THE APPLICATION OF THE ACRU MODEL TO DETERMINE THE IMPACT OF ALIEN VEGETATION ON STREAMFLOW, AND THE CONSEQUENCES OF THESE INFESTATIONS FOR CONSERVATION AND MANAGEMENT.

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March 1995
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ABSTRACT

About 92% of the Baviaans River catchment is infested with Pinus pinaster and Hakea sericea. Alien invasions lead to several negative ecological effects that affects the natural functioning of the aquatic ecosystem and its ability to deliver a sustainable yield of high quality water. Water is a scarce multi-purpose natural resource and has an important economical value. A hydrological modelling system (ACRU) was used in an attempt to simulate the impact of alien vegetation on streamflow. Vegetation parameters were adapted to represent changes in vegetation characteristics following alien invasion. The model proved to be effective in simulating the effect of alien invasion over a period of 16 years. Invasions resulted in a mean annual streamflow reduction of 19.5% and 24.2% in dry years. Observed flow (actual flow measured at a weir) reflected a reduction in streamflow when it was compared with simulated natural flow. The study showed that the ACRU model can be used by conservation agencies to determine priorities of individual catchments within mountain catchment management.

INTRODUCTION

Fynbos is the most prominent vegetation type in the Cape Floristic Region, one of the six floral kingdoms of the world. The high level of diversity of fynbos in terms of species richness, species density and high degree of endemism, emphasises its high conservation significance. Mountainous areas in particular, with their variation in lithology, relief, soils and climate, form the unique environmental setting for fynbos (Cowling et al., 1992). The conservation and management aims for fynbos in mountains are multi-objective (Wilson, 1995):

To maintain the optimal sustainable yield of water of the highest quality possible.
To maintain habitat and species diversity of the mountain ecosystems of each catchment as a whole.

To maintain an adequate natural plant cover to prevent accelerated erosion of the soil mantle.

A recent feature of fynbos landscape is the widespread occurrence of dense stands of alien trees and shrubs. Although relatively few species have invaded the fynbos biome, they cover extensive areas and are increasing in density and distribution. In mountain catchment areas, *Pinus pinaster* and *Hakea sericea* are two of the most important aliens. Both these species have a high resilience against the natural fire regime and are aggressive invaders of mountainous areas (Richardson 1989). Compared to fynbos species, these invaders have a fast growth rate, a short youth phase and have the ability to accumulate large stores of highly mobile seeds. These attributes, combined with the absence of natural enemies, enables these species to dominate the landscape by outcompeting the natural vegetation and then to increase their distribution at a phenomenal rate (Richardson *et al.*, 1992). Alien invasions lead to a decrease of diversity, they change species composition, and disturb the natural fire regime (Richardson *et al.*, 1992; Richardson & Cowling, 1992). Clearing alien invasions increases chances of soil erosion and nutrient losses from catchments due to hot fires which reduces seed stores and natural plant cover (Breytenbach, 1989). The increased water consumption by alien vegetation is related to their higher biomass, and changes the natural hydrology of the ecosystem by reducing streamflow (Versveld *et al.*, 1994). Changes in the quantity and quality of water can have a significant effect on the functioning of aquatic ecosystems. It leads to the alteration and loss of natural habitat for aquatic organisms and can eventually result in a decrease in species diversity and changes in community compositions within different river zones (Day *et al.*, 1986; Dallas & Day, 1993).
In the field of mountain catchment management, the need exists for an effective hydrological model for planning purposes. Managers and planners must be able to evaluate and prioritize single catchments of any size in terms of runoff and the potential effect of alien infestations on streamflow. For this reason a modelling system called ACRU (Agricultural Catchment Research Unit) was used to simulate streamflow and the influence of alien infestation on streamflow, from the Baviaans River catchment. In essence ACRU can be described as a hydrological modelling system which attempts to combine and integrate hydrology with agrohydrology in terms of the functions and responses of the various components that form a terrestrial hydrological system. In the more conventional aspects of hydrology the emphasis for planning purposes and effective resource management, falls on understanding the various components that drive terrestrial hydrological systems. In contrast, agrohydrology is more aimed at evaluating the influence of available water on agricultural potential and to promote the most efficient use of water resources (Schulze, 1989).

