AN EXPERIMENTAL STUDY OF THE EFFECT OF *ACACIA MEARNSII* (BLACK WATTLE TREES) ON STREAMFLOW IN THE SAND RIVER, ZWARTKOPS RIVER CATCHMENT, EASTERN CAPE.

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EXECUTIVE SUMMARY

The quality and availability of water have become major issues of concern both in the industrialised and developing world. Water managers have realised that the effective management of catchment vegetation can improve both the quality and quantity of water a catchment delivers. Integrated catchment management will have to become an integral part of planning to solve the water shortage problem in South Africa.

In South Africa water shortages are a daily problem for millions of people. Although such shortages are often attributed solely to droughts, the problem of water scarcity cannot be blamed on climatic factors alone. Alien plant invasions reduce the flow of water to streams and rivers during the dry season. *Acacia mearnsii*, an Australian exotic and the focus of this report, is regarded as one of the greatest invaders of riparian zones in South Africa. Trees growing in the riparian zone are believed to use proportionately more water than those further away from rivers, and therefore pose a threat to a valuable source of water in a country already facing water shortages.

In September 1995 Professor Kader Asmal, the Minister of Water Affairs and Forestry, launched the Fynbos Water Conservation Project to create jobs, win the war against alien plants and, above all, deliver water to the people. The RDP (Reconstruction and Development Plan)Water Conservation Programme, commonly known as the Working for Water programme, has a mission to enhance water supplies by training local communities for catchment management projects that focus on the eradication of invasive alien plants.

Alien vegetation is recognised as having significant, but mostly unquantified effects on water consumption. On a catchment scale the effect of alien species on streamflow has been investigated in various parts of the country, but *A. mearnsii*, which accounts for a large proportion of alien invasions in the riparian zones of Eastern Cape rivers, has not been studied specifically. A review of published research on the effect of alien trees on streamflow confirmed that there is a need for a broader body of information to assess the effects of individual species, density and age distribution, and different catchment and climatic conditions on streamflow responses to clearing invasive trees. There is a specific need for research on the effects of clearing *A. mearnsii* from riparian zones.

The Zwartkops River Water Resources Management Plan (ZRWRMP) was formed to coordinate the management of land and water within the Zwartkops River catchment, situated to the north of Port Elizabeth in the Eastern Cape Province, South Africa. In 1995 the ZRWRMP formed a

Task Group to control and research the extent of invader plant species. They identified the Elands River sub-catchment, which was heavily infested by invader tree species, especially *A. mearnsii*, as a suitable river in which to monitor the effect of trees on streamflow and to establish a rehabilitation and aftercare programme for the riparian zone. Together with the project researchers, the task group identified an initial experimental site on a tributary of the Elands River, the Sand, approximately 500m downstream from the Sand River Dam

The aim of the research was to determine the effect on streamflow of clearing *A. mearnsii* from the riparian zone. The primary aim of this research was to determine the effect on streamflow of *A. mearnsii* within the riparian zone. A secondary aim was to determine additional impacts of *A. mearnsii* within the riparian zone.

A number of primary objectives were identified: to identify a suitable research site, to compare streamflow in a cleared and uncleared section of a river, to estimate biomass of the invader trees within the cleared area, to relate flow response to evaporative demand, to assess the effect of alien vegetation on soil moisture. The following secondary objectives were also identified: to monitor water quality within the areas before and after clearing, to assess the effect of *A. mearnsii* on channel stability, to implement a rehabilitation and restoration programme within the cleared area.

Field monitoring was initiated in the Sand River in order to assess the effectiveness of clearing *A. mearnsii* from the riparian zone as a means of increasing and restoring streamflow. Two adjacent reaches of the river were monitored to allow a comparison between a cleared and an uncleared section of river. The northern bank of the river was steep hillslope, invaded by *A. mearnsii*; the riparian zone as such was of limited extent. The riparian zone to the south of the river covered an area of 5 hectares, forming a strip of approximately 50 m in width invaded by *A. mearnsii* at a density of 162 tonnes per ha

To facilitate a longer term study to compare seasonality of streamflow response to the removal of riparian vegetation, three permanent weirs were constructed. The area was divided into two 2.5 ha sections each 500 m in length. One section was cleared, the other left as a control section. Three 90° v-notch weirs were constructed approximately 500m apart from each other. Data loggers recorded the flow level at 12 minute intervals. The three weirs allowed the comparison of two adjacent sections with similar catchment conditions, channel morphology and initial vegetation densities. Both sections had an area of 2.5 ha.

The initial aim of the experiment was to monitor the effect of clearing the riparian vegetation during the time presumed to have the highest moisture stress, that is during the summer months of January and February. Streamflow was to be monitored for a short period before clearing to establish the baseline conditions, monitoring was to continue during clearing and for some time afterwards. Actual events proved somewhat different; high floods during the clearing period meant that the monitoring was discontinued for ten days, but was continued for several months through the dry winter season so as to evaluate seasonal differences in water use. The data loggers were removed in September as they were required by DWAF elsewhere.

Flow monitoring started on January 10th 1996. Clearing of *A. mearnsii* was initiated on January 22nd. Clearing was confined to the more accessible land lying on the south bank of the river, where a ha strip was cleared between the two upstream weirs. Monitoring ceased on September 8th 1996. The monitoring period thus covered both the end of the summer and the winter season. This period differed significantly from average conditions. The early summer had well above average rainfall whereas the winter was particularly dry. This should be borne in mind when interpreting the results. The increase in streamflow following clear felling should, however, represent conditions when water supply is likely to be the most critical, that is during a dry winter.

The experimental study on the Sand River in the Swartkops catchment showed that water use by *A. mearnsii* amounts to some 34 m^3 per day following the clearing of the riparian zone for 500 m on one side of the channel. The width of the cleared zone was 50 m, but it is not known what the relative effect of clearing a narrower strip would have been. On the one hand the results are very similar to those found in Mpumulanga by Dye *et al.* (1995) who cleared a 500 m long 25 m wide strip of mixed *Pinus patula* and *A. mearnsii* from either side of the channel. On the other hand, a comparison of water use with evaporative demand indicated that the "effective" width of the riparian zone was in the region of 35 m to 40 m.

The experimental design used in this experimental set up involved clearing wattle from the entire riparian zone, that is to a width of 50 m. Further experiments are needed to assess the effects of different widths of clearing.

Water use by *A. mearnsii* shows a strong seasonal pattern, with relatively low rates during the summer despite a high evaporative demand. The highest water use occurred during the winter and, within this period, did appear to respond to evaporative demand. There was evidence that the maximum daily water use occurred when the daily pan evaporation was between 2 and 3 mm. Water use was apparently reduced on days with a higher evaporative demand. Moreover, increases in streamflow just after midday were noted on days with a high evaporative demand.

It is possible that during periods of high evaporative demand *A. mearnsii* exerts a physiological control over water use, with transpiration rates being depressed at times of moisture stress.

The seasonality displayed by the results justified the use of a long term experiment using permanent weirs. It would be beneficial to extend the experiment further. No effective monitoring took place during the time of maximum summer evaporative demand. Moreover the monitoring period itself was atypical of long-term climatic conditions in the area, with a particularly dry winter following a wet summer. It would also be beneficial to monitor the riparian zone hydrology with respect to soil moisture and groundwater levels and canopy interception. Monitoring should also be continued to evaluate the effect of regrowth of natural vegetation in the area.

Rehabilitation of cleared sites is an important issue. Repeated visits were made to the site to monitor the regrowth of wattle seedlings and the emergence of seeded grass. Because of the very dry winter little regrowth was noted. Three representative channel cross-sections were set up in each section in order to monitor the long term effects of clearing on bank processes. No change was observed over the initial monitoring period. Monitoring should be continued at regular intervals (for example, six monthly) over a period of up to five years.

ACKNOWLEDGEMENTS

The research reported on herein was initiated by the Task Group on the Control of Invasive Plant Species, which is a group of the Zwartkops River Water Resources Management Plan (ZRWRMP). This group consisted of representatives from the Department of Water Affairs and Forestry (Port Elizabeth and Craddock Regional Offices and the Institute for water Quality Studies), the Port Elizabeth Municipality, East Cape Nature Conservation, and the Department of Resource Conservation under the chairmanship of Mr Francois de Kock of the Department of Water Affairs, Directorate of Environment Studies. The members of the above group are thanked for their support and guidance. The Department of Water Affairs and Forestry was in addition responsible for designing and constructing flow measuring weirs and for flow monitoring. The Port Elizabeth Municipality was responsible for the clearing programme and follow up work.

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ACRONYMS

DBH	Diameter at Breast Height
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
et al.	Latin *et alii* (and others)
HPV	Heat Pulse Velocity
IBT	Inter Basin Transfers
ICM	Integrated Catchment Management
l/s	litres per second
m^3/d	cubic metres per day
$m^3.ha^{-1}.yr^{-1}$	cubic metres per hectare per year
mS/m	milli-siemens per metre
PEM	Port Elizabeth Municipality
RDP	Reconstruction and Development Programme
WRC	Water Research Commission
ZRWRMP	Zwartkops River Water Resources Management Plan

CHAPTER 1

INTRODUCTION

1.1 The Problem

"People sometimes have the attitude that 'Gaia will look after us'. But that's wrong. If the concept means anything at all, Gaia will look after herself. And the best way for her to do that might well be to get rid of us." (Gribbon, 1990, pp 1).

The quality and availability of water have become major issues of concern both in the industrialised and developing world. In the North, attention has focussed primarily on the threat posed by chemical pollution while, in the South, bacterial contamination and the lack of water are the main issues (Goldsmith and Hildyard,1992). The Presidential Address to the International Water Reserves Association examined the water crisis facing many arid and semi-arid countries and stated that the issue will only become worse (Biswas, 991). Water managers have realised that the effective management of catchment vegetation can improve both the quality and quantity of water a catchment delivers (Boucher and Marais, 1995; Versveld *et al.*,1998). The concept of managing land and water in the context of a drainage basin has been applied successfully all around the world over the past twenty years (Mitchell and Pigram, 1989) and will have to become an integral part of planning to solve the water shortage problem in South Africa (Ninham Shand Inc., 1993).

In South Africa water shortages are a daily problem for millions of people (RSA White Paper, 1994). Decreasing water supplies are often attributed to droughts, but the problem of water scarcity cannot be blamed on climatic factors alone. Ecological degradations - in particular those practices which reduce the capacity of soils to absorb water, and the threat of alien plant invasions which reduce the flow of water to streams and rivers during the dry season - are also to blame (O'Keeffe, 1986; 1989). *Acacia mearnsii*, an Australian exotic and the focus of this report, is regarded as one of the greatest invaders of riparian zones in South Africa (Stirton, 1987; Vermeulen, 1989; Versveld *et al.* 1998). Trees growing in the riparian zone are suspected of using proportionately more water than those further away from rivers, and therefore pose a threat to a valuable source of water in a country already facing water shortages (Dye and Poulter, 1995b; van Wilgen *et al.*, 1996).

1.2 Research Context

South Africa is a developing country with a high rate of urbanisation, rapid population growth, and the majority of the population hoping to improve their standard of living. The new government which now, for the first time, represents the majority of the population, wants to satisfy their needs and supply sufficient water to all South Africans (RSA White Paper, 1994). These are issues that have to be taken into account when planning for the future water demands around the country.

South Africa has one of the lowest conversions of rainfall to runoff (8.6%) of any country in the world (Petitjean and Davies, 1988). Water resources are unevenly distributed, with subtropical conditions in the east and dry desert conditions in the west, leading to one-third of the country yielding a mere 1% of the total runoff. Rainfall is almost invariably equal to or less than the potential evaporation (Petitjean and Davies, 1988). According to the Department of Water Affairs (DWA, 1986), the assured yields in South Africa are estimated at 60 460 x 10^3 m^3/d of water, with a potential maximum of only 75 010 x 10^3 m^3/d. The rapidly rising demands will exceed maximum estimated yields even before the end of the century. South Africa is also afflicted by prolonged droughts which are often terminated by sizable floods (Davies and Day, 1986). In view of these problems the future water manager in South Africa is going to be faced with a challenge to meet the promises of the new government and the needs of the population, industry and agriculture.

The Department of Water Affairs and Forestry (DWAF) has exploited a large percentage of the available water sources in South Africa (DWA, 1986) and innovative and new approaches are going to be required to meet the increasing demand for water. The potential for exploiting ground water reserves is limited. The majority of water occurs in secondary aquifers where the delivery rate of the water is slow, and therefore only useful on a small scale (DWA, 1986). The renewable sources of ground water usually have an inadequate recharge rate and will only be effective at high rates of consumption for a short period (DWA, 1986).

The transfer of water from areas of surplus to areas of deficit is one solution to meeting the needs of the growing population, industrial and agricultural demands (Petitjean and Davies, 1988). Inter Basin Transfers (IBTs) have been used within the country since the early 1970s, and are being developed between neighbouring countries, to assist in the supply of water to areas in need (Petitjean and Davies, 1988). However, IBTs are costly in both engineering and environmental terms (Le Maitre *et al.*, 1996; Petitjean and Davies, 1988).

Ground water and IBTs were the only options DWAF exploited in the past until the Fynbos Forum, where a group of researchers decided in October 1993 to turn scientific data and good intentions into effective actions. This was the start of "...an idea that drew together the need for water, the need for employment and the need for conservation in one miraculous neat package" (Barrett, 1996; pp 30). In September 1995 Professor Kader Asmal, the Minister of Water Affairs and Forestry, launched the Fynbos Water Conservation Project to create jobs, win the war against alien plants and, above all, deliver water to the people (Barrett, 1996). The RDP Water Conservation Programme, commonly known as the Working for Water programme, has a mission to enhance water supplies by training local communities for catchment management projects that focus on the eradication of invasive alien plants (DWAF, 1996a).

Invasive alien vegetation is found throughout South Africa, covering a condensed area (total invaded area cover adjusted to a percentage cover of 100%) of 1.7 million hectares in South Africa (Versveld *et al.*, 1998). In the Eastern Cape the equivalent figure is 151 258 hectares. Versveld *et al.* (1998) rank *A. mearnsii* as the worst invader, covering a condensed area of 131 341 hectares in the country as a whole and 49 022 hectares in the Eastern Cape. The most severe invasions are along riparian zones. Alien vegetation is recognised as having significant but mostly unquantified effects on water consumption (Ninham Shand Inc., 1993; Dye and Poulter, 1995b; DWAF, 1996b), biodiversity within streams (Dunne and Leopold, 1978b; Cambray and de Moor, 1995; Belcher, 1996) and channel stability (Macdonald and Richardson 1986; Rowntree, 1991; Beyers, 1994).

The effect of alien species on catchment scale streamflow has been investigated in various parts of the country (Smith and Bosch, 1989; Dye and Poulter, 1995b; Le Maitre *et al.*, 1996), but studies have focussed mostly on commercial forestry species such as *Pinus patula* and *Eucalyptus* *grandis* (e.g. Smith and Bosch, 1989). Although *A. mearnsii* accounts for a large proportion of alien invasions in the riparian zones of Eastern Cape rivers, few studies have been directed at this species. Likewise there is a paucity of studies on the effect of clearing invasive trees in the riparian zone. Dye and Poulter's (1995b) research in Mpumulanga is one of the few relevant South African studies. Related research on the effect of alien trees on streamflow and the effect of the *A. mearnsii* in the riparian zone, will be discussed in greater detail in the Chapter 2.

Using data from catchment scale research on water use for a range of species, Versveld *et al.* (1998) estimated that the combined alien plant invasions in the Eastern Cape use in excess of 3 300 million m^3 of water. These authors recognised that their estimates did not take into account the increased dry season water use by riparian vegetation compared to water use of trees on the catchment slopes that would have been limited by water availability. Their estimates also did not incorporate data specific to *A. mearnsii*. Ninham Shand Inc. (1993) investigated the effect of *A. mearnsii* in the Krom and Kouga catchments in the Eastern Cape, but, like Versveld *et al.* (1998), had to use a general value for the water consumption of the trees taken from catchment experiments worldwide. There is a clear need for a broader body of information to assess the effects of individual species, density and age distribution, and different catchment and climatic conditions on streamflow responses to clearing invasive trees (Nännie, 1972; Dye and Poulter,1995b).

1.3 The Present Study

The Zwartkops River Water Resources Management Plan (ZRWRMP) was formed to coordinate the management of land and water within the Zwartkops River catchment. In 1995 the ZRWRMP formed a task group to control and research the extent of invader plant species. They noted that the Elands River sub-catchment was heavily infested by invader tree species, especially *A. mearnsii*. It would thus be a suitable river in which to monitor the effect of trees on streamflow. Once the trees were removed, a rehabilitation and aftercare programme for the riparian zone would be established by the task group. A proposal for the experiment on the effect of invader trees on streamflow was drawn up, which the task group used to secure funding through the Water Research Commission for the duration of 1996. The purpose of the experiment would be to use the results in a motivation for the removal of invader trees from riparian zones throughout the country and, specifically, the Zwartkops River catchment. The results can also be used to assess the likely success of the programme in the Eastern Cape region and create a local initiative by property owners to remove the invader trees.

The removal of alien trees on a catchment scale will only be successful if it is implemented by a catchment management plan and carried out in conjunction with the local owners of the riparian properties (Ninham Shand Inc. 1993). Integrated Catchment Management (ICM) is a relatively new concept in South Africa that has been adopted around the world to manage water resources effectively within a particular catchment. Mitchell and Pigram (1989) define ICM as the coordinated use and management of land, water, vegetation and other natural resources in the context of a river basin. Doolan *et al.* (1994) developed an ICM technique in Australia and concluded that ICM is a useful decision making tool for catchment managers which provide a technical base for the decision making process: the integration of ecological, economic, and social considerations, stakeholder involvement and the opportunity for community understanding and commitment.

The aim of the present study is to determine the effect on streamflow of *A. mearnsii* in the riparian zone. The results of the study can be used to justify (or not) clearing programmes and help to guide clearing within an integrated catchment management plan. Through the ZRWRMP the catchment communities can be shown the effects of removing *A. mearnsii* for augmenting water supplies and improving the riverine habitats. The government has recognised the threat posed by alien invasions along river courses, but for the long term success of the projects it will be necessary to include riparian land owners to combat the inevitable regrowth in the future. The ZRWRMP is one of the first successful examples in South Africa of an operating ICM plan which will be able to communicate the advantages of removing the alien trees.

The need for this study arises from past research focussing on modelling, assumptions and comparisons made between invasive species, to quantify the effect alien trees have on water yields on a catchment scale (Bosch and Hewlett, 1982). In the case of *A. mearnsii* there is a need for data on the more localised effects of removing trees from the riparian zones within the fynbos biome (Boucher and Marais, 1995; Dye and Poulter, 1995b; van Wilgen, 1995). Fynbos catchments throughout the Western and Eastern Cape yield large quantities of good quality water which is an essential resource in the region (Cowling, 1995). In order to eradicate invasive species such as *A.*

mearnsii from river courses and to stop the inevitable regrowth, it is going to take the cooperation of all riparian land owners to continue the work started by the government programmes. The results of small scale experiments will help to convince local land owners of the immediate advantages of clearing alien trees from their riparian zones, both for themselves and for downstream water users.

1.4 Research Aims and Objectives

1.4.1 Research aims

The primary aim of this research is:

to determine the effect on streamflow of *A. mearnsii* within the riparian zone.

The secondary aim of this research is:

to determine additional impacts of *A. mearnsii* within the riparian zone.

1.4.2 Research objectives

The following primary objectives were identified:

1 to identify a suitable research site;
2 to compare streamflow in a cleared and uncleared section of a river;
3 to estimate biomass of the invader trees within the cleared area;
4 to relate flow response to evaporative demand;
5 to assess the effect of alien vegetation on soil moisture;
6 to extrapolation to other sites and to larger areas within catchments.

The following secondary objectives were identified:

1 to monitor water quality within the areas before and after clearing;
2 to assess the effect of *A. mearnsii* on channel stability;
3 to implement a rehabilitation and restoration programme within the cleared area.

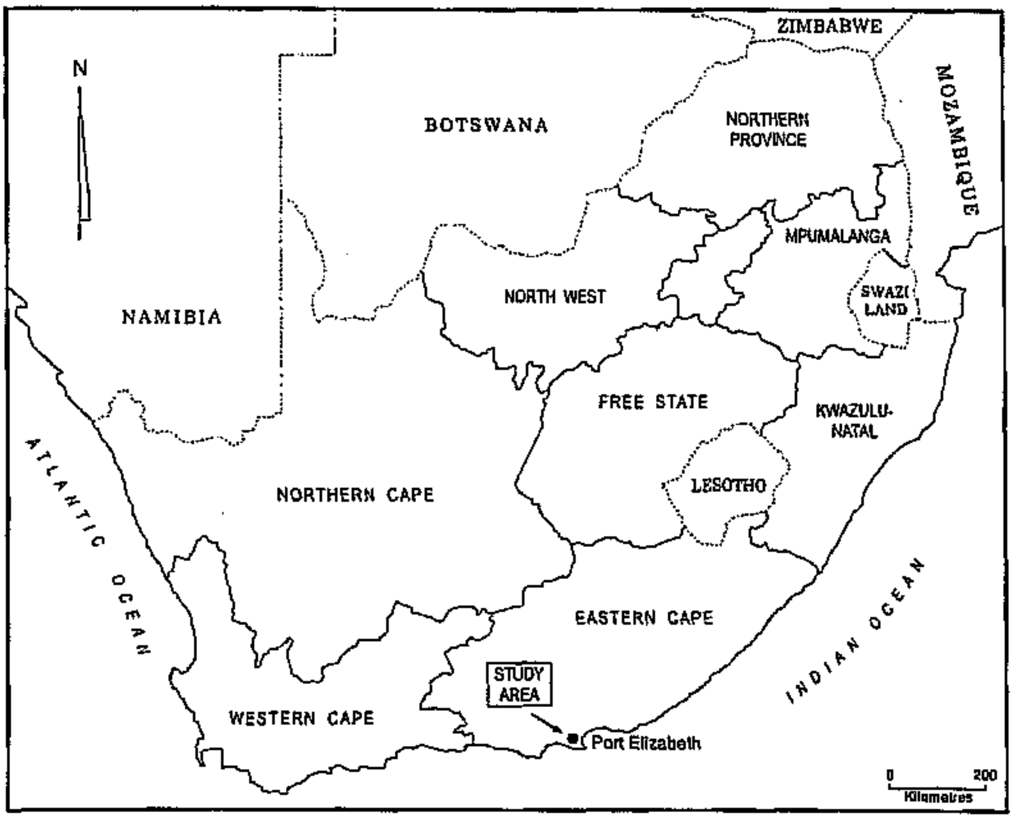


Figure 1.1: Location of the study site within the Republic of South Africa.

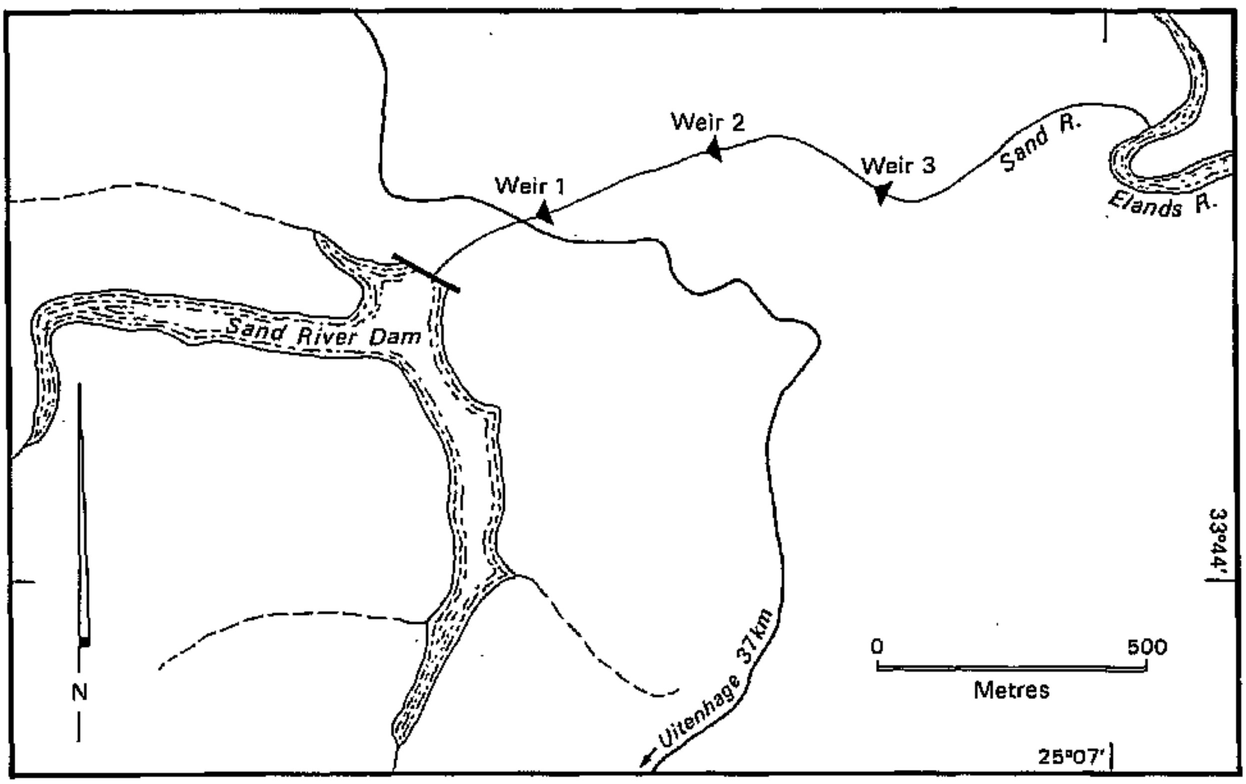


Figure 1.2: Location of the study site and weir positions on the Sand River.

It had also been anticipated that a biomonitoring exercise would be included to assess the effect of clearing on the stream biota. Unfortunately the decision by the task group to undertake biomonitoring was made after the summer period. The research team was informed that little information would be gained from an assessment during the winter period (Uys per s. comm.) Related work by Cambray and Moore (1995) is referred to in the relevant section.

1.5 The Study Area

1.5.1. Setting

The Zwartkops River Water Resources Management Plan (ZRWRMP) oversees the Zwartkops river catchment, situated just north of Port Elizabeth in the Eastern Cape Province, South Africa (Figure 1.1). The catchment encompasses two tributaries, the KwaZunga and Elands rivers, which combine to form the Zwartkops river which flows into the ocean approximately 10km north of Port Elizabeth. The task group on the control of invader plant species noted that the Elands river would be suitable for the present study. This river was infested by invader tree species, in particular *A. mearnsii*. Together with the present researcher, they identified an initial experimental site on a tributary of the Elands River, the Sand, approximately 500m downstream from the Sand River Dam (Figure 1.2). Various factors were taken into consideration in determining the location of the study site, other than the presence of *A. mearnsii* in the riparian zone and the river in the Zwartkops catchment. These will be discussed in greater detail in Chapter 3.

