with the CSIR curves incorporated for three river systems, i.e. Mhlatuze, Sabie and Upper-Berg. She has also set up the WRYM system model for these river systems. Her work is now fairly advanced and illustrates clearly the various types of differences that result in the water resource evaluation outcomes when alternative methodologies and scales are applied. At a work-in-progress Workshop under this project in April 2003, a framework of criteria for the planned Guidelines was also formulated.

THE WAY FORWARD

(i) Field-based Projects in Progress: SBEEH of UN (Researchers: Simon Lorentz, Graham Jewitt, Roland Schulze and their Post-graduatess) and the CSIR (Researchers: Peter Dye, Colin Everson, Jan Bosch, Caren Jarman, David le Maitre, Marilyn Govender, Arthur Chapman and colleagues).

A range of field-based projects, with various levels of innovative instrumentation to observe hydrological changes during changes in vegetation cover for plantations/ invasive alien plants (IAPs)/ indigenous vegetation (as the case may be) are in progress, in locations in the Eastern Cape, KZN Midlands, KNP and the Western Cape. These projects are funded by the WRC and/or the Working for Water (WfW) Programme, as well as some international programmes. Some of the research involves highly sophisticated direct measurement of consumptive water use by individual woody plants or from discrete blocks of canopies, backed up by soil-water and groundwater monitoring and intensive modelling. Mature findings from these empirical studies and field experiments should become available during the next 12-24 months and such findings will lead to improvements in models and SFR quantification methodologies.

(ii) Strategic Planning of SFR-related Research by the WRC and WfW

Although the WfW-funded research projects focus on IAPs, their results speak directly to afforestation-related SFR questions as well, as invasive alien trees are often commercial species. Therefore, it is important to recognise the potential for much synergy between WRC and WfW. Both the WRC, under Renias Dube (who succeeded the late Hugo Maaren), and WfW, under Christo Marais and Ahmed Khan, and with support from the WfW Hydrology

Research Review Panel, have engaged in respective processes of Strategic Research Planning around SFR-related and “low flow”-related objectives.

Renias Dube has held a series of Workshops to this end during the past few months, the outcomes of which will lead to various multi-year “solicited research” projects relevant to SFR quantification, the first three starting in April 2004, and the others in following years.

The WfW Hydrology Research Review Panel commissioned me in late 2000 (with DWAF funding) to conduct a framework assessment of knowledge gaps and research needs regarding the impacts of IAPs on water resources in SA. This was followed by a WfW Hydrology Research Programme design by consultants, PHD, and the University of Zululand. Some of the field-based projects referred to in the previous section fall under the WfW ambit and more WfW-funded projects will follow.

It should be noted that the WfW Panel conducts very robust debates about SFR-related research and its influence should progressively deepen in this domain. Much closer integration of WRC and WfW research strategies on SFRs can also be expected in the near future.

(iii) Can We Devise “Protocols” for WRM Decision-making that Recognise our SFR Quantification Uncertainties?

The uncertainties in SFR quantification need more “calendar time” to elapse before they become diminished by maturing research. In the interim, licensing, water use allocation scheduling, bulk and strategic water supply planning, water resource augmentation design and water resource operations all continue to require some form of SFR quantification. Can we devise “Protocols” for WRM decision-making that recognise our SFR quantification uncertainties, that cuts through all the “concern, ignorance, frustration, confusion, panic, disappointment and mild hurt” that I referred to in the beginning and that helps keep WRM on an even keel in this regard? I believe we can. Tembi Dzvukamanja’s project (described above) outcomes represent some tentative steps towards it, but a wider process is needed.

A typical “*Straw Dog*” Protocol for afforestation-related SFRs that comes to mind (by far not the only option!) could be along the following lines:

Regional or Large-Scale Decision-making:

- Accept that we will not have vastly improved estimates for SFRs for a number of years yet and that our decision-making must recognise our uncertainties.
- Accept the National SFR Tables as the standard for the next “N” years.
- Apply the Confidence Bands described above and detailed in the Gush Report, depending on the type of conservatism that prudent decision-making requires.
- For decisions about allocating SFRA licences – use the upper limit values according to the Confidence Bands.
- For decisions about water balances in catchments or calibration of the Pitman Model – use the median values.
- For decisions about conversion of land-use away from afforestation, use the lower limit values according to the Confidence Bands.
- For WR management charges by CMAs use median or lower limit charges.
- Additional similar Guidelines for additional management needs.