In the context of this study, the modelling capabilities of ACRU are tested for its ability to simulate streamflow from a single catchment, using rainfall data, vegetation, soil and other parameters to determine streamflow. Previously, several studies have been done to determine the impact of commercial afforestation on streamflow (Van Wyk 1987; Scott and Le Maitre, 1993; Smith & Scott 1992). A few studies attempted to simulate the effect of natural alien infestation (Versveld et al., 1994; Marais et al., 1994 and Gorgens et al., 1993), but were also based on the results from planted commercial plantations. The underlying assumption of all these studies is that the impact of alien infestation is comparable to that of commercial plantations. Furthermore, all the above-mentioned studies depended on the existence of observed streamflow data from gauged catchments. Where attempts were made to determine the impact of infestations on catchments without knowledge about streamflow
volumes, only estimates were made, based on the ratio between runoff and rainfall, or the paired catchment method (Smith & Scott, 1992). The general application of these results are also limited, as they can only be applied on catchments with similar physiographical and climatic attributes.

Apart from simulating streamflow, the model was used to determine the effect of alien vegetation on streamflow elements by simulating the changes in vegetation characteristics following alien invasion. Aliens reduces streamflow as a result of an increase in the above-ground biomass, which increases evaporation rates (Van Wilgen & Van Hensbergen, 1992; Versveld et al., 1994). Finally, the financial costs of alien eradication and the potential loss of revenue are discussed.

STUDY AREA

The Baviaans River catchment and its associated weir are situated on the southern side of the Riviersonderend mountain range near the village of Genadendal and extends over an area of 2,240 ha (Figure 1). A water weir (H6H005), from the Department of Forestry and Water Affairs (DWAF), is located above the village (33°01'44" S, 19°33'27" E). Jonaskop peak (1,646 m), the second highest peak in the Riviersonderend mountains, forms the North-west boundary of the Baviaans River catchment and the town of Genadendal the south-east boundary.

The Riviersonderend mountain range falls within the winter rainfall region. It receives an average annual rainfall of 550.6 mm (measured at Greyton), mainly between May and August. The high mountain peaks intercepts the moist air from the coast, resulting in a rainfall on the southern side of the mountain double that of the interior. The Baviaans River flows throughout the year and water is utilized for human consumption and agricultural use by the Genadendal community and surrounding areas.
The soils in the catchment are derived from the Table Mountain Series, and are characterised by their sandy texture, acidity, and high degree of leaching (Le Roux & Erasmus, 1982). The whole of the Baviaans River catchment is covered by Mountain Fynbos (Acocks, 1953), which ranges from tall shrubveld dominated by Protea and Leucadendron spp, to short veld dominated by Restionaceae, Erica spp and several other smaller species. Pineus pinaster plantations were established in the lower part of the catchment early in the last century (Le Roux & Erasmus, 1982). Although the plantation was felled long ago (date unknown), P. pinaster has invaded most of the catchment and currently dense infestations cover most of the slopes. Hakea sericea has also established itself throughout the catchment, but although widespread, it does not occur at the same density as the pines.

Land uses include the Genadendal hiking trail which runs through a part of the catchment, but with no apparent detrimental effect as it is a well-maintained footpath. Water is extracted from the Baviaans River at a rate of 37 l/sec. (97 500 m³/month) for human and agricultural use (De Wet pers. comm.), at a point above the weir and within the study area.