The altitude of the study site is 300 metres above mean sea level and the gradient between the weirs over the 1km stretch of river is 0.02. Mean annual precipitation measured daily at the Sand River Dam is 611.64 mm, with rainfall occurring all year round. An historical rainfall record is included for the Sand River Dam from 1908, in Appendix 1a. Mean annual pan evaporation averaged for two local stations (Loerie Dam and Groenwal Dam) is 1445 mm (Appendix 1b.) Weather conditions for the duration of the experiment will be described in greater detail in Chapter 4.

1.5.2 Vegetation

The majority of the Sand and upper Elands River catchments is characterised as South Coast Renosterveld, part of the Fynbos Biome (Belcher, 1996;). Renosterveld is one of two major vegetation groupings in the Fynbos Biome, the other being Fynbos (Low *et al.*, 1996, No. 63). Renosterveld is dominated by members of the Daisy Family (Asteraceae), specifically Renosterbos *Elytropappus rhinocerotis*, from which the vegetation type gets its name (Low *et al.*, 1996). South Coast Renosterveld differs from the other Renosterveld types due to the high proportion of grasses such as *Themeda triandra*, *Brachiaria serrata* and *Sporobolus africanus* (Low *et al.*, 1996).

1.5.3 Geology and soils

The geology forms part of the Cape Supergroup, Bokkeveld group and Ceres subgroup. The main soil forming lithologies are the sandstones of the Table Mountain formation and undifferentiated shales and sandstones of the Bokkeveld and Ceres group. Soils within the riparian zone are of alluvial origin, consisting of a mixture of coarse loamy sands and cobbles. When intact, the sandstone bedrock is impermeable to water but fractures in the rock are common (Rust, 1988; Toerien and Hill, 1989).

1.6 Structure of the Report

The report is structured as follows. Chapter 2 provides a theoretical background to the invasion of *A. mearnsii* and a review of related research on the water use of trees, which provides a framework within which the research is conducted. General effects of *A. mearnsii* invasions are also discussed. Chapter 3 explains the reasons for the research design and the methodology used in attempting to achieve the aims. Results of field work and analysis of data are presented in Chapter 4. Factors determining the effect of *A. mearnsii* in the riparian zone on streamflow are synthesised and discussed in Chapter 5. General conclusions are given in this chapter.

CHAPTER 2
THEORETICAL REVIEW

2.1 Introduction

"*The trouble with trees is they drink too much*" (Stober, 1992).

Trees need water to survive, but the issue is rather the amount of water they should be allowed to use (Stober, 1994). In South Africa large proportions of certain catchments are covered by plantations of alien vegetation and, while these plantations form a vital part of the country's economy, they compete for a resource which everyone relies on - water (Bosch and van Gadow, 1990; Stober, 1992; van Wilgen *et al.*, 1996). The biggest concern for catchment managers and water users is the assumption that alien trees use considerably more water than indigenous plants and trees (DWAF, 1996a,1996b; Dye and Poulter, 1995a, 1995b; Le Maitre *et al.*, 1996). The cost of clearing alien species for increased water yield can be expensive but, when compared to alternatives such as dams, recycling and inter-basin transfer schemes, the cost per unit of water delivered is considerably less (van Wilgen *et al.*, 1996).

Pristine fynbos catchments are known as reliable sources of large quantities of high quality water, but with the invasion of alien trees this reliability is being threatened (Le Maitre *et al.*, 1996). The mountain catchments of the Fynbos Biome yield large amounts of water - essential for the social and economic development of the region (Cowling, 1995). Fynbos shrubs provide a stable ground cover inhibiting sheet erosion and encouraging infiltration, as opposed to stands of *Acacia mearnsii* which develop bare soil under the canopy (Macdonald, 1987). The indigenous plants also require less water to survive than the high biomass stands of *A. mearnsii*, resulting in more water reaching the streams and rivers (Cowling, 1995; Le Maitre *et al.*, 1996).

The Eastern Cape is a convergence zone for more than twenty different vegetation types recognised by Acocks (1988). The flora of the region is therefore extremely varied and includes many endemics, but, since the invasion of exotic species, the diversity of indigenous vegetation has deteriorated (Boucher and Marais, 1995). Catchments become destabilised, leaving the soil exposed to erosion and depleting the soil of its reserves, decreasing the quality and quantity of water delivered by the catchment (Boucher and Marais, 1995; Ninham Shand Inc., 1993). The process of exotic plants invading indigenous communities can be complex and, when researching the effect of *A. mearnsii* trees on streamflow in the riparian zone, it is essential to have an understanding of the history of the introduced species and the factors which determine their growth patterns (Dye *et al.*, 1994).

A. mearnsii occurs naturally in south-east Australia, where it forms part of the undergrowth in *Eucalyptus* forests, or grows in dense stands along roads (De Beer, 1986). Authors are in agreement that the first *A. mearnsii* seed was brought to South Africa from Australia in 1864 by John van der Plank, an English seafarer who settled on a farm in the Camperdown area in Natal (De Beer, 1986; Stirton, 1987; Wells *et al.*, 1986). The seed was distributed to travellers by van der Plank which led to *A. mearnsii* trees spreading far from the original locality (De Beer, 1986). It is not certain whether the trees in the Cape descended from the original van der Plank progeny as there are other records of seed being received in Cape Town from Australia around the late 1800s (Macdonald and Richardson, 1986). Records show that it was already in the Cape Town Botanical Garden by 1858 (Stirton, 1987).

By 1880, *A. mearnsii* bark had been analysed and discovered to be rich in tannins, a compound used in the process of tanning leather (Macdonald and Richardson, 1986; Stirton, 1987). This information led to *A. mearnsii* being cultivated in vast plantations as a resource for both firewood and the extraction of tannins from the bark. The commercial plantations in Natal soon became the centre of a large and profitable export industry (De Beer, 1986), with the first record of exports to Britain in 1886 (Stirton, 1987). *A. mearnsii* is still grown for these purposes in Natal, where the industry continues to thrive with additional markets for the wood in the paper manufacturing, charcoal, and parquet flooring industries (De Beer, 1986; Stirton, 1987; Azorin, 1992). Although the trees were not planted on the same scale in the Cape as in Natal, they have spread throughout the region, and the saying that Natal rejoices in the bark but the Cape suffers from the bite holds true.

The Fynbos Biome is susceptible to alien plant invasions (Richardson *et al.*, 1992). A combination of the intentional introduction of invader species and the unintentional creation of disturbed environments has played an important role in the success of an exotic plant invasion within the Fynbos Biome (Cowling, 1992; Macdonald and Richardson, 1986). Henderson and Wells (1986) claim that the most impacted ecosystems in southern Africa are those of the riparian zones and give a number of reasons why stream banks are particularly prone to invasions compared to terrestrial environments. These include their exposure to periodic natural and human related disturbances, the perennial availability of moisture, reliable dispersion of seeds by water and the role of stream banks as a seed reservoir.

The Fynbos Biome is bioclimatically suited to support the growth of woody trees, but indigenous examples are relatively uncommon (Acocks, 1988). Fynbos shrubs rely on, and exploit, the brief period after a fire, but lack the capacity as individuals or as a community to optimise resource use later on in stand development (Richardson *et al.*, 1992; Stock *et al.*, 1992). The success of the invasions into the biome, seen by the higher steady-state biomass of invaded compared with non-invaded communities, strongly suggests a surplus of resources associated with a vacant niche in fynbos for this life form (Richardson *et al.*, 1992).

A. mearnsii propagates by means of seeds that can remain viable for at least 50 years in the upper soil horizons where they accumulate and can form densities as high as 20 000 seeds per square metre (De Beer, 1986). *A. mearnsii* seeds are dispersed by birds (Le Maitre *et al.*, 1996), but once they have invaded the riparian zone the water allows for rapid dispersal downstream (Henderson *et al.*, 1987). Germination of the seeds is stimulated by fire, a common characteristic of plant species found in the Fynbos Biome. Dense thickets form in the burnt areas (Macdonald, 1987; De Beer, 1986). The availability of water close to the soil surface in riparian zones makes it a favourable area for plants and trees to grow. *A. mearnsii* is an aggressive invader of the riparian zone where disturbances are common due to farming and grazing practices (Macdonald and Richardson, 1986).

In view of the aims of the present research and the lack of information on water use by *A. mearnsii*, the following sections will discuss related studies on the effect of exotic trees on streamflow, at both a catchment scale and within the riparian zone. A brief review of the general effects of *A. mearnsii* in the riparian zone will be discussed in section 2.3.

2.2 Water Use by Trees and Effects on Streamflow

2.2.1 Introduction

Research has been undertaken to quantify how much water invasive trees and plants use, but there is still a need for further investigation (Bosch and Hewlett, 1982; Dye *et al.* 1995b; Poulter *et al.*, 1994). The effect of vegetation changes on water yield has been investigated in all parts of the world at a catchment scale (Bosch and Hewlett, 1982), but very little research has been undertaken on how streamflow is affected by the removal of invasive vegetation in the riparian zone (Dye and Poulter, 1995b; Nänni, 1972). In South Africa, research has focussed on regions where forestry stations were established, and several long term experiments were laid and monitored since 1940 (Van Der Zel, 1987). In 1935 the Jonkershoek Forest Hydrological Research Station was established, followed by Cathedral Peak in 1945 and at Mokobulaan in 1955 (Van Der Zel, 1987). These stations are responsible for the majority of research on the effect of vegetation cover on water yield in South Africa (Bosch and Smith, 1989, Bosch and van Gadow,1990; Smith and Bosch, 1989; van Wyk, 1987).

It is standard practice for plantation managers to avoid planting trees in the riparian zones to reduce the risk of soil erosion close to the channel, and to minimise the water use of plants in these areas (Dye and Poulter, 1995b; Scott and Lesch, 1995, 1996; Van Der Zel, 1987). It is suspected, and has been remarked upon by various researchers, that trees growing in the riparian zone use proportionately more water than those further away, due to the increased availability of water (Dye and Poulter, 1995b; Scott and Lesch, 1995, 1996; Ninham Shand Inc., 1993).

There is a continual debate between researchers over the rate of water use by trees (Dunne and Leopold, 1978a; Dye *et al.*, 1994). Dunne and Leopold (1978a) state the difference between rainfall and runoff is largely explained by evapotranspiration. Evapotranspiration refers to the combined loss of water from a vegetated surface through evaporation and transpiration (Dunne and Leopold, 1978a; Kramer, 1983). Transpiration is the loss of water through the stomatal openings in the leaves whereas evaporation refers to the loss of water directly to the atmosphere from a surface water source such as the water held as interception storage on the leaf surfaces. The rate of transpiration and evaporation are governed by the same atmospheric factors and are usually considered under the combined title of evapotranspiration (Dunne and Leopold, 1978a; Kramer, 1983).

2.2.2 The effect of alien trees on streamflow: catchment studies

The effect of vegetation changes on water yield has been investigated in all parts of the world on a catchment scale, including South Africa (Bosch and Hewlett, 1982). Bosch and Hewlett (1982) reviewed 94 catchment experiments worldwide to investigate the effect of vegetation changes on water yield.

The assimilation of information allowed Bosch and Hewlett (1982) to derive approximate values for the changes in water yield, but they explain that error limits cannot be set on these figures due to the wide variability of catchment conditions. Results from the catchment experiments are influenced by certain general trends of which precipitation is the most significant. Extreme low or high rainfall regions showed the greatest changes in water yield in response to vegetation change. Variability in topography, climate and soils were also recognised as affecting the outcome of results and are important considerations in experimental design (Bosch and Hewlett, 1982). If a site is too small, the results may not represent the catchment as a whole, but as an experimental catchment increases in size it becomes more difficult to control treatments, estimate precipitation and measure streamflow accurately (Bosch and Hewlett, 1982).

Figure 2.1 summarises the relationship between annual streamflow increases and the reduction in cover according to Bosch and Hewlett's (1982) synthesis. The authors concluded that coniferous and eucalypt cover types have the greatest influence on water yield, followed by deciduous and mixed hardwoods and, lastly, scrub or grasslands.

Acacia mearnsii was not studied specifically in any of the catchment experiments reviewed, but for comparative purposes falls into the mixed hardwood category. The accumulated evidence of water yield changes in response to vegetation changes allowed Bosch and Hewlett (1982) to conclude that valuable information is available and can be used as a general guideline for practical purposes in catchment management around the world. For example, the information has been used by Ninham Shand Inc. (1993) for Algoa Water Resources Stochastic Analysis in the eastern Cape, South Africa. The authors used an approximate value of water usage to estimate the effect of *A. mearnsii* in the Kouga and Krom catchments and provided future management recommendations.

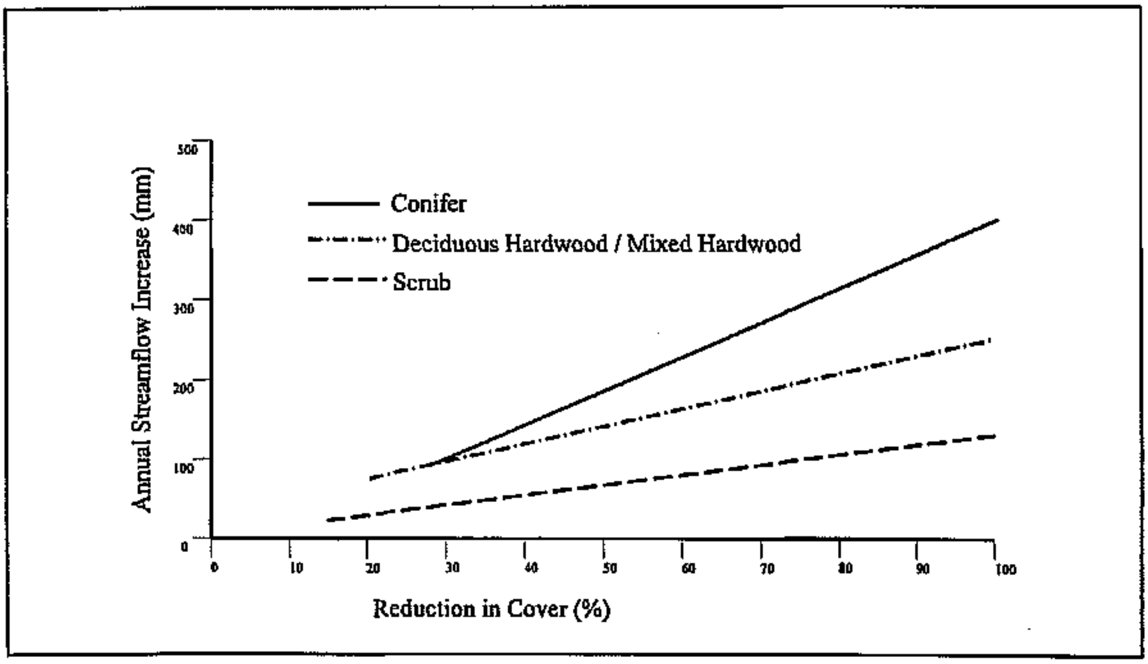


Figure 2.1: Water yield changes following changes in catchment vegetation cover (Adapted from *Bosch and Hewlett*, 1982)

Selected results from reviews of catchment experiments within the Fynbos Biome have been summarised in Table 2.1 (Van Wyk, 1977, 1987). The results originate from a multiple catchment experiment in the South Western Cape Province of South Africa (Van Wyk, 1987). There have been similar experiments in other regions of the country, but catchment conditions differ. The temperate climate and fynbos vegetation of the Western Cape Province is similar to the Eastern Cape, allowing acceptable comparisons to be made.

Le Maitre *et al.* (1996) used the results from 11 gauged catchment experiments in the attempt to develop a model simulating the effects of alien plant invasions on water yield. Data from catchment experiments in the Cape mountains extend over a period of at least 50 years and have shown that afforestation with alien trees decreases streamflow (Van Der Zel and Kruger, 1975; Van Wyk, 1977, 1987; Bosch and von Gadow, 1990).

Table 2.1: Streamflow reductions for *Pinus patula* from catchment experiments within the Fynbos Biome (after Van Wyk,1987)

Streamflow reduction $m^3.ha^{-1}.month^{-1}$	(mm. $year^{-1}$)	Percentage of catchment afforested	Duration of experiment
207.5	(249 mm)	57%	28 years
260.8	(313 mm)	98%	20 years
142.5	(171 mm)	36%	16 years
154.2	(185 mm)	89%	8 years

Natural fynbos and alien vegetation, with a 15-year interval between fires, were used for the model (Le Maitre *et al.*, 1996). Above ground biomass was assumed to be zero immediately following a fire, thereafter the density of the alien plants increased dramatically and, in addition, invaded adjacent areas. The increase in biomass was simulated between fires at rates known for both natural and alien vegetation. Aliens grow faster than the indigenous vegetation which meant the biomass within catchments increased as the simulation continued over a 15-year period (Le Maitre *et al.*, 1996).

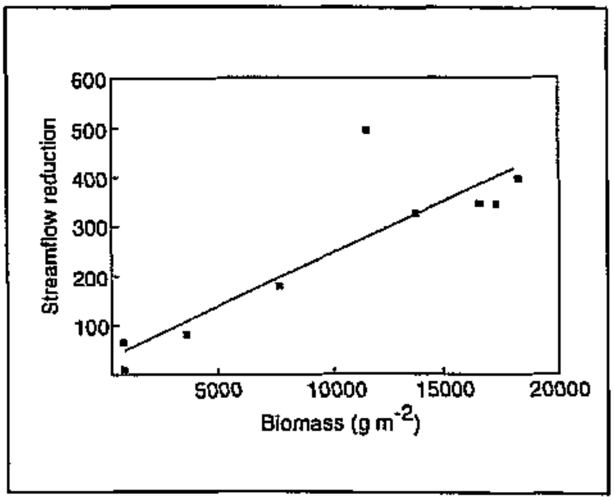


Figure 2.2: Relationship between Above Ground Biomass and Reduced Streamflow (Source: Le Maitre *et al.*, 1996).

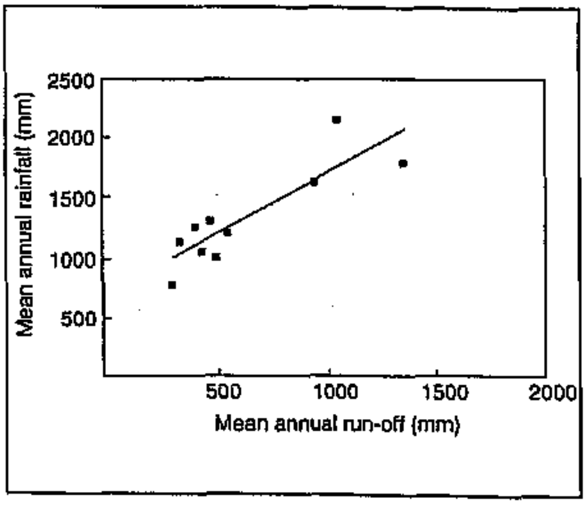


Figure 2.3: Relationship between mean annual rainfall and run-off (Source: Le Maitre *et al.*, 1996)

The results from 9 and 10 catchments respectively were used by the authors to find a statistically significant relationship between above ground biomass and reductions in streamflow (Figure 2.2) and a relationship between mean annual rainfall and run-off (Figure 2.3) within catchments with minimum vegetation cover (Le Maitre *et al.*, 1996). The exact mechanisms controlling the reductions in streamflow are not clear, but biomass can be used as a function of transpiration and interception, which can be interpreted as a surrogate measure of leaf area (Le Maitre *et al.*, 1996). The occurrence of fire, rainfall-to-runoff ratios, growth and changes in biomass between fires and the effects of these changes on streamflow were used by Le Maitre *et al.* (1996) to simulate the spread of alien trees and subsequent decrease in water yield from the Kogelberg area in the south Western Cape (Figure 2.4).

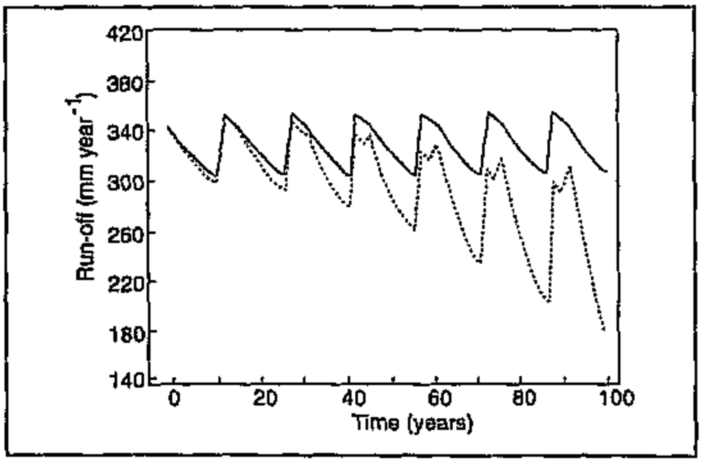


Figure 2.4: Simulations of annual run-off with alien trees absent (——) and alien trees present (········) with a fire return interval of 15 years. (Source: Le Maitre *et al.*, 1996)

It was predicted that 40% of the area would be invaded by exotic trees within 50 years, and 80% within 100 years, resulting in an estimated average decrease of $347 m^3.ha^{-1}.yr^{-1}$ (34.7 mm) of water, accounting for an average loss of 30% of the water supply to the city of Cape Town (Le Maitre *et al.*, 1996). The speculated figure of $347 m^3.ha^{-1}.yr^{-1}$ is based on an area of 250 000 hectares and the percentage loss of water would be considerably higher in areas with below average rainfall and when large areas are covered by mature stands of trees. Losses of approximately 50% of the run-off were predicted (Le Maitre *et al.*, 1996).

Many catchment scale experiments reported in the international literature have been carried out in areas of high runoff. These act as the main runoff areas for water supply as well as being those areas where commercial woody species grow best. In South Africa very few quaternary catchments have a mean annual runoff exceeding 500 mm; a value of 100 mm can be considered as separating the wet and dry areas of the country. Riparian vegetation such as *A. mearnsii* not only grows in the catchments of the wetter areas, but because of the increased water supply can extend into the riparian zones of the drier areas. The relative impact of these riparian species can be expected to be particular high in such areas.

Modelling on a large scale to show the implications of vegetation change provides valuable information for catchment managers. Catchment experiments show increases in water flow when alien vegetation is removed, but in the case of *A. mearnsii* where invasion is worst in the riparian zone, further research is necessary at a smaller scale within riparian zones around the country.

2.2.3 The effect of alien trees streamflow: riparian zone studies

The few field demonstrations that have been undertaken to investigate the effect of clearing of indigenous and invasive vegetation in riparian zones have shown increases in streamflow (Nänni, 1972; Dye and Poulter, 1995a, 1995b; Scott and Lesch, 1995, 1996). Dye and Poulter (1995b) investigated the effect on streamflow of clearing *Pinus patula* and *A. mearnsii* from the riparian zone, but no field demonstrations on clearing homogenous stands of *A. mearnsii* have been conducted.

Dye and Poulter (1995b) demonstrated the effect on streamflow of clearing invasive *P. patula* and *A. mearnsii* from a riparian zone in an afforested catchment in Mpumalanga. Two portable weirs were set up 500m apart on the same stream to monitor flow before and after clear felling. Between the weirs, trees were cleared to an average distance of 25m on either side of the stream accounting for a cleared area of approximately 2.5 hectares. Measurements at the lower weir were less than those at the upper weir before clearing, but equalled the readings at the upper weir after clearing (Figure 2.5). Dye and Poulter (1995b) found clearing of the trees accounted for a 120% increase in streamflow, equivalent to 30.5m^3/day.

The authors concluded that the trees in the riparian zone exerted a strong influence on the streamflow as seen by the daily fluctuations reflecting transpiration by the trees during the hours of daylight (Figure 2.5). They also recorded an increase in streamflow on days with cloudy, rain free weather conditions due to the reduced evaporative demand of the air, causing transpiration rates to drop as well (Point A; Figure 2.5). The V-notch at the upper weir was partially blocked at point B, but was cleared at point C.

Dye and Poulter (1995b) concluded that invasive exotic trees should be removed from riparian zones to increase streamflow from afforested catchments. It was stated that before the effect of clearing invasive trees on streamflow responses can be reliably assessed more information is needed on the effects of individual species, density and age distribution, as well as catchment characteristics.

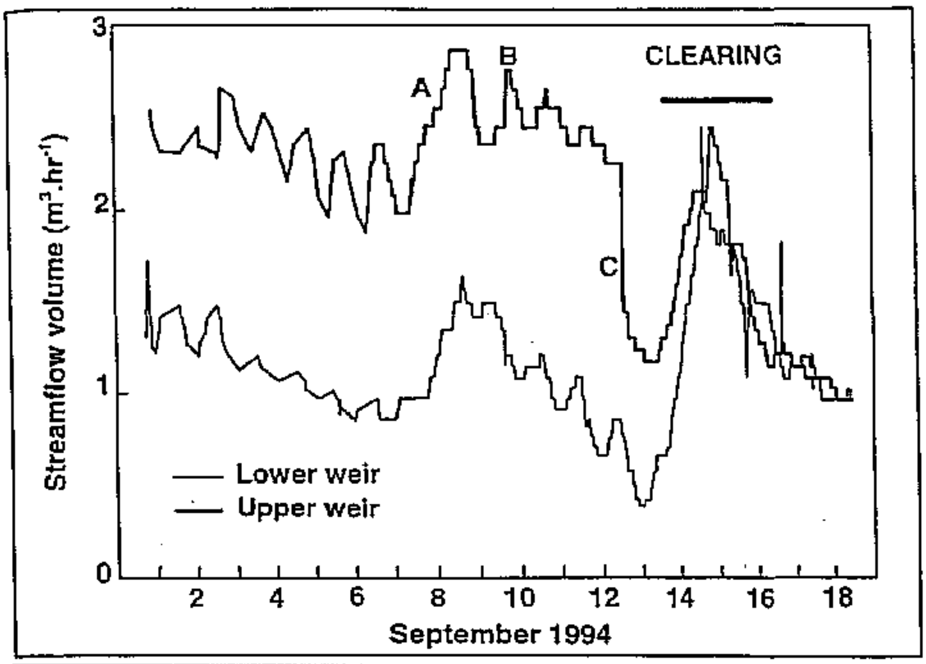


Figure 2.5: Streamflow volume recorded at the upper and lower weirs over the duration of the experiment. Point A marks an increase in the streamflow caused by overcast weather. The upper weir was partially blocked at point B and cleared at point C. (Source: Dye and Poulter, 1995b).

The technique of using two portable weirs to measure streamflow was first used by Nänni (1972) to study the effect of clearing indigenous riparian vegetation on water use at Cathedral Peak. There were either no exotic trees present in the Nänni (1972) experiment or they were left untouched, but his major conclusion was that portable weirs were a practical way of measuring the changes in streamflow after the clearing of riparian vegetation. Dye and Poulter (1995b) demonstrated the suitability of using the portable weirs and agreed with Nanni (1972) that the technique was cost effective and the ability to move the weirs to various sites is an advantage. Nänni (1972) also concluded that this type of experiment would be successful during dry periods, and light rainfall events, while in the event of heavy rain the financial loss would be small. It was mentioned that portable weirs are useful for short term experiments when the risk of theft or vandalism is a factor (Dye and Poulter, 1995b).