Fine-scale or Site-Specific Decision-making:

Apply the ACRU Model, or some other appropriate model, to the site in question with site-specific soils, land-cover, land-use and meteorological data and an appropriate assumption about baseline (or natural) conditions.

REFERENCES

DWAF, 1998. *Quantification of streamflow reductions due to afforestation in South Africa: a review study.* Report by Ninham Shand to DWAF, Report No. RSA/00/0398

Görgens AHM and Lee J, 1992. *Hydrological impacts of forestry: A research planning study.* Report KV 37/92 by Ninham Shand Consulting Engineers to the WRC, Pretoria.

Görgens AHM and Tukker J, 1998. *Quantification of streamflow reductions due to afforestation in South Africa.* Report by Ninham Shand to DWAF, Report No. RSA/00/0398

Gush M, Scott D, Jewitt G, Schulze R, Lumsden T, Hallows L, Görgens A, 2002. *Estimation of Streamflow Reductions Resulting from Commercial Afforestation in South Africa.* WRC Report TT 173/02

ICFR, 1997. Personal communication by letter, R Kunz, May 1998.

Larsen EJ, Görgens AHM and Little PR, 1995. Alien vegetation impacts on water resources of the Riviersonderend System. *Proceedings of the Seventh South African National Hydrology Symposium*, Grahamstown.

Le Maitre DC, Scott DF and Fairbanks DHK, 1997. The impacts of timber plantations on runoff in South Africa: A handy reference manual. Report by Environmentek, CSIR to DWAF, Pretoria.

LHA, 1998a. *Comparative differences between streamflow reduction of dry-land agricultural crops and commercial forestry.* Technical Note (1651/98) by LHA Management Consultants, Pretoria.

LHA, 1998b. Presentation to the DWAF *Workshop on Streamflow Reduction Impacts due to Commercial Afforestation*, Pretoria, 3 June 1998.

Midgley DC, Pitman WV and Middleton BJ, 1994. The surface water resources of South Africa 1990. Volumes 1 to 6. Water Research Commission, Pretoria.

Scott DF, Prinsloo FW, Moses G, Mehloakulu M, Simmers ADA, 2000. A re-analysis of the South African catchment afforestation experimental data. WRC Report No. 810/1/00.

Schulze RE, Summerton M, Meier K, Pike A and Lynch S, 1997. The *ACRUforest* decision support system to assess hydrological impacts of afforestation practices in South Africa. *Proceedings of the Eighth South African National Hydrology Symposium*, Pretoria.

Scott DF, le Maitre DC and Fairbanks DHK, 1998. Forestry and streamflow reductions in South Africa: A reference system for assessing extent and distribution. *Water SA*, 24 (3): 187 - 199

Scott DF and Lesch W, 1995. The water yield gains obtained from clearfelling riparian zone vegetation. *Proceedings of the Seventh South African National Hydrology Symposium*, Grahamstown.

Scott DF and Smith RE, 1997. Preliminary empirical models to predict reductions in total and low flows resulting from afforestation. *Water SA*, 23 (2): 135-140.

Van der Zel DW, 1990. The afforestation permit system. Information Leaflet No. 1, department of Environment Affairs

APPENDIX A

EXAMPLE OF ACRU-BASED AFFORESTATION-RELATED SFR TABLES

Quaternary catchment streamflow reduction tables – median values

The following table presents median reductions in streamflow within selected quaternary catchments across South Africa following complete afforestation with one of three primary commercial forestry tree species. For each quaternary catchment (QC) number given at the far left of the table there are columns of general information (area in hectares, Mean Annual Precipitation and *ACRU*-simulated Acocks baseline streamflow), followed by 18 possible streamflow reduction values. These are represented by abbreviations at the top of the table which indicate the following:

Abbreviation	Interpretation
QC	Quaternary Catchment no.
AREA	Quaternary Catchment area (ha)
MAP	Quaternary Catchment Mean Annual Precipitation (mm)
ASTF	Acocks baseline vegetation on shallow soils – Median Annual Total Flow (mm)
AMTF	Acocks baseline vegetation on medium soils – Median Annual Total Flow (mm)
ADTF	Acocks baseline vegetation on deep soils – Median Annual Total Flow (mm)
ASLF	Acocks baseline vegetation on shallow soils – Median Annual Low Flow (driest three months - mm)
AMLF	Acocks baseline vegetation on medium soils – Median Annual Low Flow (driest three months - mm)
ADLF	Acocks baseline vegetation on deep soils – Median Annual Low Flow (driest three months - mm)
ESTFR	Eucalypts on shallow soils – Median Annual Total Flow Reductions (mm)
EMTFR	Eucalypts on medium soils - Median Annual Total Flow Reductions (mm)
EDTFR	Eucalypts on deep soils – Median Annual Total Flow Reductions (mm)
ESLFR	Eucalypts on shallow soils – Median Annual Low Flow Reductions (mm)
EMLFR	Eucalypts on medium soils – Median Annual Low Flow Reductions (mm)
EDLFR	Eucalypts on deep soils – Median Annual Low Flow Reductions (mm)
PSTFR	Pines on shallow soils – Median Annual Total Flow Reductions (mm)
PMTFR	Pines on medium soils - Median Annual Total Flow Reductions (mm)
PDTFR	Pines on deep soils – Median Annual Total Flow Reductions (mm)
PSLFR	Pines on shallow soils – Median Annual Low Flow Reductions (mm)
PMLFR	Pines on medium soils – Median Annual Low Flow Reductions (mm)
PDLFR	Pines on deep soils – Median Annual Low Flow Reductions (mm)
WSTFR	Wattle on shallow soils – Median Annual Total Flow Reductions (mm)
WMTFR	Wattle on medium soils - Median Annual Total Flow Reductions (mm)
WDTFR	Wattle on deep soils – Median Annual Total Flow Reductions (mm)
WSLFR	Wattle on shallow soils – Median Annual Low Flow Reductions (mm)
WMLFR	Wattle on medium soils – Median Annual Low Flow Reductions (mm)
WDLFR	Wattle on deep soils – Median Annual Low Flow Reductions (mm)