**METHOD**

**Determining the effect of aliens on streamflow**

Initially, runoff from the catchment (a static mature fynbos state) was modelled with ACRU to represent a natural functioning mountain catchment. Thereafter, vegetation parameters were changed to model a static fully invaded catchment, simulating the effects of alien infestation. The mean annual runoff regime from the catchment (taken for the period 1976-1992) was then depicted as frequency distribution tables for different non-exceedence levels, for simulated natural fynbos vegetation and invaded fynbos. Non-exceedence levels are the probability that monthly streamflow values will not exceed a specific value (Schulze, 1989; Dunne & Leopold, 1987). In other words, the mean monthly runoff volumes were subjected
to a probability analysis by the ACRU model, and runoff values not exceeded in 10%, 33%, etc. of the years, were determined. The effect of alien vegetation on the streamflow was determined by analysing the frequency distributions of non-exceedence levels or percentiles for monthly streamflow. Non-exceedence levels of streamflow volumes from a natural fynbos catchment were compared with that from a catchment infested with alien vegetation.

After the streamflow from an unininvaded catchment had been simulated, it was correlated with the actual flow data (observed flow as measured at the weir by DWAF). The comparison and the calculations of statistics from these comparisons were done by ACRU. The observed flow was obtained from the Computing Centre for Water Research (CCWR). This was done in an attempt to explain the impact of alien vegetation on runoff (decreasing streamflow) and to determine the confidence with which the ACRU model can be used to predict runoff and the influence alien vegetation for fynbos catchments in general.

A sensitivity analysis was also performed to determine the effect of changing crop coefficient values on the output (streamflow) of the model. The crop coefficient ($K_{cm}$) is a dimensionless value that reflects the dependent relationship of maximum evaporation for a given stage of plant growth and phenology under conditions when soil water can meet atmospheric demands and with soil surface conditions at an average wetness. It is assumed that alien vegetation will increase the biomass and that the higher transpiration rate will result in a reduction in streamflow. As changes in transpiration rates are related to different $K_{cm}$ values, the accuracy of this parameter is important.

**Alien Vegetation Classification**

About 92% (field observations and measurements from photographs) of the Baviaans River catchment is infested with alien vegetation, primarily *Pinus pinaster* and to a lesser extent *Hakea sericea*. For modelling purposes, no distinction was made between *H. sericea* and *P.*
The whole catchment burnt down in 1988/89 and the vegetation is now between 5-6 years old, interdispersed with adult pine trees (15+ years) which survived the last wildfire. The young trees form dense thickets, reaching densities of up to 15 stems m\(^{-2}\) (150 000 stems ha\(^{-1}\)). All other alien species was ignored as it only occurred at single localities and in low numbers. The natural occurrence of fires in fynbos results in a continual change in vegetation structure, distribution and densities of alien vegetation (Richardson & van Wilgen, 1992). To keep the modelling exercise simple, a static or single state growth phase was considered. All vegetation was viewed as mature veld (15 years), fixed at their present spatial distribution. It was assumed that areas presently covered by pines, would have reached a closed canopy density at age 15 years as canopy size increased with age.

The \(K_{cm}\) for fynbos was assumed to be similar to that of Macchia, and set at a value between 0.4 and 0.5, depending on the phenology during different months (Table 1). \(K_{cm}\) for a fully invaded catchment was set at 0.8 for all months, a value closely correlated to that of commercial plantations (Schulze et al., 1989).

Rooting depth and the distribution of root mass within the different soil levels influences the soil water budget. As little information is available on the soils of the catchments, it was taken as moderately shallow (Le Roux & Erasmus, 1982), and for modelling purposes, it was assumed that 60% of the vegetation root mass is distributed within the topsoil (A- and B-horizons) and 40% within the subsoil (Schulze et al., 1989).