In an attempt to answer the question of whether water use by riparian vegetation is higher than that by vegetation in other parts of a catchment, Scott and Lesch (1995) analysed three paired catchment experiments. Two catchments in the Mpumalanga Province and one in the Western Cape were used. In the two catchment experiments in the Mpumalanga Province, different vegetation types were cleared from the riparian zones and the surrounding catchment, but in the Western Cape *P. patula* was cleared from both areas. The authors found that the comparison of water use between riparian and catchment vegetation more significant in the latter experiment where the same species, age and density of trees were removed from all parts of the catchment (Scott and Lesch, 1995). It was found that the water use by *P. patula* was roughly three times that of the same trees on non-riparian slopes. The results from all the experiments allowed Scott and Lesch (1995) to conclude that trees in the riparian zone are liberal users of water when compared to vegetation in the surrounding catchment.

In a similar experiment, Scott and Lesch (1996) used the paired catchment method to measure the effects of riparian zone clearing and clear felling of indigenous vegetation on streamflow. A forested riparian zone of a humid Northern Province catchment was cleared and kept clear of vegetation. The riparian clearing resulted in a small 55mm (9%) increase in annual streamflow, but by the second year these effects diminished and the total streamflow decreased to below total expected flow. Although the authors interpret this result partly as a serious drought at the time of treatment, it was concluded that clearing of riparian and other indigenous forest and scrub vegetation is not a practical means of augmenting streamflow in this region (Scott and Lesch, 1996).

Research on the effect of exotic trees on streamflow in riparian zones are based on short periods of observation, on different kinds of streams and in different parts of the country. Researchers agree that experiments should be repeated over a wider geographical and vegetation range in order to improve estimates of water use by riparian vegetation (Dye and Poulter, 1995b; Scott and Lesch, 1995, 1996).

2.2.4 Water use by *Acacia mearnsii*

Advances in technology have made it possible to measure sap flow rates, and thus transpiration, for individual trees using the Heat Pulse Velocity Technique (HPV) (Swanson *et al.*, 1981). Smith and Scott (1992) verified the technique for *A. mearnsii*, concluding that it will have applications in commercial forestry, riparian zones, and on mining sites successfully colonised by the species. Poulter *et al.* (1994) used the technique in a comparative study of water use by invasive and indigenous forest species found in riparian zones. The results indicate major differences in water use between riparian tree species. Competition for light, water and nutrients were given as a possible explanation.

Smith and Scott,(1992) estimated the average water use for an *A. mearnsii* tree (diameter 9.2 cm) at approximately 30 *ℓ*/day, whereas Poulter *et al.* (1994) used two *A. mearnsii* trees (diameters 14.7 and 17.2cm) in their comparisons and found an average water use of 20 *ℓ*/day. Poulter *et al.* (1994) were also able to demonstrate *A. mearnsii* exhibited early control of water loss as the vapour pressure deficit (VPD) increases and the air dries out (Figure 2.6).

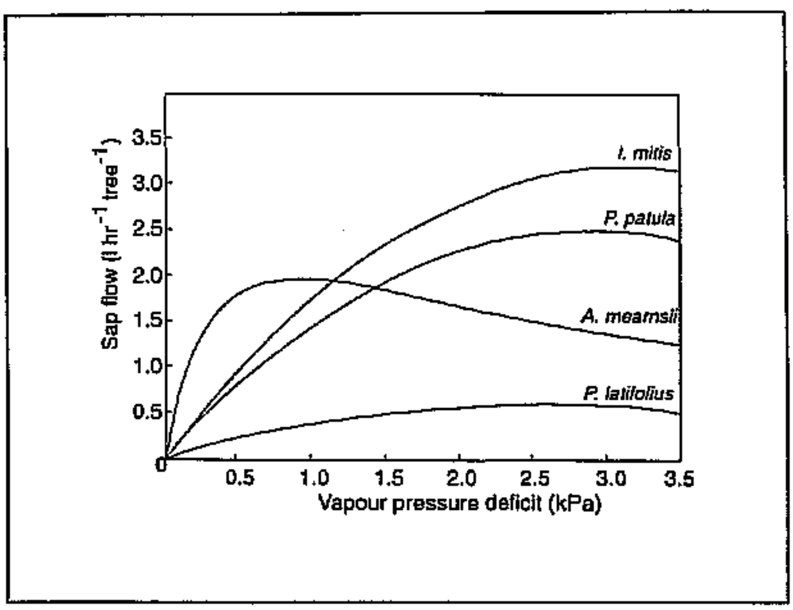


Figure 2.6: *A. mearnsii* exhibiting control of water loss as VPD increases and the air dries out. (Source: Poulter *et al.*, 1994, p. 24)

HPV provides useful information about the water use characteristics of trees (Poulter *et al.*, 1994) and the technique has been verified for *A. mearnsii* (Poulter *et al.*, 1994; Smith and Scott, 1992). However, further research is recommended by the authors who suggested that the choice of species grown in riparian zones could lead to important differences in streamflow characteristics.

2.3 General Effects of *Acacia Mearnsii* in the Riparian Zone

2.3.1 Plant species diversity

Acacia mearnsii has no natural enemies in South Africa (Glen-Leary, 1990) and it is known to have widespread effects on ecosystems which it invades. Conservationists have been attempting, however, to eradicate *A. mearnsii* from fynbos catchments for years (Macdonald and Richardson, 1986; Barrett, 1996). The control of *A. mearnsii* has received an abundance of attention in the past year due to the potential to increase streamflow by removing the dense stands of trees from catchments (Barrett, 1996; DWAF, 1996a, 1996b; Odendaal, 1996; Pithers, 1996).

It was mentioned that the Eastern Cape is known for its wide diversity of plant species, but with the invasion of alien species, including *A. mearnsii*, the diversity of the indigenous plant communities is being threatened. This reduction in species richness is well documented in the literature. Macdonald and Richardson (1986) summarised the reduction in plant species richness in fynbos communities dominated by alien plants relative to uninvaded indigenous fynbos communities (Figure 2.7).

A. mearnsii out competes natural fynbos vegetation, forming dense stands of trees. In the Fynbos Biome, where fire plays a vital role in the success of the ecosystem, high biomass stands of *A. mearnsii* pose a major threat (Macdonald and Richardson, 1986). Fires under these conditions are extremely difficult to contain and are potentially more damaging to ecosystems than fires in indigenous vegetation (Van Wilgen and Kruger, 1985). The intensity of fires is considerably higher in dense stands of alien vegetation which can cause irreparable damage to the soil structure, thus destroying any future possibilities of restoring a region to its original pristine form (Van Wilgenand Kruger, 1985).

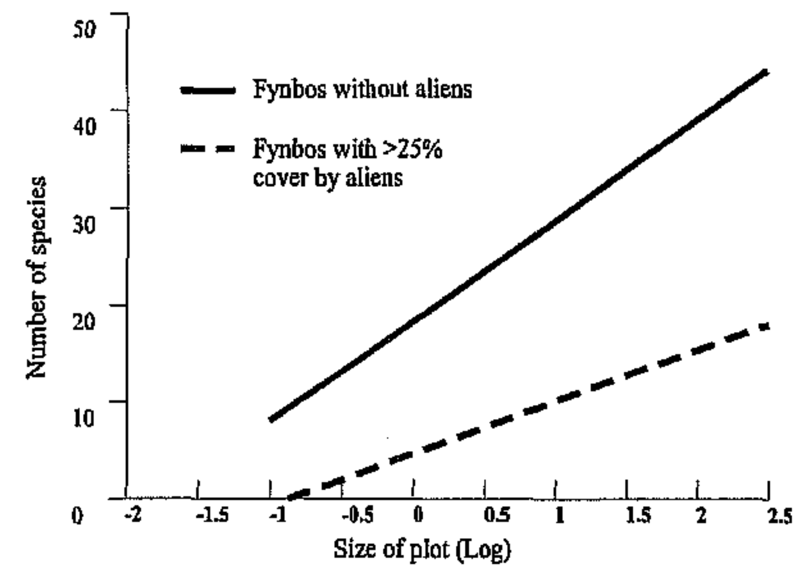


Figure 2.7: The relationship between the number of indigenous vascular plant species and plot size in fynbos areas densely infested by alien woody plants and in uninfested areas. (Adapted from Macdonald *et al.*, 1986)

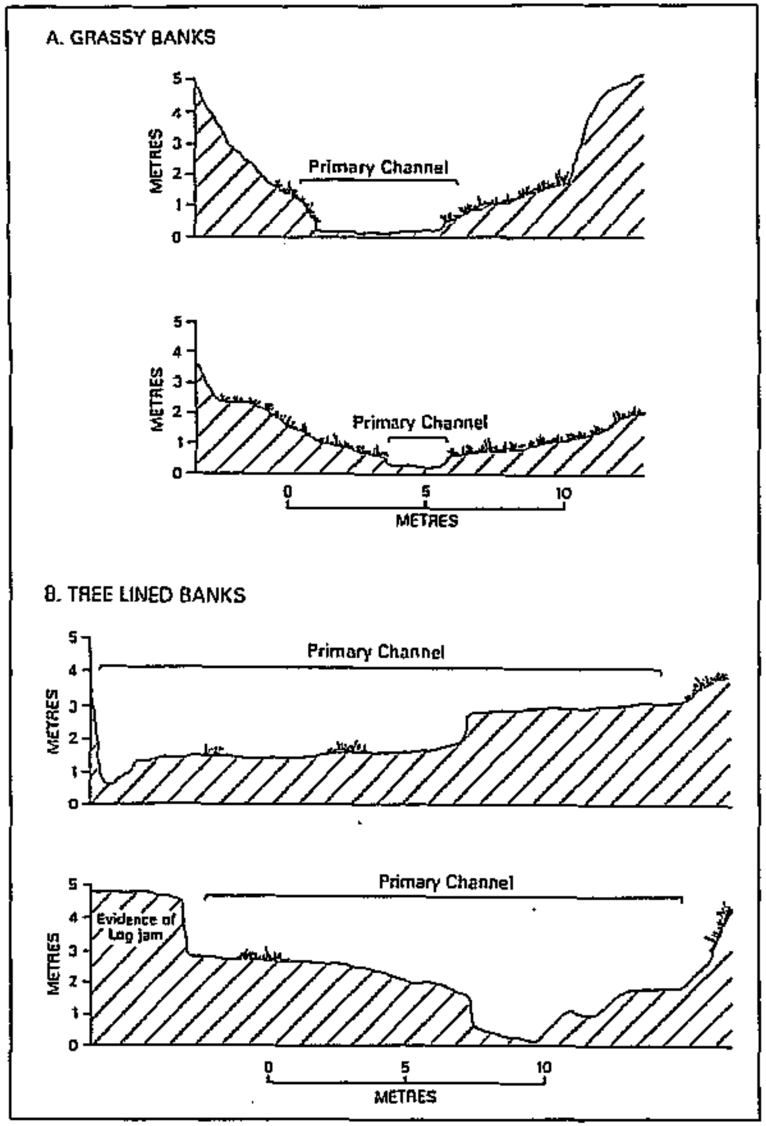
.3.2 Channel form and stability

Vegetation has often been played down as a significant variable in channel instability, partly because it is difficult to quantify effectively. Fluvial geomorphologists are, however, increasingly recognising its importance in controlling channel processes and form (Murgatroyd and Turnan, 1983; Gregory and Gurnell, 1988; Thorne, 1990; Rowntree, 1991; Dollar, 1992). Vegetation is known to exert significant controls over channel processes and hence channel form, but the response is complex, depending on the type of channel and the vegetation communities involved (Gurnell and Gregory, 1984; Gregory and Gurnell, 1988). Natural fynbos vegetation is well adapted to the flash floods that occur in most catchments (Macdonald and Richardson, 1986), whereas alien woody species are not able to withstand these floods and are ripped out, often dislodging mats of indigenous vegetation (Macdonald and Richardson, 1986), leading to bank instability.

It is known that *A. mearnsii* uses water for seed dispersal (Henderson *et al.*, 1987), which is the reason for the dense impenetrable thickets often found in the riparian zones of Eastern Cape rivers. River channels flowing through areas of large woody species in the riparian zone are known to have deeper and narrower channels than those flowing through grasslands (Rowntree, 1991), but may be more susceptible to erosion. Channels in two adjacent catchments in the Kouga river system, the Rachels and Huis rivers, have a contrasting morphology (Beyers, 1994). Both catchments receive very similar rainfall and are largely vegetated with fynbos. A major flood, in September 1993, was observed to cause much erosion on the channel of the Rachels river, invaded by *A. mearnsii*, but not on the Huis river which has indigenous vegetation. It was noted that the Huis river with indigenous vegetation has a small channel while the Rachels river which has the invasive vegetation has a wide and deep channel (Figure 2.8). The cross sectional area of the Rachels river was found to be ten times that of the Huis river (Beyers, 1994).

The recent flood could have played a major role in the channel morphology. It is known that *A. mearnsii* has an effect on the channel stability (Macdonald and Richardson, 1986; Rowntree, 1991) and it was seen by the clear difference in the size of the channels compared in this study (Figure 2.8) that the invasive vegetation on the Rachels river played a major role in the damage caused to the river channel during the flood event. In comparison the Huis river showed no signs of bank instability. After approximately one year the vegetation in the riparian zone had recovered completely and there was no evidence of any damage or large organic debris left on the banks or flood plain (Beyers, 1994).

There are similarities found with a study undertaken on the Mooi River in the north east Cape where *A. mearnsii* has also invaded the riparian zone (Rowntree, 1990). The results of the Mooi river study (Rowntree, 1991) also showed marked differences in channel size for channels with different types of bank vegetation (Figure 2.9). Rowntree (1991) noted that a reach of the Mooi river invaded by *A. mearnsii* had a decreased width-depth ratio, but a larger cross-section compared to that of a grassy reach.



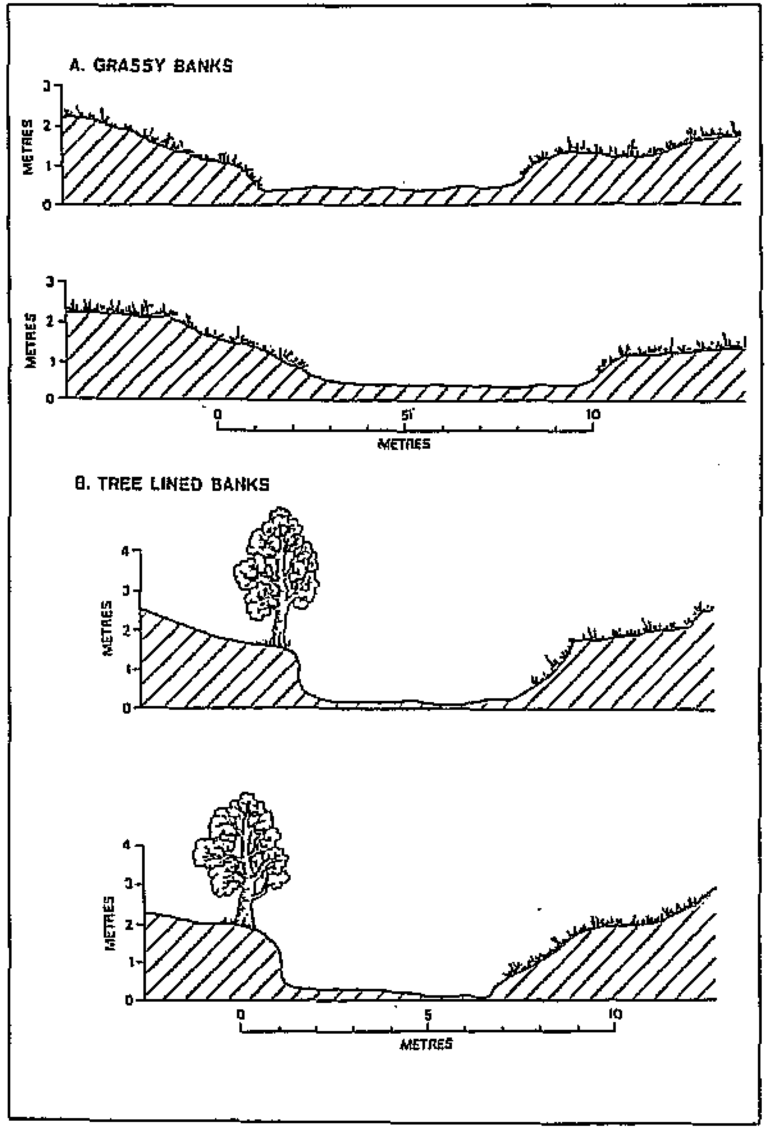


Figure 2.8 The effect of invasion by *Acacia mearnsii* in contrast to grassy banks on channel morphology of the Huis and Rachels rivers (Source: Beyers, 1994)

Figure 2.9 Results of invasion by *Acacia mearnsii* on channel morphology of Mooi River, North east Cape (Source: Rowntree, 1991)

Rowntree (1991) discusses the important distinction between grassy and woody vegetation in terms of their effects on bank stability. It was hypothesised that the tree roots increased the shear strength of the river bank, allowing a steeper cross-section to be maintained (Figure 2.10). Grasses have a low biomass and are shallow rooting whereas trees have a high biomass and are deep rooting. Good grass cover is effective against surface scour, but will have no effect on the stability of deep-seated failures. The high biomass pushing down on the banks with the deep root systems cause the bank to fall away in large blocks (Figure 2.10). This was seen to be true in both the Rachels river and the Mooi river as a direct result of the *A. mearnsii.* On the Rachels river trees were not close to the banks, but rather grew a little distance away. There were, however, small seedlings on the banks, indicating that trees grew on the river bank before the recent floods. At least in the short term these trees would have increased the bank strength and allowed a steeper cross-section to be maintained. The Rachels river did not have a deeper, narrower channel as found in the Mooi River study, rather a considerably wider but also deeper channel (Beyers, 1994).

A. mearnsii trees on the Rachels river banks which were washed away in the flood were still evident in numerous places along the length of the river, in the form of large piles of debris on either side of the river (Beyers, 1994). During the flood these logs formed temporary dams trapping debris and damming up the river. Marston (1982) explains that when water flows over these temporary dams, or log steps as he refers to them, they could increase or decrease the potential energy dissipation with changes in river stage. This means that during a flood event damming of water behind a log step higher up in the river could increase the potential energy of a body of water. When the pressure exceeds the logs holding capacity, the water from an ensuing dam burst will cause bank erosion and bed scour.

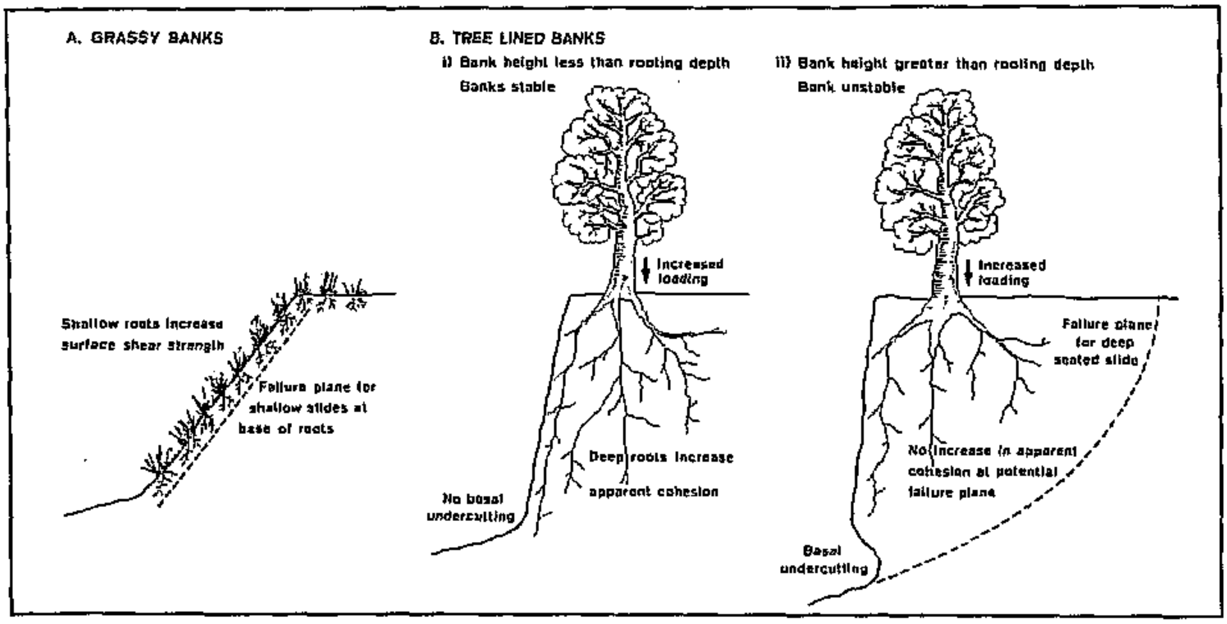


Figure 2.10: The effect of vegetation on bank stability (Source: Rowntree, 1991).

2.3.3 Biodiversity and water quality

Alien woody species are thought to adversely affect the fauna of the Fynbos Biome (Cambray and de Moor, 1995; Belcher, 1996). The variety and composition of the population, visible and/or microscopic, is recognised as a reliable indicator of the biotic health of a stream (Belcher, 1996; Dunne and Leopold,1978b; Macdonald and Richardson, 1986). Dunne and Leopold (1978b) state that a healthy stream usually has a high diversity of organisms and a moderate population of most taxa. Dempster (1991) suggests that insects are extremely sensitive to environmental changes and problems in conservation are often first observed in insects. Biomonitoring is regarded as a valuable method in determining the short term water quality history of a river system in contrast to chemical monitoring, which only portrays conditions at the time of sampling (Belcher, 1996).

In a survey conducted by Cambray and de Moor (1995) to compile an inventory of the fish and aquatic macro invertebrates found in selected invaded and pristine rivers in the Eastern Cape, various recommendations were made. *A. mearnsii* formed a large proportion of the alien vegetation on the invaded rivers in the survey. During the survey, the Rachels river (section 2.3.2) was noted for the damage caused to the system due to *A. mearnsii* growing along and destabilising the banks, resulting in a serious loss of habitat which accounted for the lack of biodiversity reported (Cambray and de Moor, 1995). Specific recommendations were made for individual rivers, but the major concern arising from the survey was the need to remove alien vegetation, or at least control the extent of the invasions to maintain a perennial supply of water. The loss of habitat due to the destabilised banks caused by invasions is a major concern, and needs to be addressed to conserve the already threatened indigenous fish and aquatic invertebrate communities (Cambray and de Moor, 1995).

As part of Cambray and de Moor's (1995) survey, water quality was tested by means of pH and conductivity tests to gain a knowledge of the conditions between pristine and invaded riverine habitats. The conductivity readings for the invaded rivers were considerably higher (175-404uS.cm^{-1}) than those measured in rivers without alien vegetation (54-119uS.cm^{-1}), whereas pH varied between sites due to the poorly buffered Table Mountain sandstone streams in the Eastern Cape. It was concluded that low conductivity readings can be expected in the rivers sampled unless there are disturbances such as invasive alien vegetation.

In a report on an assessment of a catchment water quality monitoring programme, Belcher (1996) agrees with Cambray and de Moor (1995) that the loss of habitat is one of the major problems arising from alien vegetation invading riparian zones. In a summary of the concerns, the reduced flows due to dense forests of alien vegetation, increased bank erosion and reduced habitat status needs further attention to improve aquatic ecosystem health (Belcher, 1996).

CHAPTER 3
METHODOLOGY AND RESEARCH DESIGN

3.1 Introduction: Experimental Design and Study Area

The ZRWRMP Task Group on the Control of Invader Plant Species secured funding for an experimental study to monitor the effect on streamflow of removing *A. mearnsii* from the riparian zone, for the duration of one year. In collaboration with researchers from Rhodes University, members of the task group identified a site on a section of the Sand River (section 1.5) where a suitable experiment could be laid out. After further investigation of the catchment by the present researcher, the site was confirmed as a suitable location for various reasons. First, the site allowed for the establishment of two sections of similar morphology and vegetation density, thus satisfying the needs of the experimental design. There were also a number of practical factors which favoured the site. The proximity of the dam wall above the site allowed the control of streamflow through the system to protect the weirs in case of floods and to augment flow during dry periods. Staff of Port Elizabeth Municipality based at the Sand River Dam could assist for the duration of the experiment and the nearby road allowed accessibility to the site for the removal of the trees, construction of weirs, and monitoring of streamflow for the duration of the study.

Previous studies of the effect of riparian vegetation on streamflow used either paired catchments (section 2.2.2) or two temporary weirs on a section of river over a short period of time (section 2.2.3). To facilitate a longer term study to compare seasonality of streamflow response to the removal of riparian vegetation, three permanent weirs were constructed. The construction and layout of the weirs will be discussed in greater detail in section 3.5.

A detailed map of the site was constructed from a survey of the area and information taken from aerial photographs and 1:50 000 topographical maps (Figure 3.1). The northern bank of the river was steep hillslope, invaded by *A. mearnsii* (Figure 3.1). The riparian zone as such was limited to a half hectare section 100 m downstream of weir 1. The riparian zone to the south of the river covered an area of 5 hectares, forming a strip of approximately 50 m in width. Here land invaded by *A. mearnsii* formed 90 % of the total riparian zone in the study area. The area was divided into two sections each 500 m in length, one of which was to be cleared, the other to be left as a control section. Three weirs were constructed approximately 500m apart from each other (Figure 3.1). This allowed the comparison of two adjacent sections with similar catchment conditions, channel morphology and initial vegetation densities. The area of each section south of the river was calculated from measurements during the site survey and topographical maps. The areas of both the cleared and uncleared section were found to be approximately 2.5ha.

The trees in the northern riparian zone were observed and briefly sampled to confirm no marked differences in density between the two sections. More intensive sampling of the riparian zone on the southern bank was undertaken as described in section 3.2.

The initial aim of the experiment was to monitor the effect of clearing the riparian vegetation during the time presumed to have the highest moisture stress, that is during the summer months of January and February. Streamflow was to be monitored for a short period before clearing to establish the baseline conditions, monitoring was to continue during clearing and for some time afterwards. Actual events proved somewhat different; high floods during the clearing period meant that the monitoring was discontinued for ten days, but was continued for several months through the dry winter season so as to evaluate seasonal differences in water use.

Previous studies (e.g. Dye and Poulter, 1995b) were timed so as to avoid the summer rainfall season. This as not possible in the Sand River experiment as rainfall can be expected throughout the year (Figure 4.2).

Flow monitoring started once the weirs were in place on January 10th 1996. Clearing of *A. mearnsii* was initiated on January 22nd. Clearing was confined to the more accessible land lying on the south bank of the river, where a 2.5 ha strip was cleared between the two upstream weirs (weirs 1 and 2). Plates 1 and 2 show the channel before clearing took place, Plate 3 shows the riparian zone one day after the felling of the trees was completed, and Plate 4 and 5 a few months later once the branches had been stacked into piles and had dried. Plate 6 shows the river bed condition some time after clearing.