QC	AREA	MAP	ASTF	AMTF	ADTF	ASLF	AMLF	ADLF	ESTFR	EMTFR	EDTFR	ESLFR	EMLFR	EDLFR	PSTFR	PMTFR	PDTFR	PSLFR	PMLFR	PDLFR	WSTFR	WMTFR	WDTFR	WSLFR	WMLFR	WDLFR
A21A	48187	683.3	35.7	28.6	28.5	1.5	0.6	0.4	28.0	23.7	25.0	1.3	0.6	0.4	24.4	22.5	23.0	0.8	0.6	0.4	26.7	23.4	23.4	1.2	0.6	0.4
A21B	52652	672.0	54.9	44.7	43.0	1.2	0.3	0.0	45.3	39.2	37.6	0.9	0.3	0.0	38.3	35.3	35.7	0.4	0.3	0.0	38.3	37.1	36.9	0.8	0.3	0.0
A21C	76096	695.1	44.0	39.9	36.0	1.9	0.6	0.3	34.4	32.0	28.3	1.6	0.6	0.3	32.9	30.1	27.8	1.1	0.5	0.3	34.1	30.0	27.9	1.4	0.6	0.3
A21D	37155	712.6	46.3	38.9	36.5	1.7	0.6	0.0	38.1	33.7	31.5	1.6	0.6	0.0	32.4	31.2	30.3	0.7	0.6	0.0	35.0	32.3	30.7	1.2	0.6	0.0
A21E	28982	710.0	45.4	36.8	30.9	2.7	0.9	0.2	38.2	32.8	27.0	2.4	0.9	0.2	32.0	30.8	26.5	1.1	0.9	0.2	32.9	32.1	26.3	1.6	0.9	0.2
A21F	100020	676.7	44.8	36.8	36.8	1.4	0.3	0.0	34.7	30.1	30.1	1.1	0.3	0.0	28.2	28.3	28.4	0.1	0.3	0.0	29.7	29.0	29.0	0.7	0.3	0.0
A21G	16052	695.7	63.7	52.5	44.8	1.5	0.8	0.2	42.8	39.6	33.6	0.9	0.8	0.2	38.7	40.4	32.7	-0.3	0.6	0.2	36.6	39.5	31.9	0.4	0.8	0.2
A21H	51372	668.1	33.7	29.1	29.1	1.4	0.3	0.0	25.6	24.7	25.3	1.2	0.3	0.0	21.5	21.7	24.2	0.8	0.3	0.0	22.7	22.6	24.1	1.1	0.3	0.0
A21K	86415	652.4	41.8	32.3	30.4	0.8	0.2	0.0	31.5	27.9	26.1	0.7	0.2	0.0	25.4	24.8	23.9	0.1	0.2	0.0	23.7	25.0	24.6	0.3	0.2	0.0
A22G	49859	655.2	50.0	42.1	42.0	1.8	0.5	0.1	32.5	33.0	32.9	1.2	0.5	0.1	26.2	29.1	31.9	0.3	0.5	0.1	25.8	29.6	32.2	0.7	0.5	0.1
A22H	57866	660.6	50.6	41.1	34.8	2.1	0.4	0.0	34.0	32.3	26.1	1.5	0.4	0.0	30.8	30.7	26.7	0.3	0.4	0.0	26.6	31.3	25.7	0.5	0.4	0.0
A23A	68239	698.3	85.0	74.7	68.6	3.1	1.3	0.3	58.0	53.8	47.9	2.4	1.3	0.3	48.2	47.1	44.5	0.8	1.0	0.3	49.9	47.8	45.4	1.4	1.3	0.3
A23D	14482	647.0	58.2	52.5	50.5	2.3	0.6	0.1	37.2	40.6	38.6	1.7	0.6	0.1	31.6	37.7	39.0	0.2	0.6	0.1	32.6	37.9	38.2	0.8	0.6	0.1
A23E	49044	703.0	67.3	64.2	59.3	1.7	0.2	0.0	47.5	48.1	44.4	1.2	0.2	0.0	29.9	44.6	44.3	-0.1	0.2	0.0	35.5	44.8	44.1	0.3	0.2	0.0
A42B	52160	675.1	69.4	65.2	60.9	1.9	0.6	0.2	43.3	47.4	43.1	1.1	0.6	0.2	33.0	42.7	43.1	-0.6	0.1	0.2	32.6	43.1	42.5	0.1	0.5	0.2
A42C	69834	660.3	59.4	53.1	52.1	1.2	0.3	0.0	40.2	38.6	37.7	0.7	0.3	0.0	31.9	33.3	36.0	-0.5	0.3	0.0	32.0	33.4	36.2	0.0	0.3	0.0
A42D	49660	669.4	67.0	59.0	53.6	2.2	0.7	0.3	42.1	44.1	39.5	1.5	0.7	0.3	32.6	39.4	37.3	0.0	0.7	0.3	29.7	40.2	37.1	0.5	0.7	0.3
A50A	29777	655.7	45.8	33.5	31.9	1.8	0.7	0.3	36.9	28.7	28.0	1.5	0.7	0.3	26.1	23.9	27.0	0.2	0.4	0.3	26.2	24.5	26.5	0.6	0.7	0.3
A80A	28737	939.9	161.1	143.3	126.1	9.0	7.1	5.8	74.8	85.5	70.9	5.0	6.1	5.5	53.3	66.9	57.5	2.3	2.5	3.6	53.4	70.2	62.3	4.2	3.7	4.7
A80B	25132	663.6	116.8	103.5	90.0	4.3	2.2	1.0	47.7	62.9	54.9	1.2	1.9	1.0	46.8	58.1	48.3	-0.5	0.8	0.4	44.7	54.9	45.4	0.5	1.6	0.7
A91A	23230	711.5	108.8	93.3	83.3	4.6	2.6	1.5	46.4	56.6	52.4	2.6	2.3	1.5	30.1	43.1	42.8	0.9	1.3	0.9	29.3	40.0	46.2	1.8	1.8	1.2
A91C	24966	862.9	198.8	179.1	161.9	8.8	7.9	6.9	60.2	98.3	87.4	3.1	4.2	5.9	49.8	71.7	79.7	-0.3	0.9	1.3	43.3	67.0	82.1	2.1	2.7	2.6
A91D	13238	1241.0	460.5	435.3	410.2	23.2	21.8	20.6	98.5	144.9	162.5	9.5	12.3	12.9	47.7	80.5	98.6	-0.6	1.3	3.5	39.2	75.0	101.2	7.2	8.4	10.5
A91E	22309	949.8	289.0	260.7	244.5	11.8	8.4	6.7	71.4	106.0	116.2	4.2	4.1	5.4	54.5	78.2	98.4	-1.1	0.0	1.2	40.8	73.4	100.3	3.2	1.6	1.9