Climatic Data

Rainfall data is measured at Greyton, a town approximately 7 km east of the catchment. The station was selected because the collection of rainfall data at the Genadendal station was terminated in 1985. Greyton was considered as an acceptable alternative as it is exposed to the same local frontal weather systems as Genadendal, and is also situated at the foothills of
the mountain close to Genadendal. The data was obtained from CCWR for the period 1968 to 1992. This is within acceptable limits of a required record length that will ensure the scientific integrity of the data when taking into account rainfall persistence (Dent et al., 1988; Dunne & Leopold, 1987). Although unbroken daily rainfall data is desirable for continuous daily water budgeting, gaps existed within the data set. Missing data was "patched" through the use of a synthetic random rainfall generator developed by Zuchinni and Adamson (1983), which was selected for its ease of use in the suite of programs used to prepare data for the ACRU model. Mountains also acts as physical barriers that intercept rain clouds, resulting in an increase in rainfall with a rise in altitude. As the rain-gauge at Greyton is situated at an altitude of 200 m, a correction factor of 1.3 (Table 1) was applied to predict rainfall values for the catchment, based on the different isohyet values (from the CCWR database) for the Riviersonderend mountains (Dent et al, 1988).

Temperature and A-pan (American Class A evaporation pan) estimates for Genadendal were obtained from the CCWR database. Temperature lapse rates were used to adapt the point source data for the increase in altitude in the catchment. Evaporation was then determined by deriving A-pan equivalent values from temperature data and applying a wind factor according to Schulze (1989). This is automatically done in ACRU.

Soils

Very little information is available on soil types within Mountain catchments in the fynbos biome. The Riviersonderend mountains are no exception and there are no soil maps available. Based on observations during a field visit and general information available on the nature of fynbos soils (Le Roux & Erasmus, 1982; Deacon et al., 1992), a sandy soil texture class was selected, and soil depth moderately shallow to shallow (0.2 - 0.4 m). Values for wilting point, field capacity, soil porosity and soil depth was based on data from
documentation (Schulze et al., 1989). All daily soil water redistribution is internally derived by the model, based on these values (Schulze, 1989).

**Soil water and runoff response budgeting in ACRU.**

Soil water budgeting and runoff responses are the basis of the ACRU modelling system, and are calculated for daily time steps.

\( K_{cm} \) is the main criteria by which hydrological responses of fynbos and alien vegetation are differentiated. Interception loss of rainfall by vegetation is calculated by the model, based on \( K_{cm} \) and gross precipitation. Maximum evaporation, i.e. the product of referenced daily A-pan equivalent evaporation and the \( K_{cm} \) for that day, are then separated into maximum soil evaporation and maximum plant transpiration. That part of maximum evaporation available for plant transpiration, is allocated to the different soil layers in proportion to the different root mass distributions within these layers. Soil evaporation from the topsoil is computed by the model, based on A-pan values. Plant transpiration for both top- and subsoil are calculated as a fraction of maximum plant transpiration, taking into account differences in the soil water contents between layers. Stormflow is calculated based on soil depth, initial abstractions and the stormflow response. After stormflow is calculated, the soilwater content is reset, and the redistribution of soilwater within the different soil layers recalculated. Baseflow is then calculated based on drainage into the baseflow store and baseflow response. Contributions to the baseflow store depend on the water available from the subsoil and the drainage through soil levels. Finally, these values for soil water storage, evaporation, transpiration, stormflow, baseflow and baseflow store are stored, and used as initial values for the following day (Schulze, 1989; Schulze et al., 1989).

A list of the parameters used in ACRU during this study, is showed in Table 1.
RESULTS

The mean annual runoff regime from the catchment (taken for the period 1976 - 1992) is depicted as different frequency distribution tables for simulated uninvaded and invaded catchments (Table 2). The frequency values for the 10%, 50% and 90% percentiles or non-exceedence levels are presented as a probability hydrographs in Figure 2. Based on the monthly runoff for the 50% non-exceedence level, alien infestation in the Baviaans River catchment causes a reduction in streamflow ranging between 14.1% and 27.1%, with an average of 19.5% (difference in streamflow between an invaded and uninvaded catchment, as a percentage of natural streamflow). However, during the low flow periods (i.e. the 10% non-exceedence level), the average reduction in streamflow rises to 24.2% (ranging between 7.2% and 43.6%). The effect of alien vegetation can also be expressed in the following way: invasion causes runoff to drop below the level of 9 mm per month, for 6 months of the year during low flow periods. This phenomena occurs mainly during the dry summer months. In the case of uninvaded catchments, runoff only drops below this level for 2 months of the year (Figure 2).