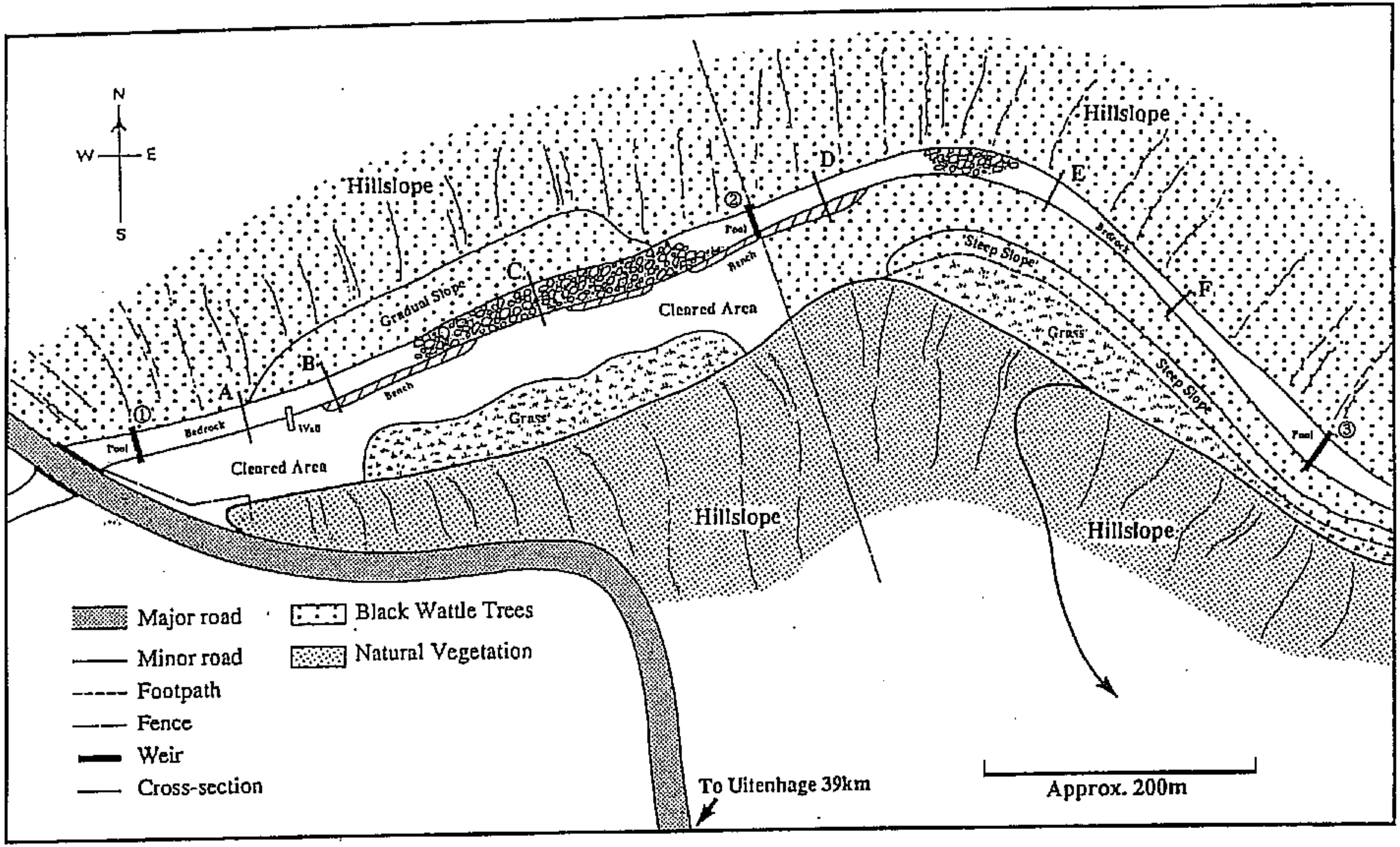


Figure 3.1 Layout of the study site

The presence of the Sand River dam upstream of the study reach enabled water releases to be made during dry periods so as to ensure a continuous input of water into the study reach through the monitoring period. A major release was made at the end of March until the middle of July to compensate for very low flows in the stream at this period.

The following sections describe the methods used to collect and analyse the data.

3.2 Vegetation Survey

Le Maitre *et al.* (1996) were able to show a relationship between above ground biomass and reduced streamflow (Figure 2.3), but *A. mearnsii* was not included in these calculations due to the lack of data. In order to understand the relationship between the amount of biomass removed from the riparian zone and the subsequent effect on streamflow the homogenous stand of *A. mearnsii* in the riparian zone was sampled. Brower *et al.* (1990) state that plot or quadrat methods of sampling are often labourious and time consuming, and the results are dependant on size, shape, and number of plots used. Smith (1990) agrees with Brower *et al.* (1990) and suggests a plotless sampling technique, point quarter sampling, for sampling homogenous stands of trees. This method was adopted in the present study.

The trees in the two sections south of the river (Figure 3.1) were divided into five different classes according to their diameter at breast height (DBH) (Table 4.1). Points were selected randomly within the stands where each point represented the centre of four compass directions (N, S, E, W), which divided the sampling site into four quarters. In each quarter the distance was measured from the centre point to the centre of the nearest tree. One tree per quarter was measured so that data for a total of four trees were recorded for each point sampled. The raw data are tabled in Appendix 1.

The point to plant distances and stand area were used to calculate the total density of trees and density of each size class (Table 4.1) for both sections of the riparian zone south of the river. To calculate the total density of trees in each section, the mean point-to-plant distance was squared and divided into the total unit area of 25 000 m^2 (2.5ha).

The relative density of each size class was calculated by dividing the total number of trees in all DBH classes into the number of trees for each individual DBH class. The density of each DBH class was then calculated by multiplying by the total density of all species (Smith, 1990). The densities of each of the size classes in the cleared and uncleared section of the riparian zone are shown in Table 4.1.

When the trees were felled between January 22nd and 26th, samples in the different size classes were weighed (Appendix 2). Larger trees were cut into manageable sizes and then weighed using a spring scale. The average weight of each class was multiplied by their respective densities to obtain a total above-ground wet biomass value of trees removed in the cleared and uncleared section of the study site. The relationship between the above-ground wet biomass and the DBH of each size class is shown in Figure 4.1.

3.3 Channel Cross Section Surveys and Flood Plain Characteristics

Three representative cross-sections of the channel were surveyed in both the cleared section and uncleared section. These sections, presented in Figure 3.2, provided a physical description of the channel and the immediate riparian zone and would be used also in the event of a flood to compare channel shape before and after the event.

The cross sections were surveyed by stretching a tape measure across the width of the channel and taking depth readings using a surveying pole at half metre intervals or at closer intervals when there were smaller features to be taken into account (Appendix 3).

The sediment characteristics of the bed and channel banks were also noted. The alluvial sediments which made up the banks and the flood plain were comprised of cobbles within a sandy matrix. The coarse nature of the sediments made it difficult to use an auger so instead the nature of the flood plain deposits was inferred from the sediments exposed in the banks. The alluvium and bedrock depths shown on Figure 3.2 are estimates based on an extrapolation from the surface observations. Water levels were taken at the time of the survey in January 1996.

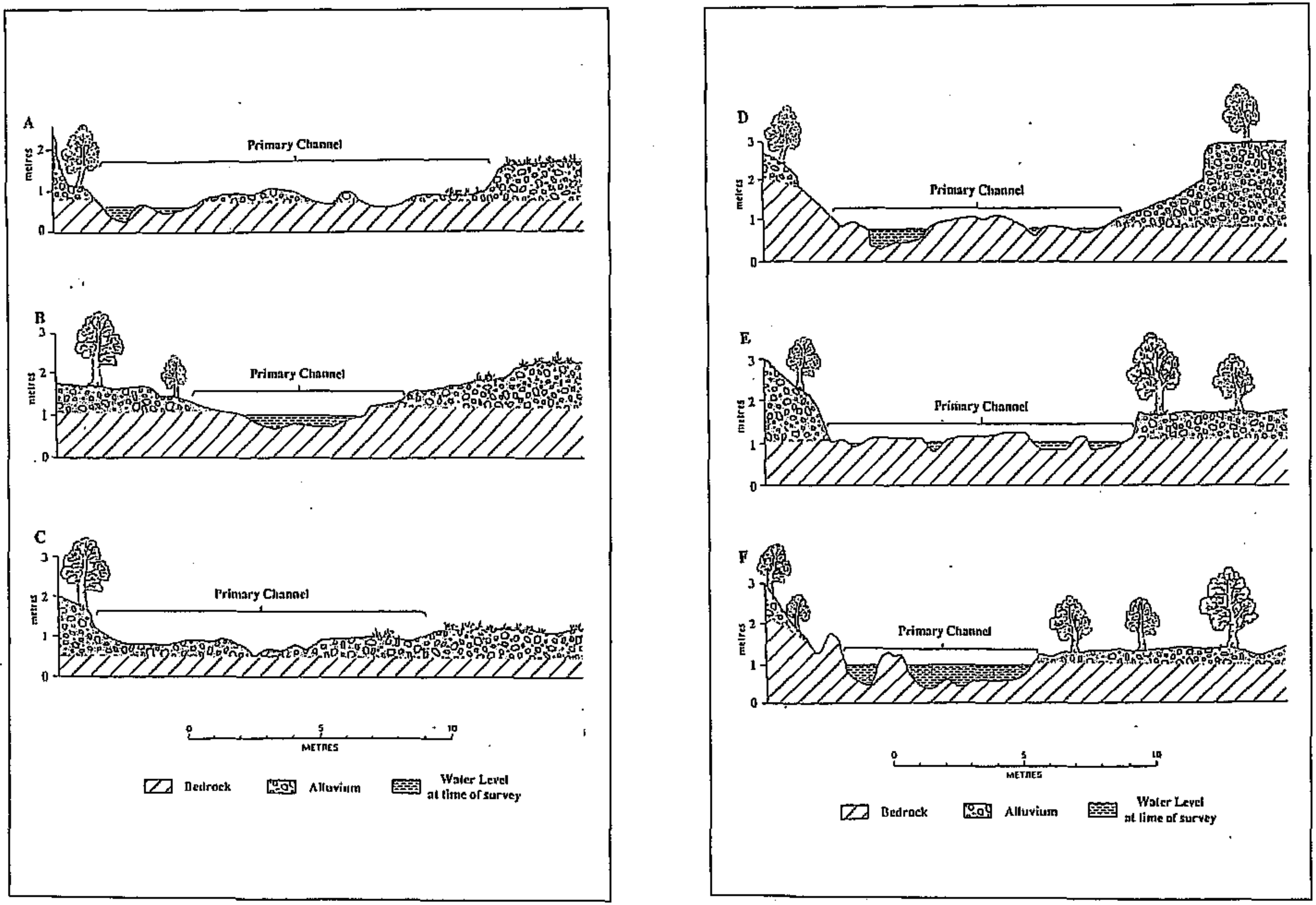


Figure 3.2 Channel cross-section surveys: A-C cleared section, D-F uncleared section

3.4 Climatic Data and Weather Conditions

Bosch and Hewlett (1982), in their review of 94 catchment experiments worldwide, state that weather condition is the most important factor governing the magnitude of streamflow responses to vegetation change. In order to relate streamflow response to weather conditions, rainfall and evaporation data for the area were analysed.

Rainfall has been measured at the Sand River Dam since 1908 (Appendix 4). Mean monthly rainfall was compared to actual monthly rainfall to contextualise the rainfall for the duration of the monitoring period (Figure 4.2). Rainfall was analysed for 3 months prior to the experiment to include conditions leading up to the period of monitoring (Figure 4.2). The conditions observed during the monitoring period and the long term conditions are compared in Figure 4.2.

There was no evaporation pan at the site, but data was available from Groendal Dam (33° 42' S 25° 1' E) and Loerie Dam (33° 51'S 25° 02' E) in the catchments to the north-east and south-western respectively. The Department of Water Affairs and Forestry (Pretoria) supplied daily and monthly potential open water evaporation data, measured at the respective dams (Appendix 5). The monthly evaporation rates are compared to the long term mean monthly evaporation for the past 20 years in Figure 4.3.

The combined daily evaporation measured at Groendal and Loerie Dams and daily rainfall measured at the Sand River Dam are presented in a time series graph (Figure 4.4).

3.5 Soil Moisture Monitoring

Soil and ground water are vital components in the relationship between streamflow and vegetation changes. Although Dye *et al.* (1994) explained that it is technically difficult to use rates of soil water depletion as an indirect measure of water use by plants, the authors concluded that an understanding of soil water movement should be considered when assessing the long term hydrological effects of land use changes. In agreement with the above authors it would have been preferable to monitor ground water levels for the duration of the experiment.

A month prior to the monitoring period attempts were made with various different size augers to set up access tubing for use with a neutron probe. Unfortunately the alluvium in the riparian zone was too coarse and drilling would have been necessary to install the tubes. Even if there was sufficient funding for drilling there was insufficient time to allow the ground surrounding the access tubes to stabilise before readings would have to be taken.

As an alternative, surface soil samples were taken from the cleared section (site 1) and the uncleared section (site 2) on a number of occasions before and after clearing. The sites in each of the sections were chosen before the clearing of the trees in order to find two areas of similar characteristics. Due to the destructive nature of removing surface soil, three soil samples on the various days were removed from a plot of approximately 20m by 20m. The samples were taken from the respective sites on the various days of sampling, sealed and taken back to the laboratory for further analysis. The wet samples were weighed and then placed in an oven for 2 weeks to dry before re-weighing the samples. The difference in weight between the wet and dry samples was converted into a percentage moisture content of the original sample (Table 4.2). The trend in percentage moisture content before and after clearing is shown in Figure 4.5. The response to rainfall in the two areas can be seen from this graph.

3.6 Measurement of Streamflow

Three weirs were used in the study to allow for a comparison between a cleared and uncleared section of the riparian zone (Plates 7 to 14). Following the survey of the study site, the locations for the construction of three permanent weirs were established 500m apart from each other (Figure 3.1). The Department of Water Affairs and Forestry (Cradock) designed and supervised the construction of the weirs, after obtaining permission from the relevant land owners to utilise their properties (Appendix 7). All three weirs had the same design except for the length of the weir wall across the river channel. Full design details are given in Appendix 6. A 90° v-notch weir was mounted in front of a settling pool with a small stage plate for manual readings and wire mesh to stop debris from blocking the notch and interfering with the flow of water (Plates 10 to 12). An ODS pressure probe was placed behind the v-notch in the settling pond; this measured the 'stage' or height of the flow as a function of depth. Ott:Log data loggers recording values from the probe were placed in secure boxes close to the river bank (Plate 13).

The data loggers recorded the flow stage at 12 minute intervals for most of the duration of the study between the 10th of January and the 8th of September. At regular intervals throughout the monitoring period manual readings from the stage plates were compared to the data logger readings to check their accuracy. A flood event on the 26th January necessitated the removal of the data loggers for a ten-day period (Plate 14).

During the clearing period the weirs were checked for blockages at regular intervals during the day, thereafter they were checked on daily basis either by Port Elizabethg Municiplaity staff of by the researcher. No blockages were observed during the monitoring period.

Data was received in ASCII text format (Appendix 7) and converted into spreadsheets (Appendix 8). Due to the large data set (83 520 values), a combination of Quattro Pro and Sigma Plot spreadsheet packages were used to convert raw data to a format facilitating further analysis. The ASCII text values from the data loggers were measurements of streamflow stage height flowing through the v-notch at the individual weirs. Streamflow stage heights were converted into discharge using the following equation (Dunne and Leopold, 1978a):

$$Q = 1.35.h^{2.5} \qquad \text{Equation 3.1}$$

where Q is the discharge measured in litres per second and h is the streamflow stage height measured by the pressure probe and recorded by the data loggers. The 12 minute discharge values were used to calculate mean daily flows at each weir. These daily flows formed the basis of the bulk of the ensuing analysis (Appendix 9). The time series graph of daily flows as measured at each weir is presented in Figure 4.6.

3.7 Estimation of Water Use

The effect of *A. mearnsii* on water consumption was found by comparing the net gain or loss to the streamflow between the two pairs of weirs. The streamflow increment between weirs 1 and 2 (A) could be attributed to seepage of water from the banks in the absence of *A. mearnsii*. A reduced increment, or even a reduction in flow, was observed between weirs 2 and 3 (B) which was attributed to the presence of *A. mearnsii*. The net effect of the *A. mearnsii* was estimated as the difference between the water released between the two pairs of weirs (A - B).

The above exercise was carried out for daily flows. This assumed steady state flow conditions, with the upstream and downstream sites being in equilibrium. During and shortly after storm events this would no longer be the case so that errors were introduced into the calculations. In some cases these are manifested as negative daily water use values for the lower sections. If the results are averaged over a longer time period, these errors become negligible.

Towards the end of March a prolonged dry period reduced flows to the extent that flow ceased over one or more of the weirs, the most downstream weir being affected first. Under these circumstances it was not possibly to estimate water use, so the streamflow was augmented by a release from the Sand River Dam in early April. As can be seen from Figure 4.6 , this resulted in an initial plug of water moving down the channel, creating unsteady flow conditions. Due to the dry antecedent conditions much of this water would have gone to filling channel storage as well as to bank storage. The system appeared to have stabilised after about ten days. The period of 16th March to 14th April was excluded from the analysis of water use.

The average daily water uptake by the *A. mearnsii* was calculated from the available data for each month after clearing took place. Water use values as a volume in cubic metres are compared to the monthly rainfall and pan evaporation in Figure 4.7 and Table 4.3. The relationship between water use, rainfall and pan evaporation rates were investigated further. A daily water budget was calculated based on the difference between daily evaporation and rainfall. This gave evaporative demand in millimetres. The water use values were converted to millimetres by dividing the daily volume by 25 ha, the riparian area vegetated by *A. mearnsii*. This therefore gives the average water use as a depth over the riparian area.

Water use values were compared to the daily evaporative demand using a number of different time periods: daily values, the average values over the last five days and the average values over the last ten days. This was to take account both of errors due to unsteady flow conditions noted above and the effect that antecedent rainfall and evaporation have on the soil moisture budget. The cumulative water use is plotted against cumulative evaporative demand in Figure 4.8. This graph shows the long term trend in water use. The short term relationships, based on daily, 5-day and 10-day averages are given in Figure 4.9a-c.

Dye and Poulter (1995b) observed daily fluctuations in streamflow, and related decreases in streamflow to evaporative demand of the air which increases towards midday (section 2.2.3). In order to observe the effect of evaporative demand on daily fluctuations in streamflow, three separate periods of three consecutive days were chosen to represent periods with no rainfall in January (before clearing), February (after clearing) and June (driest month of the year) (Figure 4.10a-c).

3.8 Additional Effects of Clearing *Acacia Mearnsii*

3.8.1. Water quality

Conductivity can be used as a basic measure of water quality (Dallas and Day, 1993; DWAF, 1996; Kempster *et al.*, 1982) and was successfully used by Cambray and de Moor (1995) to show the difference in water quality between rivers with riparian zones invaded and those clear of *A. mearnsii* in the Eastern Cape (section 2.3.2). Using a HANNA H18424 Digital Data Systems 200 conductivity metre with a Russell electrode, conductivity readings were taken in the settling pools behind the v-notch of each weir. The conductivity metre was standardised using a conductivity standard solution of 141.3mS/m before each reading was taken. Readings were taken before and after clearing to ascertain the possible need for further tests, if water quality was poor, and to monitor any changes over the duration of the experiment (Table 4.4).

3.8.2 Channel survey

Researchers agree that alien woody species in the riparian zone adversely affect the channel morphology of a river (section 2.3.2). With a view to monitoring the effect of bank clearance on channel stability, three representative cross-sections of the channel in the cleared section and three in the uncleared section were surveyed (see section 3.3). Field data collection was based on the establishment of representative cross-sections of the study site and would be used in the event of a flood to compare channel shape before and after the event. There were in fact no significant flood events apart from that which occurred in January during the clearing period itself. No erosive effects were observed. The surveyed cross sections provide a reference against which future changes can be measured.

3.8.3 Rehabilitation and restoration

As part of the research a workshop on 'The Environmental Impact of Alien Tree Eradication Along River Courses and its Rehabilitation' was arranged by Eastern Cape Nature Conservation. A detailed report outlining clearing techniques, rehabilitation and restoration is forthcoming. For the purposes of the present study, a localised rehabilitation and restoration programme was initiated at the study site.

The vegetation growing below *A. mearnsii* trees is out-competed during the invasion process (section 2.1), making it necessary to try to stabilise the soil once all trees have been cleared. Six different species of lime coated grass seed (Appendix 10) were sown in the cleared section of the study site on March 16th. The lime coating ensures a higher rate of germination by controlling the timing of germination until there is sufficient available water to penetrate the coating. The types of grasses were chosen for various characteristics such as palatability, erosion control and resistance to drought conditions. In addition, to prevent erosion of newly exposed soil, the purpose of the grass cover was to overshadow the wattle seedlings to prevent their reestablishment. The establishment of the grass species was monitored over a period of seven months since the day of sowing on March 16th, 1996.

Plate 1. The river bed downstream of weir 1 prior to clearing

Plate 2. The river bed downstream of weir 2 prior to clearing.

Plate 3. The study site immediately after clearing

Plate 4. The study site five months after clearing. Debris has been stacked into piles.

Plate 5. Brushwood stacked up on the flood plain

Plate 6. The river bed condition following clearing.

Plate 7. Weir 1

Plate 8. Weir 2

Plate 9. Weir 3

Plate 10. Flow at weir 1 on 10th January

Plate 11. Flow at weir 2 on 10th January

Plate 12. Flow at weir 3 on 10th January

Plate 13. Weir 2 showing data logger in box.

CAPTION EDITED

Plate 14. Weir 1 drowned out at high flow. Data logger has been removed from the box for safety.

CHAPTER 4
RESULTS

4.1 Vegetation and Site Survey

The results of sampling the stands of *Acacia mearnsii* within the cleared and uncleared sections are presented in Table 4.1. The total number of trees in the cleared section amounted to 11263 and the uncleared section 10209, a difference of 1054 trees, 77% of which was accounted for by trees with a diameter at breast height (DBH) of less than 5cm. In both sections the mean DBH of the trees is between 2.5 - 5cm. Although small trees obviously consume water, their effect on streamflow will be considerably less than larger trees, which make up a much larger proportion of the total above ground biomass (Table 4.1). It can be concluded that both sections having similar tree densities and above-ground wet biomass.

Table 4.1: Number of *Acacia mearnsii* and above-ground wet biomass by size class in the cleared and uncleared sections (area = 2.5ha for both sections).

Size Class (DBH) (cm)	0 - 2.5c	2.5 - 5	5 - 10	10 - 15	15 - 20	Total
cleared	3 970	3 309	2 562	1 239	183	11 263
uncleared	3 307	3 165	2 539	1 198	208	10 209
average weight per tree (kg)	3.8	11.45	43.16	157.26	267.2	
total weight cleared section (tonnes)	15.1	37.9	110.6	194.8	48.9	162.9 (tonnes per ha)
total weight uncleared section (tonnes)	12.6	36.2	109.6	188.4	55.6	160.9 (tonnes per ha)
Average weight (tonnes)						162 (tonnes per ha)

The number of trees in each size class in the sections was multiplied by the average weight of the corresponding size class and summed to obtain an approximate above ground wet biomass estimate of 162 tonnes per hectare in both the cleared and uncleared sections. A clear relationship between the above ground wet biomass and DBH of the individually weighed samples is shown in Figure 4.1.

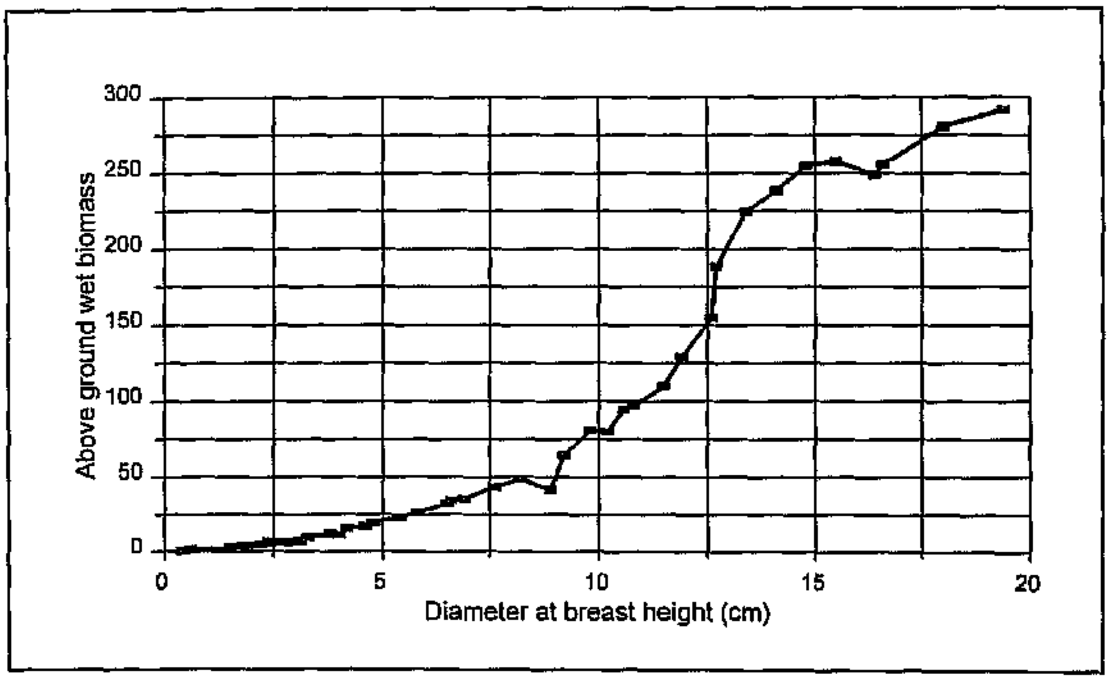


Figure 4.1: Relationship between above ground wet biomass and DBH

4.2 Climatic Data and Weather Conditions

The monthly rainfall was compared to the long term mean monthly rainfall for the duration of the experiment (Figure 4.2). In the two months prior to monitoring, rainfall exceeded the long term mean values recorded for those months. In November there was 75mm of rain compared to the mean of 63.84mm and in December, an extremely wet month, 106mm of rain was recorded compared to the mean of 43.58mm. From February onwards the rainfall was considerably below average. It can be assumed that the wet months prior to streamflow monitoring recharged the alluvium in the riparian zone. In contrast the low rainfall figures for the rest of the study period would have been insufficient to recharge the alluvium at least until July.

Figure 4.3 compares the monthly pan evaporation during the monitoring period to the long term mean monthly evaporation. Throughout the year there is relatively little difference between the two figures. Differences in part reflect the deviations in monthly rainfall. Evaporation for the region is unimodal with high potential evaporation in the summer months and lower potential evaporation rates in the winter months (Figure 4.3).