The model performance was analysed by comparing the cumulative values of total annual observed streamflow volumes from the catchment (measured at weir H6H005) with the simulated flow from an uninvaded catchment. Only the daily means and variances (i.e. deviations) around the mean were considered for the statistical analysis of the goodness of fit between the observed and simulated flows. The mean of the observed flow was 1.53 mm, with a variance of 5.79 mm. The simulated flow had a mean of 1.84 mm and a variance of 9.71 mm. A hydrograph reflecting the total annual streamflow volumes are presented in Figure 3, and that of the cumulative volumes in Figure 4.

Results from the sensitivity analysis on crop coefficients for every second month are reflected in Figure 6. The percentage change in streamflow (mean monthly flow) were determined for
crop coefficient values ranging from 0.45 to 0.80, with increments of 0.05. The percentage change was measured relative to streamflow for a crop coefficient set at 0.45 (the minimum value for fynbos). A 77% increase in the latter resulted in a 8% to 15% increase in streamflow, depending on the rainfall during the month (Figure 6).

DISCUSSIONS

Determining the effect of alien invasions on streamflow.

Risk assessment by frequency analysis

The results from the study indicate that the effect of aliens on streamflow are more severe during low flow periods (dry years). This is confirmed in studies by Smith and Scott, (1992) and Van Wyk, (1987), who found that the highest reduction in streamflow in afforested areas, occurs during low flow periods. Smith and Scott (1992) also found that some of the smaller perennial streams dried up due to afforestation. During a field visit to the Baviaans Rivet, dry stream beds were found, indicating that alien invasions have a similar effect on smaller streams within the catchment.

Ecological instream requirements of different rivers varies, depending on the ecological status and temporal rainfall distribution. An assumed minimum instream requirement of 20% (of the mean monthly simulated streamflow for an uninvaded catchment), for the Baviaans River catchment can be considered a conservative estimate (King pers. comm.). With a 20% instream requirement, a reduction of streamflow due to alien invasion and extraction of water by the Genadendal community, may have a significant ecological effect. If water extraction is set at a constant rate of 96 500 m$^3$/month, streamflow in an invaded catchment will drop below the required runoff for nine months during dry years (low flow periods), down stream of the point of extraction. In a fynbos catchment streamflow will be insufficient for three
months (Figure 5). During "normal" years (median or 50th percentile), streamflow will always be sufficient.

Analysis of model performance

In the model it is assumed that no disturbances (i.e. fire) occurs in the natural fynbos (static vegetation phase). In reality (observed results from the weir), the vegetation is disturbed by both fire and alien vegetation. The whole catchment burnt during fires in 1988 and 1989. Mean runoff can be expected to increase after fires (Bosch et al., 1986), whereas alien invasions will reduce runoff (Scott & Van Wyk, 1992). In this study, the lower mean value of the observed flow reflects the effect of the invasions of *P. pinaster* and *H. sericea* of the Baviaans River.

As a result of the disturbances, it is expected that the variance around the mean of the observed flow will be higher than that of the simulated natural vegetation. However, the results showed that the variance of the observed flow was lower than that of the simulated flow. This can be due to the inaccurate representation of rainfall values and its distribution in the catchment. Schulze (1989) also states that the accuracy of rainfall data is the most important parameter driving the ACRU model and influencing its performance. The comparison of monthly observed runoff values with the corresponding rainfall values, showed that rainfall values were under-estimated in 12.5% of the months. This is also illustrated in annual values (Figure 3), where the rainfall value for 1981 was less than the observed runoff for the same year. The under-estimation of rainfall in this study emphasises the problems associated with simulating spatial distribution of rainfall from a point source, across a mountain catchment. Variation of rainfall within a catchment, is a product of altitude, slope, aspect, exposure, steepness etc., and cannot be simulated accurately by applying a correction factor. The error associated with inaccurate representation of rainfall
values and their spatial distribution, can only be solved by accurate measurements within the catchment.

The cumulative annual values (Figure 4) for rainfall and simulated streamflow, show clear linear rates of increase. However, the observed streamflow values deviate from a linear slope, decreasing notably after 1985. This clearly demonstrates the effect of alien invasion on streamflow. Inadequate information on the distribution and density of aliens before 1988, or the fire history before 1980, prevents relating alien invasions to deviation of the cumulative observed flow.

**Sensitivity analysis of vegetation parameters on baseflow**

The results show that mean monthly streamflow is not very sensitive to changes in crop coefficient values for the Baviaans River catchment. However, this can be expected from shallow fynbos soils as their soilwater content decreases fast after rainfall occurred. Soil depth is an important parameter that influences maximum potential evaporation. Compared to shallow soils, deeper soils have a higher water holding capacity and actual evaporation can remain closer to potential evaporation for longer periods. Similarly the amount of rainfall determines the amount of moisture available for evaporation. The temporal distribution of rainfall within the catchment will also influence evaporation rates as potential evaporation changes with temperature shifts between seasons. Therefore, streamflow from different catchments will be influenced differently, depending on its unique set of conditions which influences evaporation. This variability in the potential evaporation will also be reflected in the crop coefficient values as evaporation are an integrated part of crop coefficient. Therefore, the shallow soils of the Baviaans River catchment explain the lack of sensitivity of streamflow for changes in crop coefficient.
The differences between crop coefficients for fynbos (0.45 to 0.5) and alien invasions (0.8) explains most of the impact of alien vegetation on streamflow (Figure 2).

Implications of invasion for conservation and management of mountain catchments.

According to Le Roux and Erasmus (1982) less than 40% of the Baviaans River catchment was infested in 1982, whereas 92% of the catchment currently is invaded. The density of invader plants has now increased up to 15 stems/m², with less than 50% (a conservative estimate) of the natural vegetation remaining in the dense alien thickets. This percentage will decrease further as the veld age and alien canopy cover increase (Richardson et al., 1989).

It is estimated that *H. sericea* and *P. pinaster* can increase the vegetation fuel load by up to 300% (Versveld & Van Wilgen, 1986; Van Wilgen & Richardson, 1985). This alters the natural fire regime. Fires become more intense under extreme weather conditions, due to the higher fuel loads (Van Wilgen & Van Hensbergen, 1992), and will lead to a loss of diversity and indigenous vegetation cover (Van Wilgen et al., 1992; Breytenbach 1989). Richardson and Van Wilgen (1986) found that the recovery of natural vegetation after an intense fire (the invaders were slashed a few months prior to the event), was much slower than that of uninvaded areas. The lack of sufficient plant cover then leads to increased erosion and loss of soil nutrients during the rainfall season (Breytenbach, 1989). Therefore, clearing alien invasions results in a reduction of water quality. The change in water turbidity due to accelerated erosion, leads to changes in light penetration. A reduction in light penetration decreases primary production, and reduces food availability to organisms higher in the aquatic food chain. Changes in aquatic community may occur when suspenoids smother and abrade riverine organisms, or predator-prey relationships are affected due to a reduction in visibility (Dallas & Day, 1993).
Most of the riparian vegetation along the Baviaans River has been destroyed or disturbed, following invasions. This enhances the loss of sediments and nutrients from the catchment. Riparian vegetation is essential for the natural functioning of an ecosystem, as it acts as a filter to prevent sediment and nutrient loss from catchments after fires (DeBano & Schmidt, 1990). The loss of riverine vegetation also destabilizes the banks and causes more erosion. The removal of riparian plants as a major food source, affects the energy supply to aquatic organisms in the immediate vicinity as well as further downstream (Bosch et al., 1986). A reduction in riverine vegetation also leads to changes in water temperatures. This affects metabolic processes and life cycles by altering reproductive periods, development rates and emergence of aquatic organisms (Dallas & Day, 1993).