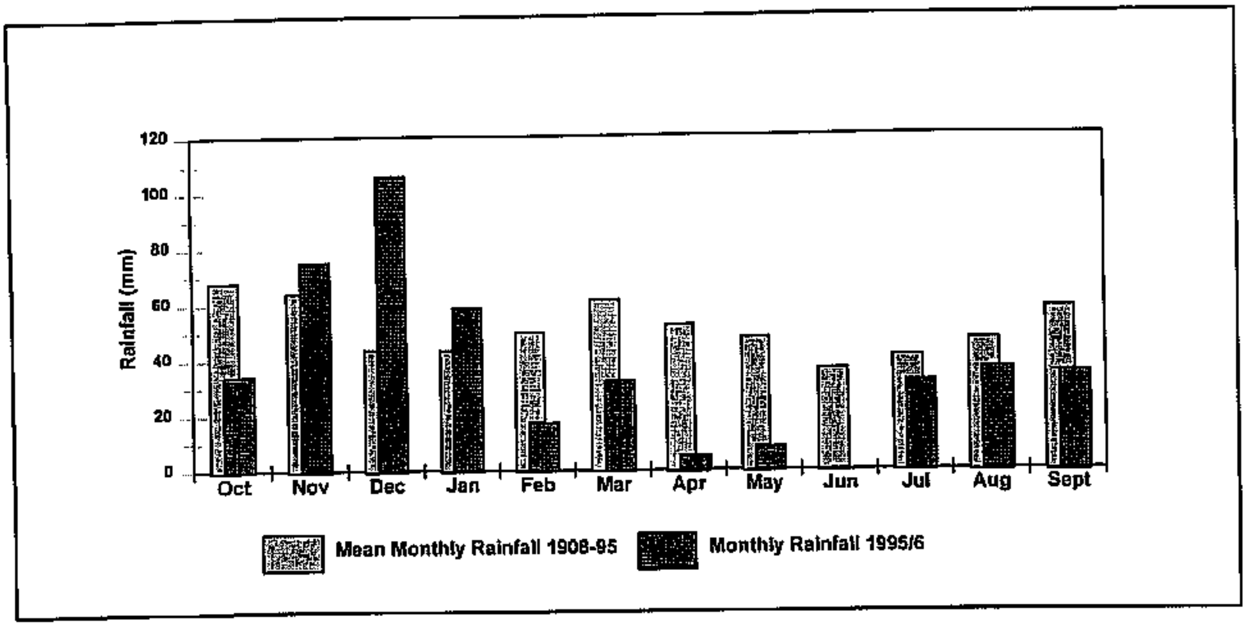


Figure 4.2 Rainfall trends

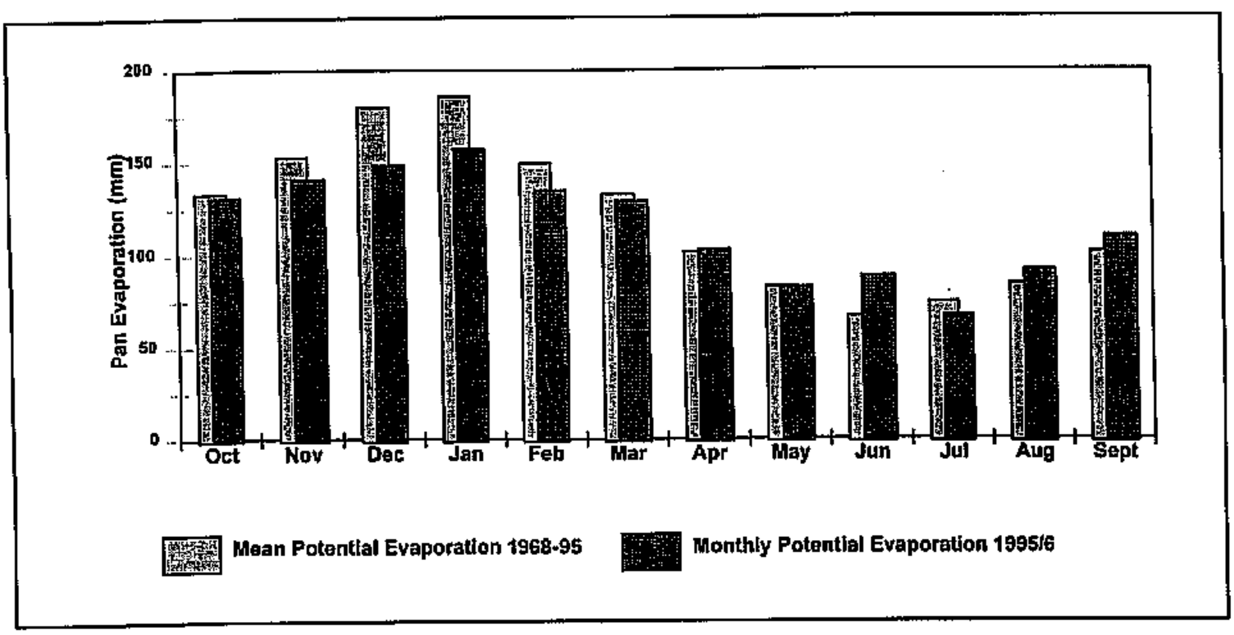


Figure 4.3 Evaporation trends

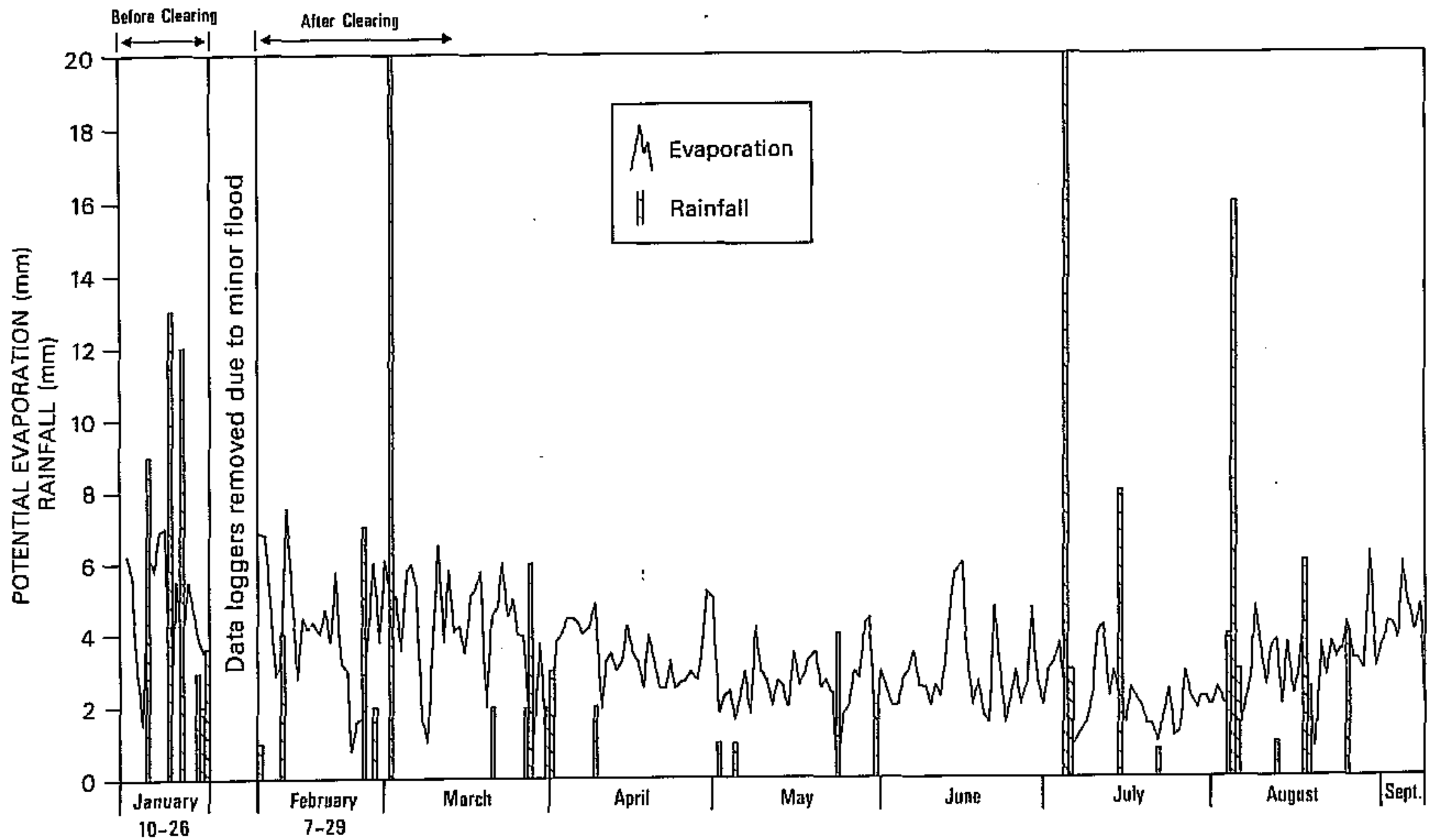


Figure 4.4 Time series graphs of rainfall and pan evaporation

A time series of daily rainfall and pan evaporation is presented in Figure 4.4. Daily potential evaporation fluctuated during the monitoring months between 8mm on the 5th of January and 0.1mm on the 24th of May around a mean for the duration of the monitoring period of approximately 2mm a day. The highest recorded rainfall events occurred on the 2nd of March and 20th of July (both 20 mm). Rainfall is expected all year around in this area, but during 1996 there were relatively few rainfall events over the winter months with no rainfall in June.

4.3 Soil Moisture

Surface soil moisture values for the days on which sampling took place can be seen from Table 4.3 and Figure 4.5. It can be seen that the uncleared site (Site 2) had generally higher values throughout the study period, probably due to localised differences between sites reflecting the surface topography or soil texture. After clearing, site 1 showed a more marked immediate response to rainfall events, and maintained relatively high moisture values compared to those early on in the experiment. This may reflect the lower interception loss in the cleared site, as well as a possible reduction of soil moisture use. To strengthen these tentative conclusions it would have been necessary to undertake an extensive survey of soil moisture in both time and space; even then only the top soil could have been sampled effectively due to the high percentage of cobbles in the lower horizons. It was not thought that the time and expense involved in such an exercise would have been justified.

Table 4.2 Surface soil moisture readings in the cleared and uncleared areas

Date	Soil moisture (percentage by weight)				
Before clearing			Site 1 cleared		
	Site 1	Site 2		Site 1	Site 2
Jan 9	5.0	5.1	Feb 6	4.9	9.7
12	4.2	4.7	7	5.1	10.5
15	10.9	17.8	8	6.1	10.1
18	9.5	14.8	Mar 4	6.6	9.4
21	5.0	12.6	5	7.0	8.9
24	6.0	10.9	April 2	6.3	10.4
			Sept 23	10.9	8.3
			24	8.7	9.5
Mean	6.8	11.0	Mean	6.95	9.6

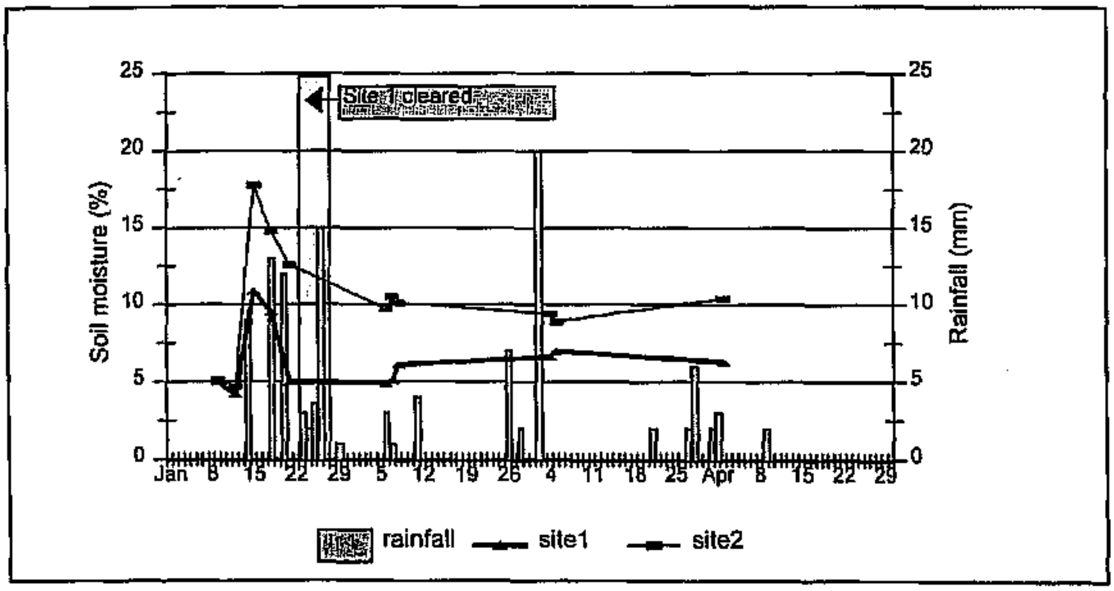


Figure 4.5 Soil moisture trends in the cleared (site 1) and uncleared (site 2) areas

4.4 Streamflow Measurements

Results are given for the analysis of streamflow for the monitoring period between the 10th of January and the 8th of September in Figures 4.6 to 4.10.

The long term trends in daily streamflow can be seen from Figure 4.6. At the start of the monitoring period in January flows were high following the heavy rainfall over the early summer period. The shape of the hydrographs indicates a general recession from high flows in late December and early January. As noted previously (Figure 4.2), December was especially wet. Despite three reasonably heavy storms during January, the general flow levels continued to decline in line with normal recession curves.

During the period prior to clearing, flow on all days increased steadily in the downstream direction, indicating augmentation from groundwater storage in the flood plain. By comparing the flow over the three weirs, the increase between weir 1 and weir 2 amounted to 640 m^3 while that for the lower section between weir 2 and weir 3 amounted to 1586 m^3. This is equivalent to 53 m^3 and 132 m^3 per day. The increased flow from the downstream section may indicate a higher flood plain storage capacity, or the augmentation of storage by lateral inflows, for example from minor seasonal tributaries.

After clearing took place, flow declined further. The rate of recession was now greatest for the uncleared, lower section so that flows decreased below those at the middle weir. This indicated that although flow augmentation from the flood plain continued in the upper cleared section, water uptake in the lower section became the dominant process. Sharp peaks were observed at weir 1 in response to rainfall. This can be interpreted as localised runoff from the road above the weir. More subdued peaks in response to rainfall events were observed at the downstream weirs. This pattern continued through the winter season. The marked increase in April due to the dam release should be noted. This must have been high enough to recharge the banks significantly as downstream flow increases between weir 1 and 2 continued through the dry months of May and June.

As explained in section 3.6, water use by *A. mearnsii* in the lower reach was estimated from a comparison of changes in flow volume between the three weirs. The results are given in Table

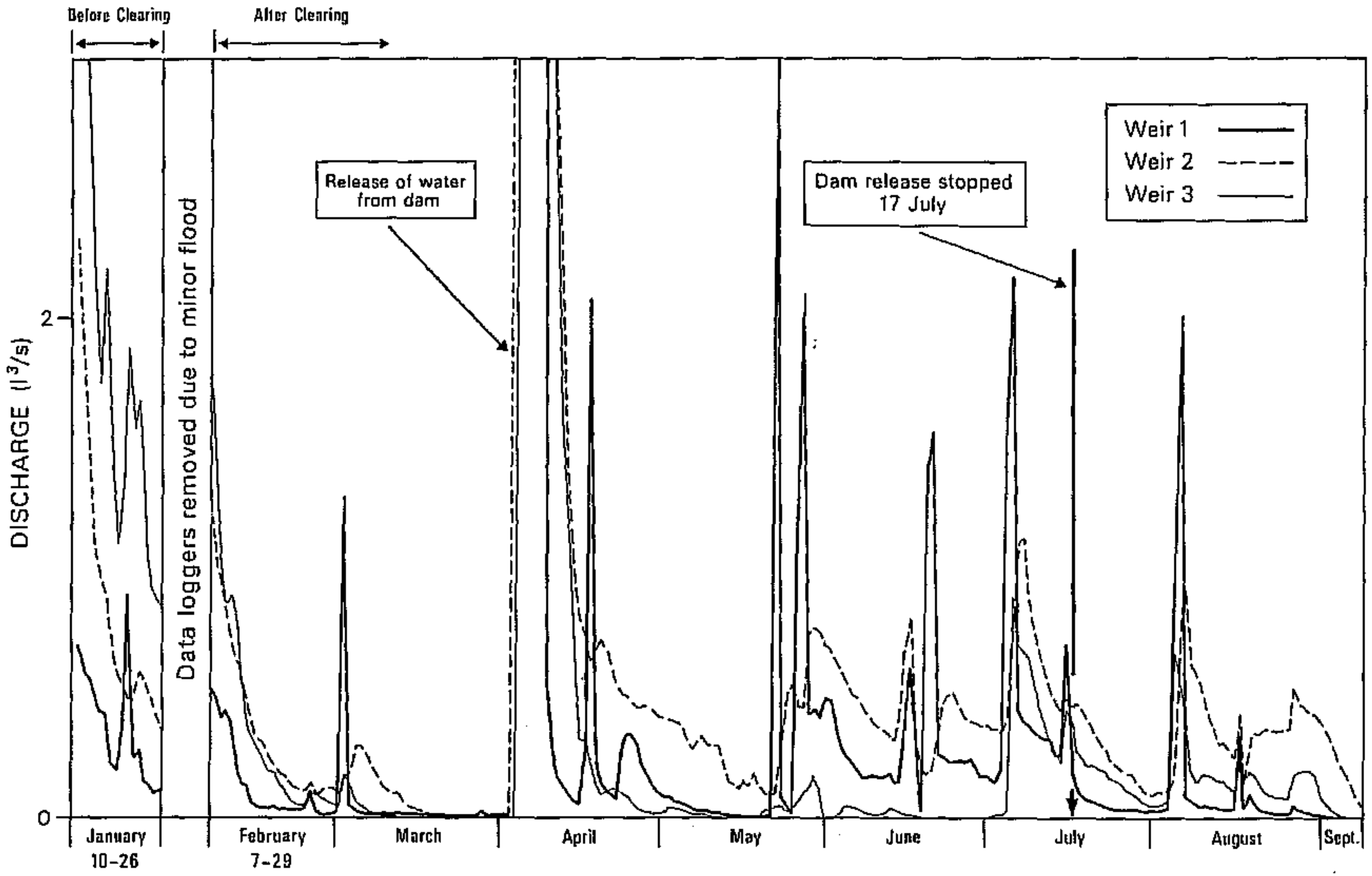


Figure 4.6 Long term trends in streamflow as recorded at the three weirs.

4.3 and presented graphically in Figure 4.7. It must be remembered that the period immediately prior to and following the dam release in April was excluded from the analysis because of the unsteady flow conditions and the significant loss of water to bank and bed recharge.

Estimates presented in Table 4.3 indicate that clearing *A. mearnsii* from the riparian zone of a 500 m length of stream channel leads to an average increase in daily flows of 34 m^3. This is equivalent to 4964 m^3 per ha per year or a runoff increase of 496 mm.

Table 4.3 Estimated water use by *Acacia mearnsii*

Month	Number of days included in analysis	Uptake (m^3)	Daily water use (m^3)
February	23	449	20
March	15	234	16
April	17	1005	59
May	31	919	30
June	30	1431	48
July	31	859	28
August	31	1147	37
September	9	301	33
Mean daily water use (m^3)			34
Mean annual water use (m^3/ha)			4964
Mean annual water use (mm)			496

Mean daily water use ranges from low values of 20 m^3 and 16 m^3 in February and March to a high of 59 m^3 in April. Through most of the winter months it varied between 28 m^3 to 48 m^3. As can be seen from Figure 4.7, this water use is not directly related to pan evaporation rates. In February and March pan evaporation is high but water use low. Evapotranspiration may have been partly compensated by high soil moisture levels. The high water use in April occurred at a time when pan evaporation was moderately high and rainfall was low. Relatively high water use was maintained through the winter period despite the lower evaporation potential. The increase evident for June coincides with a somewhat higher evaporation potential. In August and September the evaporation potential increased, but higher rainfall may have moderated water use.

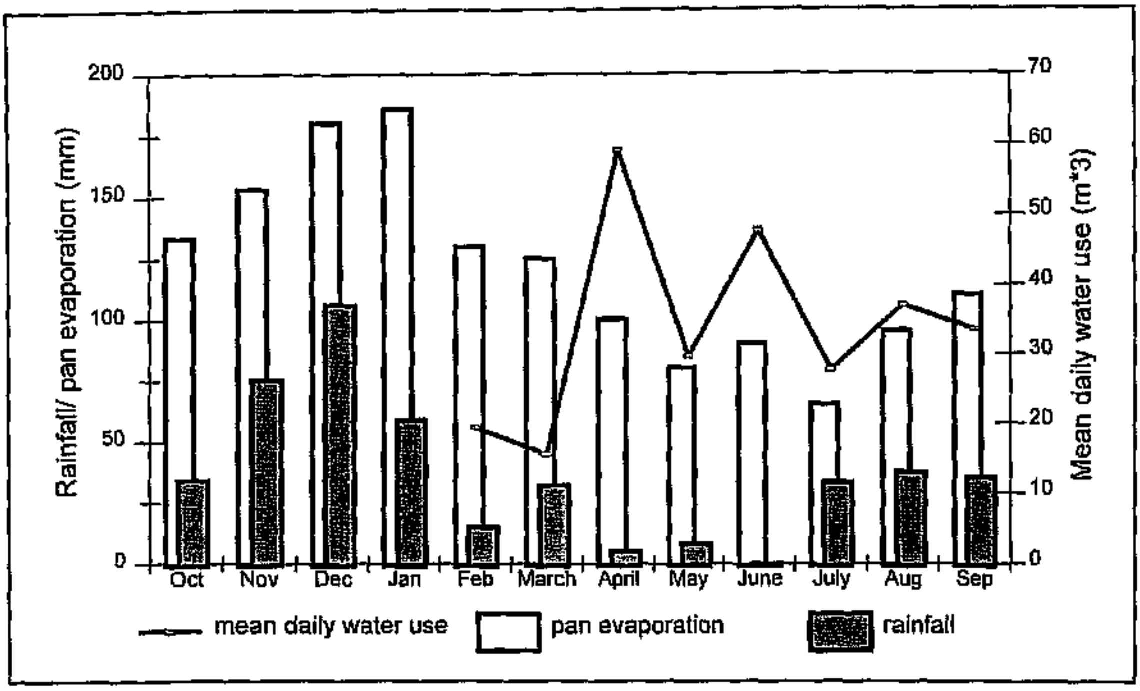


Figure 4.7 Monthly variations in mean daily water use in relation to monthly rainfall and pan evaporation

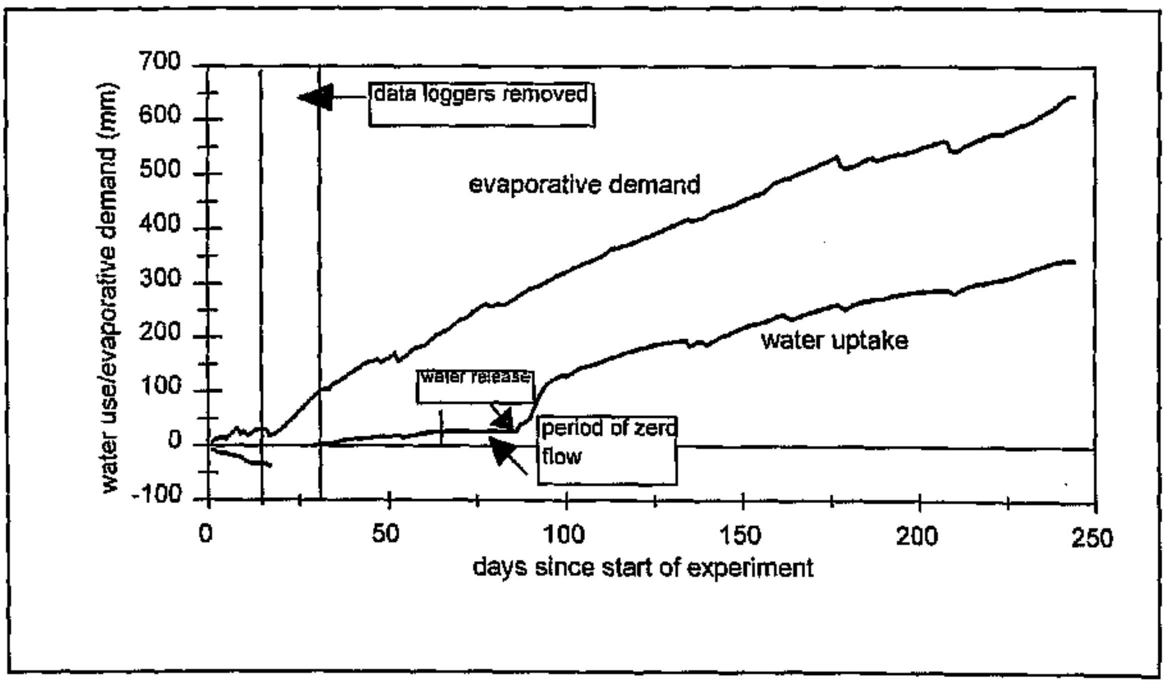


Figure 4.8 Relationship of cumulative water use to cumulative evaporative demand

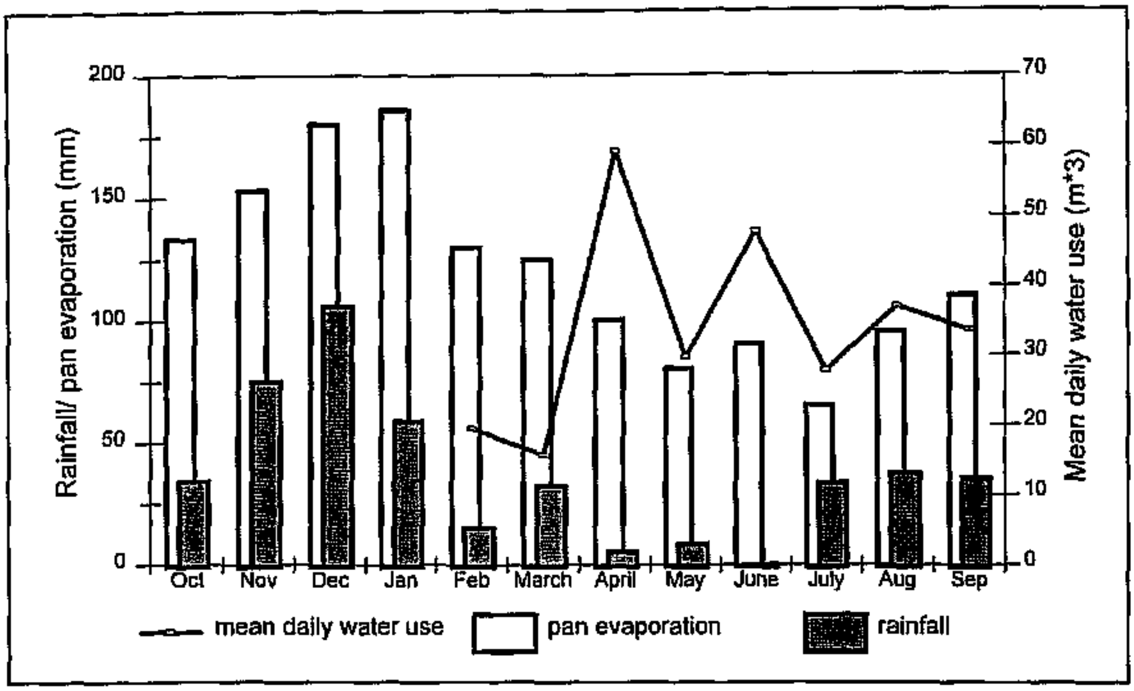


Figure 4.7 Monthly variations in mean daily water use in relation to monthly rainfall and pan evaporation

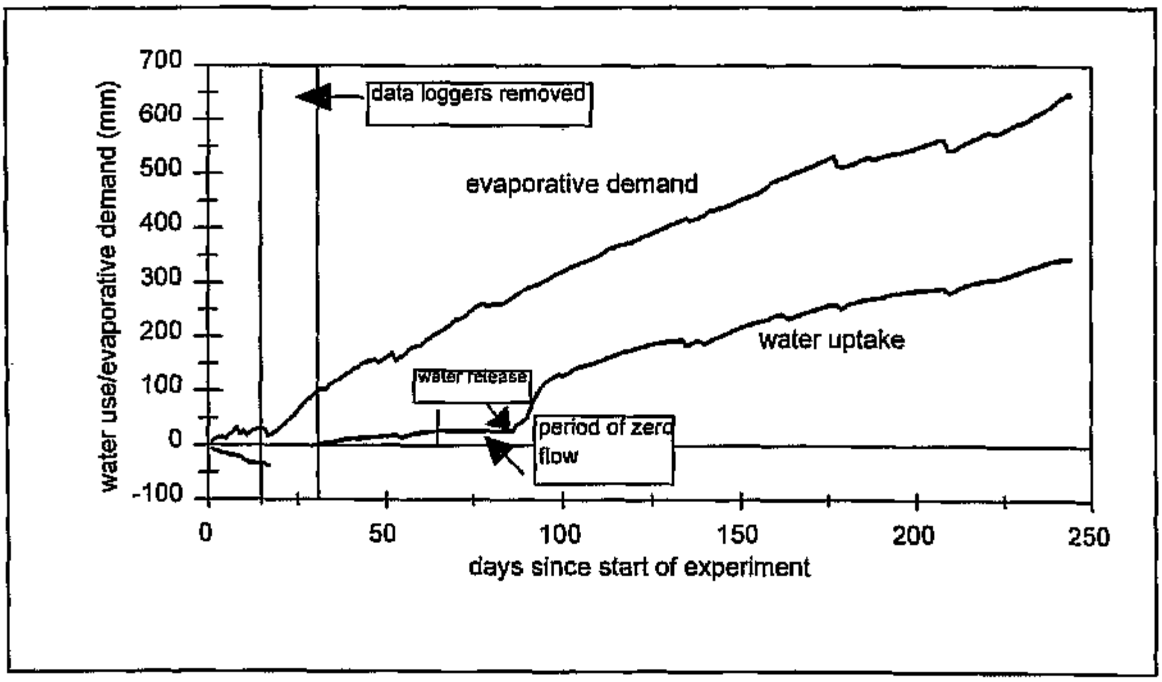


Figure 4.8 Relationship of cumulative water use to cumulative evaporative demand

These results indicate that the maximum net water use by *A. mearnsii* takes place in the driest months, irrespective of the evaporation potential. No data were available for the months with the highest evaporation potential, October to January.