As *P. pinaster* is an important commercial tree species in South Africa, no biological control agents are presently being used to control its spread. Slashing and burning are currently the only effective management tool available, but has important implications for management policies and practices concerned with the maintenance of species diversity. This control measure typically results in extremely hot, intense fires that adversely affect the recovery of natural vegetation (Breytenbach 1989), influence the species composition of communities, and reduce the seed store of natural species (Richardson, 1989; Le Maitre, 1992). To restore the vegetation in these ecosystems to their pre-invaded status could require expensive active management such as sowing of seed, erosion control and other rehabilitation measures.

Richardson and van Wilgen (1986) and Breytenbach (1989) have suggested the burning of standing aliens invasions as a possible solution. From a management point of view this should be done either before the alien vegetation matures (sets seed), or after the maturation of natural vegetation. The rationale behind the first option is to destroy the young aliens before they set seed, in order to reduce the seed bank and the follow up operations after the fire. However, this will have negative ecological consequences, as the natural vegetation takes longer to mature, leading to the reduction of the seed bank and the slow demise of
natural populations. If the veld is burned after the natural vegetation has matured (i.e. after 50% of the slowest maturing species have flowered), adverse ecological impacts will be minimized. However, the invader plants would have built up a considerable seed reserve, which will lead to dense populations of seedlings after the fire. Although burning alien standing will reduce the intensity of fires under extreme conditions with obvious ecological benefits, it will enhance the survival of more seed from serotinous species such as *P. pinaster* and *H. sericea*. The density of dead tree stems within medium and dense stands after fires will also make the movement of labourers very difficult during follow-up operations and lead to higher financial costs.

**Economical implications of alien invasions.**

Water is a scarce multi-purpose natural resource used in agriculture, industry, for human consumption and recreational use (Costanza *et al.*, 1991), and has an important economical value. The following estimates were made of gross income for some agricultural crops for 1993/94 (Burgers *et al.*, 1994):

- **Wine grapes:** ca. R1,15 per m³ irrigation water used.
- **Deciduous fruit** (excluding apples and pears): ranges between R4,00 and R8,00 per m³.
- **Table grapes:** ca. R4,77 per m³ irrigation water used (Hex river valley).
- **Pears and apples:** R6,00 to R7,00 per m³ (Grabouw area).

Burgers *et al.* (1994) estimated the Gross Domestic Product (GDP) for the Western Cape economy as a whole (industrial, agricultural and domestic consumption), to be R20 per m³ of abstracted water in 1993. It was also determined that if the invasion of catchment areas by aliens is not prevented over the next 100 years, it could result in a loss of more than 30% of the water supply to the city of Cape Town (Chapman *et al.*, 1994). During individual years
of low rainfall, losses will be much more severe (Versveld et al., 1994). If the value of water from the Baviaans River catchment is estimated at R1 per m³, a 19.5% reduction of streamflow due to alien invasion will result in an annual loss of R2.15 million. Therefore, reduction in streamflow from infested catchments must be seen in the light of its economical impact. Similarly, the urgency to supply sufficient funds for the eradication of alien invasions and the management of mountain catchment areas, must be compared to the economic benefits it provides.

Presently the Baviaans River catchment is managed by Cape Nature Conservation (CNC). The specific division within which the catchment falls is responsible for the management of mountain catchments spanning an area of 136 000 ha with a labour force of 30 and an annual budget of R1.4 million. To implement the slash-and-burn strategy in an effort to eradicate alien vegetation from the catchment, will take a team of 30 labourers approximately 900 working days (3-4 years) at a total cost of R2.8 million. This estimate is made using conservative figures of 17.5 l.u./ha (labour units per hectare) necessary to eradicate dense to closed canopy invasions, 10.25 l.u./ha for medium invasions, and 4.5 l.u./ha for scattered invasions, at an average cost of R104/l.u. (Marais pers. comm). Cape Nature Conservation will not be able to eradicate all alien vegetation from the Baviaans River catchment within the next 6-8 years, while still resuming all its other responsibilities which includes law enforcement, fire control, maintenance of hiking trails, roads and other infrastructure, as well as alien control in other catchments. The implications are that the Baviaans River catchment and other similar catchments will not be cleared of aliens with the existing funds available.

CONCLUSION

The present alien infestation in the Baviaans River catchment will reach a closed-canopy stage within a few years. This could lead to irreversible changes at community and ecosystem levels when vegetation becomes stressed to a point where it loses its resilience.
and will not recover after natural disturbances, even after the eradication of alien vegetation. The result will be:

- A change in terrestrial and aquatic population and community composition, and a reduction in local species diversity.

- Slash and burn of aliens will reduce diversity further and result in a loss of vegetation cover, which will lead to accelerated erosion and a reduction of water quality.

- The quantity and sustainability of streamflow will be severely affected. The combined effect of aliens and water extraction for human and agricultural use, will lead to sub-optimal functioning of the aquatic ecosystem. This effect will be especially severe during low flow periods.

- The management costs of eradication projects will escalate with an increase in alien densities and vegetation age. The possibility that restoration actions will have to be implemented, also increases with time.

The reduction in streamflow by alien vegetation also has economical implications in terms of rising management costs and loss of potential revenue. The socio-economical value of water in South Africa should provide sufficient evidence and motivation that adequate funding must be provided to implement effective mountain catchment management for the eradication of alien vegetation and maintaining the only source of sustainable water.

Finally, the study showed that the ACRU model can be used by conservation agencies to determine priorities of individual catchments within mountain catchment management. These priorities can be based on the simulated effects of alien invasion on streamflow and the ecological and economical implications associated with these reductions in streamflow. The
inability to simulate rainfall accurately in mountains, restrains the use of ACRU in determining streamflow volumes accurately. However, this is a general modelling problem which is not restricted to ACRU only. The accuracy of the model can be greatly improved by monitoring rainfall gradients in mountain catchments.

ACKNOWLEDGEMENTS

I would like to pay tribute to Arthur Chapman from the CSIR (Forestek). Without his knowledge of ACRU, this study would not have been possible. Other persons to be thanked for assistance with editing earlier drafts of this paper include Dr P. Ryan and Dr J.J. Midgley.

REFERENCES


Table 1: A list of the parameters used by ACRU during this study.

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<td>Area of the catchment</td>
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<td>Latitude</td>
<td>34.03 South</td>
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<tr>
<td>Longitude</td>
<td>19.55 East</td>
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<td>Altitude (m)</td>
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<td>Pot. evaporation according to the Linacre equation</td>
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<td>Coefficient of baseflow response</td>
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<td>Coefficient of &quot;A-horizon to B-horizon&quot; response</td>
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<td>Coefficient of &quot;B-horizon to ground water&quot; response</td>
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Table 2: Cumulative frequency distribution table of non-exceedence levels for simulated runoff from the Baviaans Catchment (mm) for natural and infested vegetation

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<th>Jun</th>
<th>Jul</th>
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Figure 1. Locality map indicating the location of the Baviaans River catchment in the Rivieronderend mountains, South-western Cape.
Figure 2. Probability hydrograph reflecting the 10%, 50% and the 90% non-exceedence streamflow levels for an invaded and uninvaded state of the Baviasn River catchment.
Figure 3. Hydrograph reflecting annual rainfall within the Baviaans River catchment, the total annual runoff from a simulated uninvaded catchment and the observed runoff as measured at the water weir.
Figure 4. Hydrograph reflecting cumulative annual rainfall within the Baviaans River catchment, the cumulative annual runoff from a simulated uninvaded catchment and the observed runoff as measured at the water weir.
Figure 5. Hydrograph reflecting the monthly streamflow deficits or surpluses (bottom) for an uninvaded and invaded catchment, in relation to ecological instream requirements and water extractions for human and agricultural use.
Figure 6. The effect of changes in crop coefficients ($K_{cm}$) on the mean monthly runoff.