Figure 4.8 shows the cumulative water use against evaporative demand, where evaporative demand is based on the difference between the daily rainfall and pan evaporation. Immediately after clearing until the dam release in April, i.e. during the summer period, estimated water use was significantly lower than the evaporative demand as shown by the low slope of the curve. The regression coefficient for the water use curve is only 0.65 against 2.91 for the evaporative demand. This indicates that water use was only 22 % of the evaporative demand. From early March until mid April the graph is distorted by the period of zero flow and the subsequent water release from the dam, but once the system had stabilised the estimated water in the winter months was significantly higher than at the end of the summer. Although the curve steepens, the regression coefficient of 1.4 is still only 68 % of that for evaporative demand (2.05). The average water use over the riparian zone was apparently less than the potential.

Figure 4.9 shows the relationship between daily water use and daily evaporative demand. Coefficients of determination are given in Table 4.4. Separate values are given for the period immediately after clearing and for that following the dam release in April. The relationship shown in Figure 4.9a is based on the original daily values. Negative values for evaporative demand indicate those days for which precipitation exceeded pan evaporation. As expected, these days are characterised by a generally low water use, but on days with a positive evaporative demand there is no observed relationship at this time scale. In Figure 4.9 b and c the values have been averaged over consecutive five and ten day periods respectively. As the period of analysis increases the problem of unsteady flows between the weirs is reduced. There is a clearer relationship between water use and evaporative demand, especially for the 10-day averages, but there is still a large amount of scatter. It is also evident from these two graphs that the highest water use estimates were found for intermediate values of evaporative demand. There is some evidence to suggest that water use is actually reduced on days with a very high evaporative demand.

Table 4.4 Coefficients of determination for the relationship between daily water use and daily evaporative demand

	Coefficient of determination (r^2)	
	Clearing to April water release	After April water release
daily values	.01 (n = 38)	.015 (n = 148)
5-day mean	.47 (n = 34)	.30 (n = 143)
10-day mean	.81 (n = 29)	.27 (n = 137)

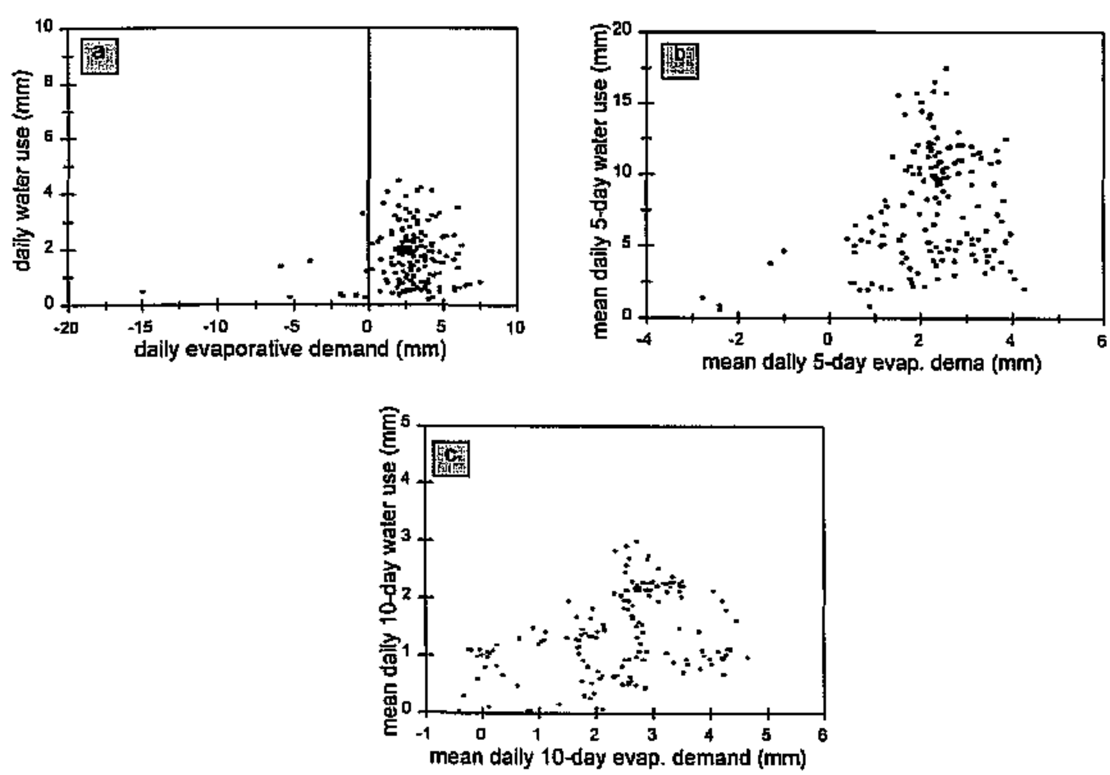


Figure 4.9 a-c Relationship between daily water use and evaporative demand

Daily fluctuations of streamflow in response to potential open water evaporation between the January 10th and 12th, February 20th and 22nd and June 4th and 6th can be seen in Figures 4.10 a-c respectively. It should be noted that y-axis scales expressing discharge values are different for the separate figures.

Figure 4.10a represents a three-day period prior to clearing when both the upstream and downstream reaches contained *A. mearnsii* in the riparian zone. Flows over the upstream weir, weir 1, showed no evidence of a daily trend. At the two lower weirs, however, superimposed on the general flow recession was a small but noticeable increase in flow at or immediately after midday. This was most pronounced for the lowest weir which integrates the combine effects of *A. mearnsii* through the two reaches. It was also most evident for the first two days which also had the highest pan evaporation rates, 6.25 mm and 5.65 mm against 3 mm on the third day. A similar trend is evident from Figure 4.10b, representing three days in February following clearing. A particularly marked peak was evident at weir 3 on the 21st; this day also had the highest evaporation rates of the three days, 5.75mm as against 3.75 mm and 3.25 mm on the preceding and following days respectively. There is no discernible trend on the third example shown in Figure 4.10c which represents three days in June. On these three days pan evaporation did not exceed 3 mm.

The results indicate that, contrary to expectations, water use is reduced in the middle of the day when evaporation potential is highest. The evidence presented above suggests that, although potential evaporation must drive water use by *A. mearnsii*, when the evaporative demand becomes high some physiological mechanism comes into play which enables a reduction in water use. This will be discussed further in Chapter 5.

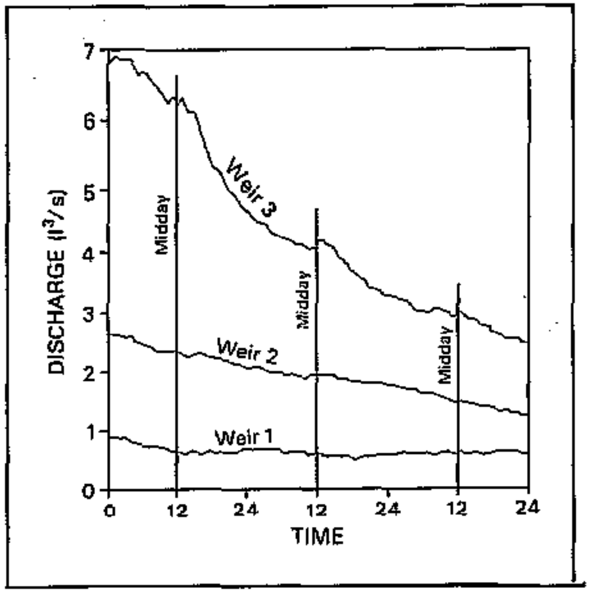


Figure 4.10a: Diurnal streamflow fluctuations from Jan 10-12. Pan evaporation was 6.25, 5.65 and 3 mm for each day respectively.

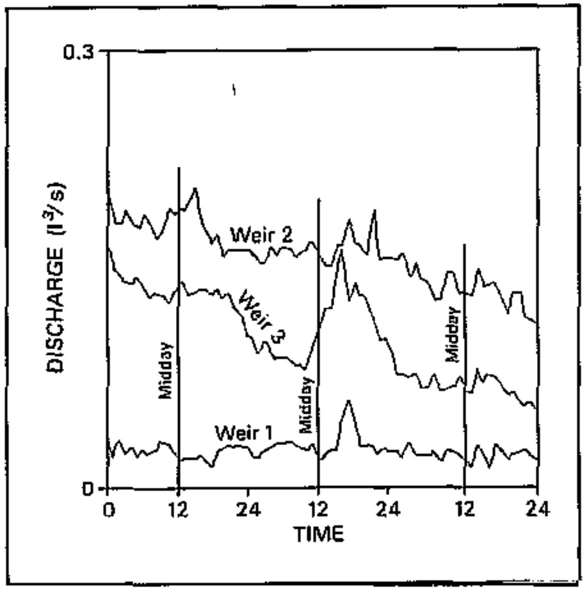


Figure 4.10b: Diurnal streamflow fluctuations from Feb 20-22. Pan evaporation was 3.75, 5.75 and 3.25 mm for each day respectively.

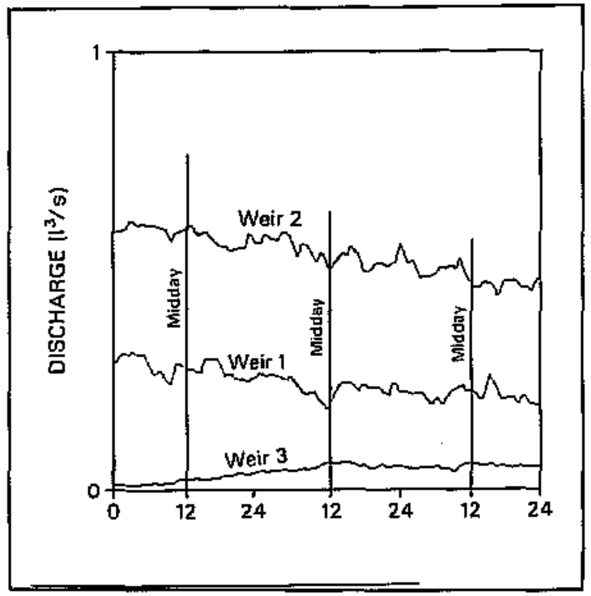


Figure 4.10c: Diurnal streamflow fluctuations from June 4-6. Pan evaporation was 2, 2.75 and 3 mm for each day respectively.

Figure 4.10: Diurnal streamflow fluctuations for three periods in the year

4.5 Effects of Tree Clearing on Water quality

Average conductivity readings calculated for the three weirs before and after clearing are presented in Table 4.5. All values represented low conductivities and there was almost no difference in readings before and after clearing of the trees at any of the three weirs. Weir 3 had the highest average conductivity readings of 32.02 mS/m and 31.83 mS/m before and after clearing respectively, whereas weir 2 had the lowest conductivity of 25.9 mS/m before clearing and 26.15mS/m after clearing.

Table 4.5: Comparison of water conductivity before and after clearing

Conductivity Readings (mS/m)							
BEFORE CLEARING				AFTER CLEARING			
	Weir 1	Weir 2	Weir 3		Weir 1	Weir 2	Weir 3
January				February			
9	25.4	21.6	26.6	6	26.2	27.2	32.6
10	26.4	22.6	27.2	7	25.6	24.7	31.2
11	26.7	22.8	28.1	8	26.8	27.2	33.5
12	26.5	22.3	27.6	9	26.3	25.9	32.1
13	25.6	20.2	28.1	10	25.8	26.7	31.9
14	26.2	21.4	28.3	March			
15	28.9	26.2	35.1	4	27.2	26.1	29.8
16	27.3	26.1	33	5	26.6	25.5	30.7
17	28.5	25.3	31.7	April			
18	28.9	28	34.6	2	25.4	24.8	31.3
22	26.1	30.4	32.5	September			
23	26.3	30.3	35.3	23	29.4	26.3	33.8
24	26.1	30.1	35.2	24	28.2	27.1	31.4
25	26.4	30.7	36.5				
26	27.4	30.5	40.5				
Mean	26.8	25.9	32.0	Mean	26.75	26.15	31.83

4.6 Rehabilitation and Restoration

The clear felling operation was carried out jointly by the Department of Agriculture (Resource Conservation) and the Port Elizabeth Municipality. After levelling the trees, branches were packed into piles while large branches and tree stumps were moved away from the channel in order to avoid debris being drawn into the channel. In the open areas between the packed branches the grass seeds were sown. Unfortunately there was insufficient rain for the most part of the year and conditions were unfavourable for the seeds to germinate. However, after September 9th (after the monitoring period) there were significant rainfall events and on a brief visit to the study site in late October, examples of all grass types originally sown were identified. There was not sufficient regrowth to justify a full vegetation survey, but it was noted that the grass seeds were more successful in colonising areas where other grass types already existed before the clearing of the *A. mearnsii*.

In late June *A. mearnsii* seedlings were starting to appear in the cleared section of the riparian zone. A follow up operation was arranged and all seedlings were removed or sprayed during July. After the follow up, very few *A. mearnsii* seedlings were seen growing in the riparian zone even after the heavy rainfall at the end of the year in September.

The site was visited again by F de Kock in July 1998. The condition of the vegetation and channel at this time are shown in Plates 15 - 18. Plates 15 and 16 show that a good grass cover has become established on the flood plane itself. Some regrowth of *A. mearnsii* is evident. The cut stumps do not show any sign of regrowth. Patches are still evident where the woody debris was burnt. The channel margins, shown in Plates 16 and 18, are being colonised by either a low shrub (Plate 17) or *A. mearnsii* (Plate 18). There is some evidence to suggest that the re-colonisation is related to the available substrate, with *A. mearnsii* re-establishing itself on a cobble substrate and the low shrubs coming in on finer textured deposits.

An adequate supply of sediment during floods is probably an important criteria for successful channel rehabilitation. The rehabilitation process in this area may be inhibited by the lack of fines available to reconstruct the channel banks due to the proximity of the dam upstream.

Plate 15. Vegetation on the flood plane, July 1998.

Plate 16. Vegetation on the flood plane, July 1998

Plate 17. Vegetation in the channel margins, July 1998. *A. mearnsii* colonising cobble areas.

Plate 18. Vegetation on the channel margins, July 1998. Low shrubby vegetation colonising fine textured sediments.

CHAPTER 5

DISCUSSION, RECOMMENDATIONS AND CONCLUSIONS

5.1 Introduction

The results of monitoring increased streamflow following clearing of *Acacia mearnsii* from the riparian zone were presented in the previous chapter. These results will be reviewed in terms of the observed streamflow increase and the possible relationships to evaporative demand. An overview of the experimental design will also be presented, leading into recommendations for follow-up research.

5.2 Flow increases following clearing of *Acacia mearnsii*

Clearing on one bank over a length of 500 m gave an effective increase in water of 34 m^3 per day, equivalent to a 496 mm loss per year for the 2.5 ha area. It is reasonable to assume that clearing alien vegetation from both banks of a river would have doubled the increase, resulting in 136 m^3 per day per km of river channel, or approximately 50 000 m^3 per year. The results for the present study were obtained by clearing a 50 m wide strip. Assuming that the entire width was effective in increasing water flows, it equates to 5 000 m^3 per hectare cleared.

There was significant variation in flow increases through the year, with the highest increases observed for the winter months when the evaporation potential was relatively low. These were also the driest months. The monitoring period differed significantly from average conditions. The early summer had well above average rainfall whereas the winter was particularly dry. The increase in streamflow following clear felling should, however, represent conditions when water supply is likely to be the most critical, that is during a dry winter

The experimental results can be compared with those found by Dye and Poulter (1995) who used two portable weirs to monitor the effects on streamflow of clearing a mixed stand of *Pinus patula* and *Acacia mearnsii* from 25 m on either side of a 500 m stream course (2.5 ha). The average increase in streamflow was found to be 30.5 m^3/day over a nineteen day period in September. These results are remarkably similar to those found in the present study. The difference in climatic conditions between the two areas should be noted. The experimental site in Mpumalanga has a mean annual precipitation of 1030 mm against that for the Sand River site of 611 mm. Such climatic differences may become less important when considering riparian areas where water is more freely available.

The estimated flow increase of 496 mm per annum is significantly higher than values presented for catchment-based studies. Van Wyk (1987) quotes a maximum stream flow reduction of 313 mm for a 98% forest cover of *Pinus patula* (Table 2.1). The relationship found by Le Maitre *et al.* (1996) between above-ground wet biomass and streamflow reduction (Figure 2.3) indicates a figure of only 375 mm for the 162 t/ha riparian stand cleared from the Sand River. These results therefore support those of Scott and Lesch (1995) who showed that riparian vegetation has a higher water use than that growing more widely over the whole catchment.

The values obtained from this experiment can be compared to previous regional scale estimates of the effect of clearing alien vegetation. Ninham Shand Inc (1993) estimated a 9.5 million m^3 per annum increase in water yield if *A. mearnsii* was cleared from an estimated 3170 ha in the Krom and Kouga catchments. Their estimate was based on a water use value of 300 mm. Results from the present study indicate the increased yield would be closer to 15.7 million m^3 per annum. More recently Versveld et al. (1998) 'thumb sucked' a figure of 12 m^3/ha/day for water use by *A. mearnsii* in the riparian zones of the Eastern Cape, a figure not very different from the 13.6 m^3/ha/day estimated by the present study.

5.3 Water Use and Evaporative Demand

Water use by vegetation can be related to four main factors, the evaporative demand of the atmosphere, intercepted water within the canopy, the available moisture in the soil and physiological controls exerted by the vegetation. The daily evaporative demand was calculated as the difference between pan evaporation and precipitation as measured on that day. No meaningful measurements of soil moisture were taken due to the problems of sampling the coarse cobbly sediments. Nor were any measurements taken to monitor interception or physiological processes. Lack of these data limit the interpretation of the results.

The relationship between water use and evaporative demand was analysed using two approaches, firstly by comparison of the cumulative water use and cumulative evaporative demand against time and secondly by relating daily water use to daily evaporative demand averaged over a number of time periods.

Cumulative plots of water use and evaporative demand given in Figure 4.9 indicated that over the winter period the rate of water use was 68% of the evaporative demand. This suggests that either the effective riparian area was significantly less than the 2.5 ha, that water availability was limiting evapotranspiration, or that the potential evapotranspiration rate for *A. mearnsii* is significantly less than pan evaporation. Schulze *et al.* (1994) suggest a crop coefficient of 0.85 for commercial pine forest. If this coefficient is applied to mature *A. mearnsii* stands water use increases to 80% of evaporative demand. All three factors were probably operative. Water would have been freely available at the channel edge, but would have decreased away from the channel. Given a water use of between 68% and 80% of the evaporative demand, clearing to about 70% to 80 % of the 50 metre strip, i.e. 35 m to 40 m, would probably have had a similar effect. This conclusion needs to be confirmed by further experimentation.

During the late summer period estimated water use was only 22 % of the evaporative demand. This can largely be explained by the large water reserves in the flood plain following the wet start to the summer. It may also be explained in part by reductions in water use during periods of high evaporative demand as indicted by the more in-depth analysis of water use-evaporative demand relationships.

The relationship between daily water use and evaporative demand was investigated further as follows. Firstly the daily water use was compared to the daily evaporative demand using three time scales, the unmodified daily readings or the mean readings over five and ten day periods. The second analysis examined daily fluctuations in streamflow in relation to assumed daily variations in evaporative demand.

Plotting daily water use against daily evaporative demand (Figure 4.9) showed that no relationship was evident in the case of unmodified daily values. When values were averaged over five and ten days the relationship improved, but there was still a wide degree of scatter.

Averaging values over a longer time period would have removed the noise due to unsteady flows and would have also take account of the effect of antecedent conditions on the available soil moisture. One trend that was evident from both the 5-day and 10-day analysis was that the maximum water use occurred against an evaporation demand of between 2 and 3 mm. There was some evidence for a reduction in water use for days with a high evaporative demand.

Plots of diurnal changes in stream flow given in Figure 4.10 indicate a possibility that on days of high evaporative demand the water use was depressed at or shortly after midday, the time of day when evaporative demand would normally be at a maximum. This result differed from that of Dye and Poulter (1995b) who found that streamflow decreased during the day as a consequence of transpiration, the effect being diminished on cool, cloudy days. It is in concurrence, however, with the work of Poulter *et al.* (1994) who found that *A. mearnsii* exhibited early control of water loss as the vapour pressure deficit increased and the air dried out.

Direct evaporation from interception storage would also contribute to evapotranspiration. This process is not subject to physiological controls, but is related to the storage capacity of the foliage. Given the high biomass of the *A. mearnsii*, high interception loss would be anticipated. In cleared areas direct rainfall onto the soil surface would have a better chance of recharging soil moisture stores and ultimately the groundwater. It is not possible from the data available to isolate the effect of interception, but in this particular experiment the effect would have been less than normal due to the below average rainfall (Figure 4.2).

5.4 Overview of experimental design

The research described in this report was based on stream flow monitoring using three fixed weirs over a period of nearly nine months. Previous studies such as that by Dye and Poulter (1995) were based on short term experiments using at the most two portable weirs. These are expedient and cost effective, but the present study was shown to have a number of advantages. Firstly the use of the three weirs allowed a direct comparison to be made between a cleared and uncleared area. Whilst inflow into the channel continued for long periods after recharge for the cleared section, the uncleared section showed a significant loss of water during dry periods. These different responses would not have been picked up if only two weirs had been used. A second advantage of this experiment was the long time period over which monitoring took place. Clear seasonal differences were noticed. Of particular significance was the high water use during the dry season, despite a relatively low evaporative demand. The long term data was also used to examine the relationship between water use and daily evaporative demand. A peak water use for intermediate evaporative demand was evident in the data. It is unfortunate that the monitoring was stopped in September, before going into the period of highest evaporative demand, but the data loggers were required elsewhere by DWAF.

The results obtained relate to a 50 m strip cleared from one side of the channel only. A disadvantage of the site was the lack of a riparian strip on one side of the river. Without clearing a progressively wider strip it is difficult to evaluate the effective width of the cleared zone, though results pointed to a distance of about 35 m to 40 m from the channel. In order to evaluate the effective riparian width it would be necessary to set up a long term experiment so as to take account of seasonal effects.

If the full effect of *A. mearnsii* and its clearing are to be evaluated, it would be necessary to extend the monitoring to the full riparian zone, particularly with respect to soil water and groundwater and to interception by the vegetation. The long term effects on riparian zone hydrology in the cleared area should also be investigated. The results obtained to date are for a cleared area with no replacement vegetation. It is not known to what extent the riparian water use would be increased following re-establishment of the fynbos riparian community.

Monitoring of water quality with respect to conductivity was carried out for the duration of the experiment. The initial conductivities were very low and no changes in water quality were noted. Cambray and de Moor (1995) found that Eastern Cape rivers invaded by alien species had a significantly higher conductivity than those with natural riparian flora. Water quality in the study area may have been affected more by the upstream dam than by the local effects of the riparian flora.

Channel surveys were carried out with the intention of monitoring incidences of bank instability and long term channel change. Apart from the initial event during the clearing operation itself, no flood events occurred during the monitoring period. Provision should be made to continue monitoring over the long term.

The monitoring period extended into the winter season, which in 1996 happened to be particularly dry, with no large floods. It was not possible for reasons of lack of data loggers and available personnel to extend the monitoring for a longer period. No negative effects were recorded with respect to bank stability or stream condition, but a longer monitoring period is required before firm recommendations can be made here. Experience from around the country points to the importance of clearing woody debris away from areas likely to be affected by flooding to prevent damage downstream due to blocking of the channel by flood debris.

5.5 Recommendations

1. A survey should be carried out to establish the extent of alien invasion in the Zwartkops catchment so that an estimate can be made of the cumulative effect of clearing *A. mearnsii* from the entire area.

2. Three representative cross-sections were set up in each section in order to monitor the long term effects of clearing on bank processes. No change was observed over the initial monitoring period. Monitoring should be continued at regular intervals (say six monthly) over a period of up to five years.

3. The experimental design used in this experimental set up involved clearing wattle from the entire riparian zone, that is to a width of 50 m. From the results it was suggested that a narrower cleared strip, say of 35 m to 40 m, may have had a similar effect in terms of increased water yield. Further experiments are needed to assess the effects of different widths of clearing.

4. It was intended initially to run the experiment for a period of a few weeks only over the summer period, when evaporative demand was highest. It was later decided to extend the monitoring into the cool, dry winter period. Unfortunately heavy rainfall over the upper catchment caused flooding of the channel in the experimental site and temporary

removal of the data loggers. As a result only limited data was collected over the summer period. Because of other demands on the DWAF data loggers, monitoring was stopped in September. It was interesting to note that there was some evidence that the highest water loss was associated with intermediate water demand. It would be valuable to extend the experiments into the period of high evaporative demand so as to include a full annual cycle.

5. In order to understand the processes involved a more detailed monitoring set up is required. It would have been valuable to include monitoring of interception loss, soil moisture, groundwater levels and movement and sap flows. The experiments by the Centre for Water in the Environment at Wits University (Birkhead *et al.* 1997) would provide a useful model here. Unfortunately there was too little time in the planning stage of the present project to enable a full experimental set up to be included.

6. Monitoring should be continued so as to assess the effect of the riparian fynbos vegetation once this has become re-established.

5.6 Conclusions

This report has described the results of a medium term experiment set up to monitor the effect of clearing *A. mearnsii* from the riparian zone. It was intended that the results of this research should be used to provide guidelines for future management strategies within this and similar catchments. The results show a significant increase in water yield from the experimental area, equivalent to approximately 50000 m^3 per annum per km of channel (if cleared on both sides), or 5000 m^3 per ha per annum Much of this increase was over a period when zero flows were recorded from the uncleared area. There was evidence to suggest that water was lost from the river bed to the riparian zone. The benefit to be gained from widespread clearing would therefore be substantial.

The width of the cleared zone was 50 m, but it is not known what the relative effect of clearing a narrower strip would have been. On the one hand the results are very similar to those found by Dye and Poulter. (1995) who cleared a 500 m long 25 m wide strip of mixed *P. patula* and

A. mearnsii from either side of the channel. On the other hand, a comparison of water use with evaporative demand indicated that the "effective" width of the riparian zone was in the region of 35 m to 40 m.

Water use by *A. mearnsii* shows a strong seasonal pattern, with relatively low rates during the wet summer months, despite a high evaporative demand. The highest water use occurred during the dry winter and, within this period, did appear to respond to evaporative demand. There was evidence that the maximum daily water use occurred when the daily pan evaporation was between 2-3 mm. Water use was apparently reduced on days with a higher evaporative demand. Moreover, increases in streamflow just after midday were noted on days with a high evaporative demand. It is possible that during periods of high evaporative demand *A. mearnsii* exerts a physiological control over water use, with transpiration rates being depressed at times of moisture stress.

The seasonality displayed by the results justified the use of a long term experiment using permanent weirs. It would be beneficial to extend the experiment further. No effective monitoring took place during the time of maximum summer evaporative demand. Moreover the monitoring period itself was atypical of long-term climatic conditions in the area, with a particularly dry winter following a wet summer. It would also be beneficial to monitor the riparian zone hydrology with respect to soil moisture and groundwater levels and canopy interception. Monitoring should also be continued to evaluate the effect of regrowth of natural vegetation in the area.

REFERENCE LIST

Acocks, (1988). The veld types of South Africa. *Mem. Bot surv.S. Afr.* **40.**

Azorin, E.J. (1992). *The potential of alien acacias as a woodfuel resource in the South Western Cape.* Prepared for National Energy Council, Cape Town.

Barrett, J. (1996). Alien Inspiration. *Africa - Environment and Wildlife*, **4**, 4, 30-31

Belcher, A. (1996). Zwartkops River Water Resources Management Plan: A situation Assessment and Development of a Catchment Water Quality Monitoring Programme. Report No: N/M100/REQ/0896, DWAF, Pretoria

Beyers, G.J. (1994). *Preliminary Assessment of the Geomorphological Impact of Alien Vegetation in the Baviaanskloof Region.* Unpublished Third Year Project. Rhodes University, Geography Department.

Birkhead, A.L., Olbrich, B.W., James, C.S. and Rogers, K.H. (1997) *Developing an integrated approach to predicting the water use of riparian vegetation.* WRC Report No 474/1/97.

Biswas, K.A. (1991). Water for sustainable development in the 21st century: a global perspective. *GeoJournal*, **24**.4, 341-345.

Brower, J.E., Zar, J.H. and von Ende, C. N. (1990). *Field and Laboratory Methods for General Ecology.* Third Edition. Wm.C.Brown, Dubuque, Iowa.

Bosch, J.M. and Hewlett, J.D. (1982). A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology*, **55**, 3-23.

Bosch, J.M. and Smith, R.E. (1989). The effect of afforestation of indigenous scrub forest with *Eucalyptus* on streamflow from a small catchment in the Transvaal, South Africa. *South African Forestry Journal*, **150**, 7-17.

Bosch, J.M. and von Gadow, K. (1990). Regulating afforestation for water conservation in South Africa. *South African Forestry Journal*, **153**, 41-54

Boucher, C. and Marais, C. (Eds.) (1995). *Managing fynbos catchments for water.* FRD, Programme Report Series, 24.

Cambray, J. and de Moor, F. (1995). *Influence of alien invasive vegetation on the distribution and status of fish and aquatic invertebrates of the Baviaanskloof Wilderness Complex.* Report for: East Cape Nature Conservation.

Cowling, R. M. (1992). *The Ecology of Fynbos.* Oxford University Press, Cape Town.

Cowling, R.M. (1995). Introduction to the Workshop. In Boucher, C and Marais, C. (eds.) *Managing Fynbos Catchments for Water.* FRD Programme Report Series, 24.

Dallas, H. and Day, J. (1993). *The effect of water quality variables on riverine ecosystems: a review.* Water Research Commission TT 61/93

Davies, B.R. and Day, J.A., (1986). *The Biology and Conservation of South Africa's Vanishing Waters.* The centre for extra-mural studies, University of Cape Town.

Dawson, T.E. and Ehleringer, J.R. (1991). Streamside trees that do not use stream water. *Nature*, **350**,335-337

De Beer, H. (1986). Black Wattle. *Farming in South Africa, Weeds* A.24/1986. Department of Agriculture and Water Supply

Dempster, J.P. (1991). Opening remarks. pp. xvii - xviii. In: Collins, N.M. and J.A. Thomas (eds). 1991. *The conservation of insects and their habitats.* 15th Symposium of the Royal Entomological Society of London. 14 - 15 September 1989. Academic Press, London. 450pp.

Dollar, E.S.J. (1992). *An Historical Study of Channel Change in the Bell River, North Eastern Cape.* Unpublished Masters Thesis, Rhodes University.

Doolan, J.M., Gratson, R.B. and Lloyd, L. (1994). The use of AEAM (Adaptive Environmental Assessment and Management) in catchment assessment and planning. In *Proceedings of the Joint South African/Australian Workshop on River Classification and Stream Management,* Cape Town, 7-11 February 1994. WRC Publication . TT63/94.

Dunne, T. and Leopold, L.B. (1978a). Chapter 5 - Water use by vegetation. In *Water in Environmental Planning.* W.H. Freeman and Company.

Dunne, T. and Leopold, L.B. (1978b). Chapter 21 - Stream biota and biologic health. In *Water in Environmental Planning.* W.H. Freeman and Company.

DWA, (1986). *Management of the Water Resources of the Republic of South Africa..* Department of Water Affairs, Pretoria.

DWAF, (1996a). *Working for Water!* Information Leaflet, Department of Water Affairs and Forestry, January 1996.

DWAF, (1996b). *How much water do alien plant invaders use?* Information Leaflet, Department of Water Affairs and Forestry, March 1996.

Dye, P.J. (1995). Clearing Invasive Trees in Riparian Zones Increases Streamflow. *Quarterly Newsletter of the Division of Forest Science and Technology,* **3**, 3.

Dye, P.J., Olbrich, B.W. and Everson, C.S. (1994). *The Water Use of Plantation Forests and Montane Grassland in Summer-rainfall Forestry Regions of South Africa.* Unpublished Report, Division of Forest Science and Technology, CSIR.

Dye, P.J. and Poulter, A.G., (1995a). Clearing invasive trees in riparian zones increases streamflow. *Environmental Protection and Management*, **May 1995**, 13-15.

Dye, P.J. and Poulter, A.G., (1995b). A field demonstration of the effect on streamflow of clearing invasive pine and wattle trees from a riparian zone. *South African Forestry Journal*, **173**, 27-30

Gregory, K.J. and A.M. Gurnell (1988). Vegetation and river channel form and process. *In* H.A. Viles (ed.), *Biogeomorphology*. Blackwell: pp. 11-42.

Glen-Leary, J. (1990). Wattle Threat in Eastern Cape. *Farmer's Weekly*, **April 20.**

Gribbin, J. (1990). *Hothouse Earth.* Transworld Publishers Ltd. London.

Goldsmith, E. and Hildyard, N. (1992). *The Earth Report 3.* Mitchell Beazley Publishers, London.

Gurnell, A.M. and K.J. Gregory (1984). The influence of vegetation on stream channel processes. *In* T.P. Burt and D.E. Walling (Eds.), *Catchment Experiments in Fluvial Geomorphology.* Cambridge University Press, Cambridge: pp.515-535.

Henderson, M., Fourie, D.M.C. and Wells, M.J., (1987). *Declared weeds and alien invader plants in South Africa.* Department of Agriculture and Water Supply, Pretoria.

Henderson, L. and M.J. Wells (1986). Alien invasions in the grassland and savanna biomes. *In* I.A.W. Macdonald, F.J. Kruger and A.A. Ferrar (eds), *The ecology and management of biological invasions in Southern Africa.* Oxford Univ. Press, Cape Town: pp.109-131.

Kempster, P.L., Hattingh, W.H.J. and van Vliet, H.R. (1982). *Summarized Water Quality Criteria.* Department of Environment Affairs, TR 108.

Kramer, P.J. (1983). *Water Relations of Plants.* Academic Press, Inc.

Le Maitre, D.C., van Wilgen, B.W., Chapman, R.A. and McKelly, D.H. (1996). Invasive plants and water resources in the Western Cape Province, South Africa: modelling the consequences of a lack of management. *Journal of Applied Ecology*, **33**, 1, in press.

Macdonald, I.A.W. (1987). Advances in our understanding of alien invasions of the Fynbos biome: 1980-1985. *Foundation for Research and Development, Occasional Report* **19**

Macdonald, I.A.W. and D.M. Richardson (1986). Alien species in terrestrial ecosystems of the fynbos biome. *In* I.A.W. Macdonald, F.J. Kruger and A.A. Ferrar (eds.), *The Ecology and Management of Biological Invasions in Southern Africa.* Oxford University Press, Cape Town: pp.77-91.

Marston, R.A. (1982). Geomorphic significance of log steps in forest streams. *Annals of the Association of American Geographers*, **72**, 99-108.

Mitchell, B., and Pigram, J.J. (1989). Integrated resource management and the Hunter Valley Conservation Trust, NSW, Australia. *Applied Geography,* **9,** *196-211*

Murgatroyd, A.L. and Ternan, J.L. (1983). The Impact of Afforestation on Stream Bank Erosion and Channel Form. *Earth Surface and Processes,* **8,** 357-369.

Nänni, U.W. (1972). Water-use by riparian vegetation at Cathedral Peak. *South African Forestry Journal*, **80,** 1-10

Ninham Shand Inc. (1993). The Effect of Invader Plants, *Acacia mearnsii* (Black Wattle), in the Kouga and Krom River Catchments. *Algoa Water Resources Stochastic Analysis, Report*, PM 000/00/1193

Odendaal, D. (1996). The Fynbos Work for Water Project. Fynbos Inspiration, Job Creation. *Earthyear*, **13,** 61

O'Keeffe, J. (1986). The Conservation of South African Rivers. *South African National Scientific Programmes Report*, **131**.

O'Keeffe, J. (1989). Conserving Rivers in South Africa.. *Biological Conservation,* **49**, 255-274.

Petit jean, M.O.G. and Davies, B.R. (1988). Ecological Impacts of inter-basin water transfers: some case studies, research requirements and assessment procedures in Southern Africa. *Suid-Afrikaanse Tydskrif vir Wetenskap.* **84,** 819-826.

Poulter, A.G., Soko, S. And Maphanga, D. (1994). *A Comparative Study of Water Use by Invasive and Indigenous Species Found in Riparian Zones.* Report for Department of Environmental Affairs and Forestry, **790.**

Pithers, L., (1996). State could take on alien black wattle industry. *Earthyear,* **14**, 78-79

Richardson, D.M., Macdonald, I.A.W., Holmes, P.M., and Cowling, R.M., (1992) Plant and animal invasions. *In* Cowling, R. (1992). *The Ecology of Fynbos.* Oxford University Press, Cape Town.

Rowntree, K.M. (1991) An assessment of the potential impact of alien vegetation on the geomorphology of river channels in South Africa. *South African Journal of Aquatic Science.***17** (½), 28-43.

RSA White Paper (1994). *Water Supply and Sanitation Policy.* Department of Water Affairs and Forestry, Pretoria.

Rust, I.C. (1988). The geology of the eastern Cape. *In* Bruton, M.N. and Gess, F.W. (eds). *Towards An Environmental Plan for the Eastern Cape.* Rhodes University.

Schulze, R.E., Lecler, N.L. and Hohls, B.C. (1994) In: Schulze, R.E. (1994) *Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling* System. Water Research Commission, Pretoria, Reprt TT69/95. pp AT6-1 to AT632.

Scott, D.F. and Lesch, W. (1995). *The water yield gains obtained from clearfelling riparian zone vegetation.* Paper presented at the SANCIAHS 7th National Hydrology Symposium, Grahamstown.

Scott, D.F. and Lesch, W. (1996). The effects of riparian clearing and clearfelling of an indigenous forest on streamflow, stormflow and water quality. *South African Forestry Journal*, **175,** 1-13.

Seyhan, E., Hope, A.S. and Schulze R.E. (1983). Estimation of streamflow loss by evapotranspiration from a riparian zone. *South African Journal of Science*, **79**, 88-90.

Smith, R.L. (1990). *Ecology and Field Biology*. 4th Edition. Harper Collins Publishers.

Smith, R.E. and Bosch, J.M. (1989). A description of the Wesvalia catchment experiment to determine the effect of water yield of clearing the riparian zone and converting an indigenous forest to a eucalypt plantation. *South African Forestry Journal,* 151., pp26-31

Smith, R.E. and Scott, D.F. (1992). The effects of afforestation on low flows in various regions of South Africa. *Water SA*, **18,** 3, 185-194.

Smith, R.E., Moses, G. and Versfeld, D.B. (1992). Verification of the Heat Pulse Velocity Technique for *Acacia mearnsii. South African Forestry Journal*, **163**, 1-4.

Stirton, C.H. (1987). *Plant Invaders - Beautiful But Dangerous, 5th Edition*. The Department of Nature and Environmental Conservation of the Cape Provincial Administration

Stober, P. (1992). The trouble with trees is they drink too much. *The Weekly Mail and Gaurdian* April 30 to May 7.

Stober, P. (1994). Tough-talking Asmal tackles the old guard. *The Weekly Mail and Guardian* September 23 to 29.

Stock, W.D., van der Heyden, F., and Lewis, O.A.M., (1992). Plant structure and function. *In* Cowling, R. (1992). *The Ecology of Fynbos*. Oxford University Press, Cape Town.

Swanson, R.H. and Whitfield, D.W.A. (1981). A numerical analysis of heat pulse velocity theory and practice. *Journal of Experimental Botany,* **32,** 221-239.

Thorne, C.R. (1990). Effects of vegetation on river bank erosion and stability. *In* J.B.Thorne (ed.), *Vegetation and Erosion: Processes and Environments*. John Wiley, Chichester: pp 125-144.

Toerien, D.K. and Hill, R.S. (1989). *The Geology of the Port Elizabeth Area.* Geological Survey, Department of Mineral and Energy Affairs.

Van Der Zel, D.W. (1987). Hydrological implications of the changing role of forestry in a catchment context. *Hydrological Sciences Symposium Proceedings:* **2**, 671-679.

Van Der Zel, D.W. (1975) and Kruger, F.J. (1975). Results of the multiple catchment experiments at the Jonkershoek Research Station, South Africa. *Forestry in South Africa*, **16**, 13 - 18.

van Wilgen, B.W. (1995). Public funding to clear alien weeds in catchments justified. *Quarterly Newsletter of the Division of Forest Science and Technology*, **3**, 3,

van Wilgen, B.W. and Kruger, F.J. (1985). The physiography and fynbos vegetation communities of the Zachariashoek catchments, south-western Cape Province. *South African Journal of Botany*, **51**, 379-399.

van Wilgen, B.W., Cowling, R.M. and Burgers, C.J. (1996). Valuation of ecosystem services. *Bioscience* ,**46**, 3,184-189

Van Wyk, D.B (1977) Die invloed van bebossing met Pinus radiata op die totale jaarlikse afvoer van die Jonkershoek strome. M.Sc. Thesis, Univ. Stellenbosch, (Unpublished).

Van Wyk, D.B. (1987). Some effects of afforestation on streamflow in the western Cape Province, South Africa. *Water SA,* **13**, 1, 31-36.

Vermeulen, W.J. (1989). *Guide on the control of Australian acacias*. Pamphlet 365/8. Department of Environment Affairs

Wells, M.J., Balsinhas, A.A., Joffe, H., Engelbrecht, V.M., Harding, G. and Stirton, C.H. (1986). *A Catalogue of Problem Plants in Southern Africa Incorporating the National Weed List of South Africa*. Memoirs of the Botanical Survey of South Africa. Botanical Research Institute: Pretoria.

APPENDIX 1

VEGETATION SAMPLING

APPENDIX 2 BIOMASS DATA

Size Class (cm)	DBH (cm)	Weight (kg)	Ave Wt (kg)	Size Class	DBH (cm)	Weight (kg)	Ave Wt (kg)
0 - 2.5	0.4	0.8		5 - 10	5.4	23.2	
	0.6	1.7			5.8	26.4	
	1.2	1.2			6.5	32.3	
	1.5	3.1			6.6	34.5	
	1.8	4.2			6.9	35.6	
	1.9	3.8			7.6	43.2	
	2.2	4.8			8.2	48.9	
	2.2	5.3			8.9	41.5	
	2.4	5.8			9.2	64.8	
	2.4	7.3	3.8		9.8	81.2	43.16
2.5 - 5	2.5	6.3		10 - 15	10.2	80.3	
	2.8	6.8			10.6	94.5	
	3.1	8.1			10.8	97.1	
	3.1	6.8			11.5	109.8	
	3.3	9.8			11.9	129.2	
	3.8	12.4			12.6	154.8	
	4	11.4			12.7	188.6	
	4.2	15.7			13.4	224.7	
	4.6	17.4			14.1	238.6	
	4.8	19.8	11.45		14.8	255	157.26
				15 - 20	15.5	258	
					16.4	249	
					16.6	256	
					18	281	
					19.4	292	267.2

DBH - Diameter at breast height
Ave Wt - Average weight of trees measured

APPENDIX 3

CHANNEL CROSS SECTION DATA

APPENDIX 4

HISTORICAL RAINFALL DATA
AND
DAILY RAINFALL (JANUARY - SEPTEMBER 1996)
MEASURED AT SAND RIVER DAM

APPENDIX 5

OPEN WATER EVAPORATION
(GROENDAL AND LOERIE DAMS)

APPENDIX 6

WEIR CONSTRUCTION REPORT

APPENDIX 7

EXAMPLE OF RAW STREAMFLOW DATA

APPENDIX 8

EXAMPLE OF CONVERTED STREAMFLOW DATA

APPENDIX 9

DAILY FLOW DATA AND WATER USE ESTIMATES

APPENDIX 10

GRASS TYPES AND AMOUNTS SOWN IN CLEARED AREAS

Grass seeds sown on Saturday March 16th 1996 over an area of 3 hectares

Eragrostis curvula (6kg)
Varity - Ermelo
Germination specification % 70 -79

Cynodon (6kg)
Varity - Kweek
Germination specification % 80-89

Panicum maximum (C) (9 kg)
Variety - Cutter
Germination specification % 20-29

Chloris gayana (C) (9kg) (Rhodes grass)
Variety - Katambora
Germination specification % 20-29

Digitaria eriantha (C) (9kg) (Smuts)
Variety - Irene
Germination specification % 20-29

Chenchrus cilaris (C) (3kg) (Bloubuffel)
Variety - Molopo
Germination specification % 20-29

APPENDIX 1

VEGETATION SAMPLING

Control Riparian Zone - South of the Channel between weir 2 and weir 3

0 - 2.5cm					2.5 - 5cm					5 - 10cm				10-15cm		15-20cm
2.4	1.3	0.4	0.6	0.6	0.7	2.4	2.1	1.3	1.8	1.6	1.2	0.6	4.3	2.4	1.5	3.4
0.5	0.6	0.9	2.2	0.8	1.3	2	1.1	0.4	0.8	1	4.2	0.6	0.5	1.7	2.5	6.4
1.2	1.8	1.1	0.1	0.5	0.7	0.7	2.2	1.8	4.1	1.8	1.3	2.4	1.7	1.3	0.9	6.1
0.2	1.2	1.1	1.1	0.6	0.9	1.6	3.1	1.1	2.3	1.4	3.2	0.7	4.2	3.3	1.7	2.3
1.8	2.6	0.7	0.4	1	0.4	3.7	2.1	3.9	1.4	2.7	2.4	1.1	2.3	4.2	0.8	3.7
0.5	1.4	0.8	0.4	1.2	0.7	1.8	1.2	0.4	0.8	1.7	1.4	1.2	2.3	5.1	3.5	5.2
0.9	0.4	1.8	0.2	1.3	1.6	4.6	1.3	0.4	2.1	0.7	2.1	2.1	1.3	1.4	5.1	3.4
1.1	3.2	1.3	1.6	1.1	0.3	3.7	1.2	3.1	0.5	3.4	1.1	1.4	0.9	0.6	0.9	1.9
2.2	1.3	1.6	1.3	3.4	0.8	3.1	0.3	1.3	2.4	1.6	1.6	1.3	1.7	1.1	2.4	4.9
1.1	0.9	1.3	0.4	2.4	1.1	1.6	0.8	0.3	0.7	1.3	0.5	1.3	1.6	2	2.9	2.8
3.1	0.6	4.5	0.6	1.3	1.3	1.7	2.1	2.9	1.8	0.9	1.9	1.6	0.4	2	1.3	4.3
1.8	0.5	0.6	0.8	1.7	1.4	2	0.8	1.4	0.7	0.8	1.8	0.9	3.4	3.1	0.9	3.4
1.2	0.8	0.5	1	0.8	1.2	0.4	2.1	0.8	0.7	1.1	1.2	1.3	3.1	2.8	0.3	2.9
1.2	1.4	0.4	0.5	1.2	0.7	0.7	1	0.8	1.6	1.7	1.4	2.6	1.7	0.8	3.3	1.7
0.3	0.1	0.6	0.8	0.9	3.4	1.1	1.2	0.9	2.4	0.4	1.6	1.4	1.2	1.8	2.9	2.6
2.1	0.2	2.8	0.8	1.8	2.3	2.3	1.3	1.3	0.4	0.5	1.7	0.6	2.5	2.8	2.7	1.8
1.2	0.4	2.1	1.6	1.4	1.7	0.8	0.6	0.9	2.1	0.6	1	1.9	1.1	1.5	1.8	
1.5	1.6	0.2	1.7	0.7	0.7	1.8	3.1	4.1	1.8	1.8	0.8	1.9	2.6	2.2	5.2	
0.9	2.9	0.4	0.8	1.4	0.3	0.7	0.5	1.3	1.8	3.4	1.6	1.9	1.3	3.3	1.4	
0.4	2.3	0.4	0.8	1.1	0.6	2.9	1.2	0.9	1.2	2	0.5	2.2	0.7	3.8	1.5	
0.5	1.2	2.7	0.5	3.1	0.9	1.2	1.2	0.8	1.1	1.4	1.1	0.9	1.1	1.2	1.6	
0.7	0.6	0.6	0.2	0.9	1.3	1.3	0.6	0.7	0.6	1.6	0.8	2.6	2.1	2.8	1.7	
0.3	1.1	0.6	1.1	1.6	1	0.6	0.7	0.4	2.8	0.5	1.7	0.6	0.4	3.8	1.4	
0.5	0.8	0.5	1	1	1.2	0.9	1.2	2.7	0.7	3.1	0.7	2.1	2.4	0.7	3.5	
1.4	0.1	1.8	1.7	0.8	3	0.4	0.4	1.5	1.8	0.4	2.3	1.4	3.4	0.6	0.5	
0.9	0.3	2.4	0.5	0.6	2.1	0.9	2.1	1.3	4.2	0.5	2.1	2.2	0.3	3.9	2.1	
0.3	2.6	2	0.8	1.4	0.5	2.6	0.2	0.5	0.8	2.5	3.4	1.4	2.1	2.4	2.5	
1.3	1.4	0.3	1.2	2.2	0.7	2.6	1.2	1.1	1.5	1.6	1.4	0.6	0.8	1.1	3.2	
0.2	0.5	3.6	0.6	2.6	1.5	2.4	0.5	1.1	2.4	0.7	1.2	4.1	1.2	2.9	2.5	
1.5	3.4	1.5	2.4	0.6	0.3	2.3	0.9	0.8	0.2	4.5	4.7	1.1	1.7	3.1	2.8	
1.8	0.3	1.4	1.3	0.8	1.9	2.1	2.1	1.2	1.3	0.5	1.6	1.3	1	3.4	2.6	
0.8	1.2	0.6	0.6	1	0.8	1.3	0.7	1.2		1.5	1.8	1.4	2.6	2.5	2.3	
1.4	2.6	0.5	0.2	2.5	0.3	3.8	2.2	0.2		3.1	1.2	1.2	1.4	1.8	4.1	
1.8	0.9	0.5	1.4	1.7	1.1	0.5	0.7	0.6		1.2	1.2	2.6	0.7	2.4	2.5	
1.4	0.3	1.1	1.4	1.3	1.8	1.7	1.2	1		0.6	2.4	0.7	3.1	3.6	2.4	
0.3	0.9	0.8	1.5	2.3	1.2	1.9	2.1	0.4		1.2	1.4	1.4	2.1	4.2	1.3	
0.9	1	0.9	0.8	0.7	1.1	1.1	1.1	1.2		1.3	1.2	0.8		1.6	2.7	
2.4	1.1	1.1	0.6	0.5	1	0.8	2.5	2.3		1.4	1.8	1.4		4.1	0.9	
0.2	0.3	1.1	1.8	0.6	1.8	1.4	2.3	1.4		0.6	2.3	2.1		2.7	1.4	
0.6	1.1	0.8	1.2	1.6	0.9	1.1	0.8	0.7		1.4	0.6	1.4		1.9		
0.3	0.5	0.7	1.4	0.4	1.4	0.8	0.8	0.9		0.7	2	0.9		2.9		
2.1	1.3	0.6	2.4	0.3	0.8	2.4	0.7	0.9		0.7	0.8	0.8		3.1		
2	1.5	2.3	1.6		0.7	2.2	1.7	0.8		4.8	1.2	0.9		4.6		
0.4	0.7	1.8	0.6		1.3	2.7	0.6	0.6		2.4	0.8	2.1		0.7		
0.5	0.5	0.9	0.7		1.3	1.1	1.3	1.1		0.5	1.2	0.8		5.1		
2.7	1.3	1.3	0.3		2.8	0.3	3.3	4.1		1.7	0.5	1.4		3.1		
2.2	0.2	0.7	0.2		0.5	2.4	2.1	0.9		0.8	1.2	2.5		0.4		
1.5	0.6	0.7	1.2		0.3	2.5	0.6	1.7		1.8	0.9	1.8		0.6		
1.7	0.7	1.3	1.8		1.3	1.3	2.1	0.8		1.6	1.6	2.1		1.7		
3.4	0.5	1.2	0.3		3.1	2.9	1.1	1.5		1.9	2.3	2.6		1.6		
5.1	3.4	1.4	0.5		2.9	2.4	1.8	2.1		1.4	2.3	0.9		0.8		
0.2	0.6	2.2	2.6		0.7	2.1	2.1	1.6		1.6	3.8	1.6		2.3		
1.6	0.9	1.6	0.2		0.6	1.5	1.4	1.8		2.2	1.2	1.8		3.8		

Cleared Riparian Zone - South of the Channel between Weir 1 and Weir 2

0 - 2.5cm						2.5 - 5cm					5 - 10cm				10-15cm		15-20cm
1.1	2.4	1.3	0.7	1.7	0.5	1.1	1.6	0.8	0.3	2	1	4.2	0.6	1.7	1.2	1.7	2.7
0.5	0.5	1	0.7	0.9	0.4	1.2	2.9	2.4	1.8	0.8	2.5	3.4	1.4	1.4	0.5	0.4	2.6
0.1	0.3	0.9	0.8	0.6	1.5	0.9	0.3	2.5	0.6	2.3	1.3	1.2	0.8	1.2	2	1.7	1.1
0.3	1.4	1.3	1.4	1.1	0.4	1.9	2.1	2.1	1.2	2.4	0.5	1.6	1.3	0.4	0.7	0.5	3.9
1.2	0.8	1	0.6	0.6	0.9	1.4	0.8	0.8	0.9	1.4	0.4	0.7	0.8	1.6	1.5	0.7	2.4
3.4	1.5	0.6	2.4	1.5	1.6	0.6	0.5	2.4	2.1	4.1	0.8	1.9	2.6	0.6	2.5	1.3	2.9
0.9	1.8	1.7	1.4	0.5	1.9	1.2	1.9	2.1	0.4	1.8	1.1	0.7	2.1	0.9	1.1	2.9	3.9
1.2	0.5	3.1	0.5	2.7	0.2	1.3	0.6	0.7	0.6	2.4	1.4	1.8	0.9	3.1	1.1	2.6	3.4
0.9	1.1	2.4	0.4	1.3	2.1	1.1	1.1	1.1	1.2	0.7	1.1	0.9	1.1	1.8	1.3	1.7	2.4
2.9	0.9	1.4	0.8	0.4	0.7	1.7	0.8	0.6	0.9	0.8	2.7	2.4	1.1	2.3	0.3	0.6	6.2
0.3	1.8	0.8	1.3	1.4	0.6	1.8	1.4	2.3	1.4	0.7	0.9	1.9	1.6	2.3	2.4	4.1	4.5
0.8	0.5	1	1	0.5	1.1	3	0.4	0.4	1.5	2.1	1.7	1.4	2.6	1.7	2.2	2.3	1.4
1.3	2.1	1.6	0.9	1.6	1.3	1.2	1.2	0.8	1.1	1.6	1.2	1.2	2.6	0.3	3.6	4.2	4.9
0.4	1.2	1.4	1.6	2.1	0.2	0.7	2.2	1.7	0.8	2.4	3.4	1.7	0.5	0.4	3	3.8	
0.5	0.2	2.6	0.6	3.6	0.6	0.7	2.6	1.2	1.1	0.5	3.1	1.2	1.2	3.4	1.5	2.1	
0.2	2.1	1.8	0.8	2.8	2.8	1.3	2	1.1	0.4	1.8	2	0.8	1.2	3.4	0.8	2.5	
1.4	1.3	2.2	1.2	0.3	0.9	1.3	1.3	1.3	2.1	1.4	1.4	3.2	0.7	4.2	3.3	3.8	
1.4	0.7	0.6	2.6	0.4		0.7	2.1	2.1	1.6	1.4	0.8	1.8	0.9	2.1	1.5	2.8	
2.4	0.6	0.8	0.2	0.3		0.3	3.8	2.2	0.2	0.7	4.5	4.7	1.1	2.1	2.4	2.2	
2.3	0.4	1.1	0.8	0.4		1.3	1.1	1.3	1.1	2.2	1.4	1.8	1.4	1.7	1.8	3.2	
2.6	1.8	1	0.4	0.7		0.3	2.8	0.3	3.3	2.5	1.6	1.2	0.6	4.3	3.8	3.3	
1	0.9	0.7	0.6	1.5		0.3	3.7	1.2	3.1	1.1	0.5	2.1	2.2	1.4	1.6	2	
1.5	2	0.3	1.6	2.3		0.6	1.5	1.4	1.8	2.1	1.6	3.8	1.6	4.2	1.8	2.8	
0.6	0.7	0.9	0.2	0.6		0.3	2.3	0.9	0.8		0.4	2.3	1.4		1.5	0.6	
0.4	0.9	1.3	0.2	1.8		0.9	1.6	3.1	1.1		1	1.9	1.1		1.2	5.1	
3.2	1.1	1.1	1.6	1.3		1.4	2	0.8	1.4		0.5	4.8	1.2		1.6	3.5	
1.2	0.8	2.1	0.5	1.6		1.6	4.6	1.3	0.4		0.6	2.4	0.8		0.2	1.8	
0.6	1.1	0.9	1.8	0.5		0.9	1.1	0.8	0.7		0.7	2.1	2.1		0.7	3.9	
0.5	0.3	2.2	0.6	0.2		2.1	0.9	2.1	1.3		1.6	1.6	1.3		0.6	2.8	
0.2	2.2	1.3	0.2	0.7		1.2	0.4	2.1	0.8		1.1	1.2	1.3		1.4	2.5	
1.8	1.2	0.5	0.1	1.1		0.8	2.4	0.7	0.9		0.6	2.3	2.1		1.3	2.8	
1.3	2.7	1.6	0.3	1.3		2.3	2.3	1.3	1.3		1.9	2.3	2.6		2.4	5.1	
0.8	1.2	0.8	1	0.5		2.9	1.2	0.9	1.2		0.7	1.2	4.1		2.3	1.1	
1.4	0.5	1.2	0.4	0.8		0.7	2.4	2.1	1.3		0.5	2.2	0.7		2.1	3.1	
1.1	0.6	1.4	3.4	5.1		1.1	0.5	0.7	0.6		1.3	0.5	1.3		2.1	2.3	
1.3	2.2	3.4	1.3	1.6		1	3.1	2.9	1.1		1.7	1.4	1.2		4.8		
0.8	0.9	1.5	1.2	0.7		0.4	3.7	2.1	3.9		1.4	2.3	0.9		3.4		
0.7	0.4	2.1	0.6	1.8		3.4	1.1	1.2	0.9		1.6	1.4	1.2		2.3		
1.4	1.2	1.2	0.5	0.4		0.9	1.2	2.7	0.7		1.2	1.4	1.4		1.8		
0.5	1.8	1.7	0.8	0.6		0.7	1.8	1.2	0.4		0.9	1.6	1.6		4.1		
0.3	0.9	0.6	0.5	2.4		1.8	1.7	1.2	1		0.6	2.4	0.7		1.2		
1.2	0.2	0.6	1.1	1.1		1.5	2.4	0.5	1.1		1.6	1.9	1.3		2.5		
2.6	0.3	1.4	0.8	2		0.5	2.6	0.2	0.5		0.8	2.6	2.1		3.8		
0.6	0.5	0.8	2.2	0.9		1.3	1.7	2.1	2.9		1.3	1.7	0.6		2.2		
2.6	1.4	2.5	0.2	0.5		0.7	0.7	2.2	1.8		1.4	0.6	1.4		2		
1.1	0.3	1.6	1.1	0.6		0.7	0.5	1.3	1.8		1.8	0.5	1.2		1.1		
1.3	2.4	0.6	0.6	0.4		0.8	1.3	0.7	1.2		1.8	1.3	2.4		1.1		
0.1	1.4	0.8	1.7	1.8		1.3	2.7	0.6	0.6		0.7	2	0.9		2		
1.8	1.1	1.2	0.3	0.6		1	0.8	2.5	2.3		1.5	1.8	1.4		1.7		
0.6	3.1	1.3	0.6	4.5		0.8	3.1	0.3	1.3		3.4	1.1	1.4		2.1		
1.6	1.5	0.7	1.7	0.2		0.6	0.7	0.4	2.8		2.2	1.2	1.8		1.3		
0.9	0.3	2.3	1.5	0.8		0.7	1.8	3.1	4.1		1.6	1.4	0.6		1.7		
0.3	0.2	1.2	0.5	3.4		0.7	0.7	1	0.8		1.7	0.6	2.5		0.7		

APPENDIX 2 BIOMASS DATA

Size Class (cm)	DBH (cm)	Weight (kg)	Ave Wt (kg)	Size Class	DBH (cm)	Weight (kg)	Ave Wt (kg)
0 - 2.5	0.4	0.8		5 - 10	5.4	23.2	
	0.6	1.7			5.8	26.4	
	1.2	1.2			6.5	32.3	
	1.5	3.1			6.6	34.5	
	1.8	4.2			6.9	35.6	
	1.9	3.8			7.6	43.2	
	2.2	4.8			8.2	48.9	
	2.2	5.3			8.9	41.5	
	2.4	5.8			9.2	64.8	
	2.4	7.3	3.8		9.8	81.2	43.16
2.5 - 5	2.5	6.3		10 - 15	10.2	80.3	
	2.8	6.8			10.6	94.5	
	3.1	8.1			10.8	97.1	
	3.1	6.8			11.5	109.8	
	3.3	9.8			11.9	129.2	
	3.8	12.4			12.6	154.8	
	4	11.4			12.7	188.6	
	4.2	15.7			13.4	224.7	
	4.6	17.4			14.1	238.6	
	4.8	19.8	11.45		14.8	255	157.26
				15 - 20	15.5	258	
					16.4	249	
					16.6	256	
					18	281	
					19.4	292	267.2

DBH - Diameter at breast height

Ave Wt - Average weight of trees measured

APPENDIX 3

CHANNEL CROSS SECTION DATA

Cross-section A		Cross-section B		Cross-section C		Cross-section D		Cross-section E		Cross-section F	
Distance	Height	Distance	Height	Distance	Height	Distance	Height	Distance	Height	Distance	Height
0.5	3	0	1.75	0	3	0.5	2.55	0	3	0	3
1	1.9	1	1.7	1	2.7	1	2.26	0.5	2.7	0.5	2.5
1.5	1.6	1.5	1.68	1.2	2.55	1.3	2.07	1	2.4	1	2
2	1.3	2	1.65	1.3	2.24	1.35	1.79	1.5	2.2	1.5	1.7
2.5	1.1	2.5	1.62	1.7	2.07	1.5	1.77	1.8	2.1	2	1.25
3	1	3	1.65	1.9	1.98	2	1.46	2	1.9	2.5	1.8
3.5	1	3.5	1.68	2.5	1.83	2.5	1.11	2.5	1	2.8	1.6
4	0.85	4	1.43	4	1.79	3	0.8	3	1.1	3	1.2
4.5	0.85	4.5	1.41	5	1.92	3.5	0.94	3.5	0.91	3.2	0.8
6.5	0.85	5	1.32	5.5	1.91	4	0.77	4	1.11	3.5	0.6
7	0.6	5.5	1.19	6	1.87	4.1	0.69	4.5	1.16	4	0.48
7.5	0.5	6	1.12	6.2	1.96	4.5	0.31	5	1.12	4.5	1.25
8	0.55	6.5	1.05	7	1.8	5	0.46	5.5	1.1	4.8	1.3
8.5	0.7	7	1.03	7.5	1.5	5.5	0.44	6	1.13	5	1.2
9	1.07	7.5	0.84	8	1.7	6	0.53	6.5	0.78	5.2	1.3
9.5	0.62	8	0.75	8.5	1.61	6.3	0.71	7	1.09	5.5	0.8
10	0.61	8.5	0.69	9	1.79	6.5	0.85	7.5	1.13	6	0.4
10.5	0.74	9	0.8	9.5	1.65	7	0.91	8	1.15	6.5	0.4
11	0.91	10.5	0.75	10	1.95	7.5	0.97	8.5	1.14	7	0.65
11.5	1	11	0.88	12	1.98	8	1.01	9	1.2	7.5	0.4
12	1.02	11.8	0.97	13.5	1.9	8.5	0.96	9.5	1.24	8	0.6
12.5	0.81	12	1.19	14.5	2.17	9	1.05	10	1.25	9.5	0.58
13	0.85	12.5	1.2	17.7	2.19	9.5	0.97	10.5	0.86	10	0.75
13.5	0.9	13	1.29	19	2.1	10	0.82	11	0.84	10.5	1.25
14	0.8	13.5	1.54	20	2.2	10.2	0.67	11.5	0.85	11	1.2
14.5	0.75	14	1.55			10.4	0.58	12	1.15	11.5	1.28
15	0.49	14.5	1.59			10.8	0.8	12.3	1.16	12	1.31
15.5	0.38	15	1.69			12	0.72	12.5	0.86	12.5	1.33
16	0.36	15.5	1.73			12.5	0.67	13	0.88	13	1.32
16.5	0.5	16	1.75			13	0.79	13.5	0.97	13.5	1.36
17	0.57	17	1.88			13.7	1	14	1.1	14	1.3
17.5	0.1	18	1.86			14	1.04	14.3	1.7	15	1.35
18	0.2	19	1.95			14.4	1.12	14.5	1.65	16	1.4
18.5	0.7	20	1.85			15	1.31	15	1.62	17	1.35
19	1.07					15.5	1.42	16	1.69	18	1.35
						16	1.58	17	1.67	19	1.2
						16.5	1.74	18	1.71	20	1.4
						16.8	1.91	19	1.68		
						17	3	20	1.73		

APPENDIX 4

HISTORICAL RAINFALL DATA

AND

DAILY RAINFALL (JANUARY - SEPTEMBER 1996)

MEASURED AT SAND RIVER DAM

SAND RIVER DAM

HISTORICAL RAINFALL (mm)

YEAR	TOTAL	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1908	693.7	37.6	22.9	49.3	163.1	17.0	34.5	18.5	52.6	38.9	130.3	79.5	49.5
1909	676.2	61.7	50.3	39.6	66.8	42.2	4.6	18.5	63.2	93.0	93.0	46.0	97.3
1910	639.2	26.4	131.6	83.3	23.9	83.1	19.8	6.4	8.9	37.1	114.3	57.4	47.0
1911	701.2	85.1	31.5	91.4	38.1	69.6	67.1	15.2	35.3	143.0	87.6	32.5	4.8
1912	880.6	113.8	47.8	26.2	239.8	10.7	90.7	35.6	48.3	118.9	61.0	25.1	62.7
1913	618.8	29.0	113.8	89.7	14.2	41.9	8.1	41.9	39.4	133.6	63.5	31.8	11.9
1914	642.5	55.9	57.2	32.3	75.4	48.8	32.3	59.2	34.3	12.7	59.9	145.8	28.7
1915	519.7	57.7	16.3	33.0	80.3	29.2	18.8	99.3	23.6	21.3	55.1	29.7	55.4
1916	500.5	61.2	7.9	108.5	30.0	111.0	7.9	38.1	30.5	32.3	18.0	21.6	33.5
1917	843.6	25.7	29.0	82.3	80.8	18.0	129.0	67.1	53.3	66.3	237.2	42.7	12.2
1918	552.8	69.1	26.2	123.4	22.1	80.8	26.9	17.0	18.3	55.4	60.2	3.6	49.6
1919	528.2	14.7	122.2	42.7	77.0	37.8	39.4	8.1	47.8	12.2	76.7	38.9	10.7
1920	747.6	20.8	186.9	85.9	43.7	50.8	30.7	38.1	35.6	10.2	93.5	65.0	86.4
1921	734.8	33.0	52.8	112.0	69.1	43.4	36.8	25.7	31.5	60.7	26.2	96.5	147.1
1922	961.3	39.9	50.8	75.2	91.9	101.3	27.9	119.1	25.4	52.3	63.0	280.2	34.3
1923	665.5	82.3	72.4	51.3	67.3	30.2	45.2	48.5	18.3	31.5	54.6	83.6	80.3
1924	620.2	53.1	39.4	29.0	16.0	34.8	32.3	15.7	73.9	85.3	34.5	26.2	80.0
1925	654.8	22.4	35.1	53.3	78.2	47.5	30.7	26.7	47.5	107.2	45.7	53.1	107.4
1926	543.9	33.8	18.0	67.6	13.0	52.3	33.0	38.4	38.9	35.6	74.9	116.6	21.8
1927	394.0	31.5	36.3	111.8	3.6	57.4	9.1	17.5	38.1	10.2	30.0	26.9	21.6
1928	755.1	25.4	38.1	290.8	20.3	8.6	34.3	17.8	45.7	66.5	76.2	77.0	54.4
1929	528.8	11.9	33.3	47.0	29.2	31.8	50.5	63.2	43.2	116.8	56.9	10.2	34.8
1930	594.3	24.1	87.6	84.3	33.8	30.0	66.0	19.8	63.8	43.9	91.7	13.0	36.3
1931	595.0	43.4	4.6	56.4	48.0	16.8	7.9	61.2	14.0	108.2	105.2	8.4	120.9
1932	845.6	117.9	50.8	81.5	3.3	27.2	26.4	106.9	9.1	200.2	69.1	120.7	32.5
1933	896.7	15.7	92.2	47.5	126.0	36.6	25.4	10.9	150.1	269.0	19.1	65.8	38.4
1934	754.2	64.5	59.9	82.6	48.0	28.7	20.6	145.3	39.6	23.4	168.4	63.0	10.2
1935	810.3	24.1	49.8	34.5	73.2	197.6	71.9	34.3	57.9	48.3	71.6	102.6	44.5
1936	670.8	28.2	42.4	86.1	42.4	65.8	6.1	54.6	2.5	21.6	92.2	189.0	39.9
1937	570.0	30.5	32.5	51.3	13.2	13.7	44.2	54.6	12.7	55.4	70.9	96.0	95.0
1938	471.0	56.9	21.6	32.3	43.9	36.1	19.3	21.8	30.5	22.1	61.0	89.7	33.8
1939	733.7	30.5	123.7	99.1	70.1	26.4	6.9	53.6	130.6	37.3	64.3	58.4	32.8
1940	528.2	49.8	67.1	68.8	16.5	25.9	16.8	49.8	1.3	55.1	35.1	132.6	9.4
1941	643.1	52.1	48.0	53.8	92.5	4.3	81.0	6.4	39.6	19.8	127.8	37.8	80.0
1942	529.6	63.5	20.3	27.9	37.1	52.3	55.4	19.3	30.5	13.5	129.5	47.0	33.3
1943	709.0	88.6	23.4	53.1	70.6	9.1	97.5	21.8	41.1	54.4	16.3	183.6	49.5
1944	970.8	34.8	75.7	117.9	48.5	418.6	25.7	36.6	15.0	96.3	60.5	19.6	21.6
1945	587.6	28.2	65.0	33.0	8.4	146.1	99.6	22.6	33.8	22.4	97.5	0.0	31.0
1946	631.9	13.0	75.2	131.1	30.5	20.8	25.9	47.2	46.0	39.6	62.0	28.2	12.4
1947	580.8	28.2	28.2	89.2	38.9	90.2	66.0	74.7	6.4	30.2	62.5	45.0	21.3
1948	526.6	33.3	19.1	28.7	160.8	7.1	20.3	18.0	17.8	36.1	127.3	25.1	33.0
1949	481.5	51.3	35.1	26.7	41.1	25.7	0.8	28.4	13.5	19.1	7.4	227.1	5.3
1950	665.7	16.5	20.6	22.4	51.1	38.1	0.0	88.4	67.6	45.0	72.1	172.0	71.9
1951	711.8	222.3	51.6	36.3	4.6	23.4	42.9	78.2	37.1	123.4	22.4	13.5	56.1
1952	688.7	68.1	81.3	14.7	11.2	41.1	26.7	24.9	73.9	232.7	45.7	35.1	33.3
1953	711.3	47.0	22.6	21.8	14.5	1.0	43.7	35.3	37.8	77.7	259.3	101.1	49.5
1954	637.1	5.8	10.4	127.3	56.4	64.8	32.5	80.3	116.1	20.3	19.1	83.8	20.3
1955	653.7	36.8	180.6	80.3	16.5	25.4	24.1	6.4	50.8	36.8	32.0	132.8	31.2
1956	689.6	27.4	52.8	80.8	23.9	87.4	4.8	34.8	27.4	108.0	104.9	75.9	61.5
1957	589.7	27.7	112.8	75.4	43.4	32.5	52.3	19.1	31.2	113.5	48.3	7.6	25.9
1958	528.3	26.9	13.2	40.9	36.1	157.0	16.5	5.1	67.6	43.2	37.8	24.6	59.4
1959	650.6	64.8	43.2	69.3	102.9	36.8	17.8	63.0	98.6	26.7	47.0	37.3	43.2
1960	564.0	74.4	7.6	61.7	67.1	77.0	39.4	35.1	13.5	56.4	33.0	74.9	23.9
1961	503.7	37.6	29.2	82.3	56.9	82.7	7.9	68.3	26.7	5.1	47.5	38.4	21.1
1962	573.5	44.2	46.5	90.9	50.0	21.1	5.1	20.3	78.0	16.5	102.6	88.9	9.4
1963	877.7	145.8	3.3	192.3	151.6	52.1	10.2	38.9	71.1	18.3	45.2	73.2	75.7
1964	652.1	50.8	34.3	47.0	27.7	3.8	78.7	15.7	77.0	173.0	61.5	46.0	36.6
1965	718.5	22.9	21.6	82.0	38.1	79.2	29.5	41.1	10.9	39.6	146.6	141.0	66.0
1966	525.3	72.6	40.1	18.5	50.3	41.1	1.8	28.2	54.6	41.1	32.5	103.1	41.4
1967	671.0	9.7	36.6	55.6	220.0	128.0	9.7	50.3	22.9	62.7	25.9	30.5	19.1

YEAR	TOTAL	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1968	788.9	0.0	7.6	38.1	109.5	36.6	257.0	24.1	25.4	219.7	28.7	29.2	13.0
1969	368.1	14.0	36.1	61.0	32.8	5.1	46.0	15.2	32.5	46.5	60.2	13.2	5.6
1970	374.2	20.6	39.9	14.5	8.1	0.0	3.8	5.8	61.2	13.7	99.3	9.2	93.1
1971	837.3	44.2	79.3	71.9	140.2	98.9	9.9	71.4	185.7	1.3	24.4	50.3	59.9
1972	329.4	15.0	36.1	49.0	10.7	35.0	36.1	4.3	37.1	12.4	17.8	68.6	7.4
1973	484.5	9.7	62.5	62.4	56.1	49.8	13.5	10.5	29.6	17.3	38.2	111.0	24.0
1974	778.8	97.6	46.0	164.5	23.1	77.5	20.5	3.0	177.0	99.5	11.0	31.1	28.0
1975	580.8	42.5	44.0	74.5	17.5	3.0	46.5	30.5	68.5	141.8	10.7	42.4	58.9
1976	536.7	19.5	34.4	77.8	13.8	19.4	23.8	48.8	32.9	27.8	128.1	81.7	27.7
1977	678.5	20.7	134.6	35.9	76.0	121.6	31.5	4.3	22.1	34.6	48.6	76.0	72.6
1978	495.6	9.6	21.0	33.2	67.3	12.0	50.5	40.5	40.0	32.0	80.3	53.5	55.7
1979	790.0	47.0	43.2	13.8	16.5	42.7	53.0	202.6	243.5	40.0	56.2	6.0	25.5
1980	501.3	38.0	10.0	7.5	43.0	9.0	48.5	8.0	19.8	64.5	15.5	86.5	151.0
1981	610.8	104.0	34.7	*465.0	26.5	108.0	22.3	8.2	102.0	14.0	78.0	83.1	30.1
1982	363.2	27.0	12.0	40.2	85.3	4.0	35.3	36.8	30.5	36.0	43.3	5.0	7.8
1983	680.8	9.5	35.5	22.0	11.0	40.0	23.6	382.0	12.0	19.8	65.9	40.5	19.0
1984	268.8	25.5	10.5	48.7	8.0	13.8	27.5	23.5	15.5	19.8	6.0	42.0	28.0
1985	604.5	71.5	95.0	14.5	33.0	7.0	48.5	34.1	4.3	12.0	91.8	112.8	80.0
1986	456.9	49.0	48.0	35.6	11.6	3.0	21.2	23.0	49.7	24.0	122.2	33.8	35.8
1987	291.9	2.0	33.8	29.2	31.8	5.4	41.8	6.0	17.2	60.8	15.5	5.0	43.4
1988	521.2	17.9	68.2	37.2	118.0	13.4	20.4	16.0	50.2	26.6	65.4	44.4	43.5
1989	537.9	29.5	40.2	20.2	60.2	22.4	3.8	24.2	10.6	22.6	138.8	159.2	6.2
1990	378.2	21.7	63.5	66.0	24.2	28.4	46.8	5.6	34.0	22.4	35.8	17.6	12.2
1991	288.9	25.0	26.4	9.4	5.4	13.8	21.4	11.4	11.4	12.6	101.1	14.0	37.0
1992	613.4	19.4	83.6	15.0	28.4	13.2	23.0	50.3	50.3	46.5	160.0	116.7	7.0
1993	782.3	65.0	58.8	11.1	68.0	43.3	135.0	2.0	40.0	194.0	27.6	50.5	87.0
1994	543.6	29.5	55.0	53.0	20.5	15.0	25.0	44.6	115.0	16.0	45.0	12.5	112.5
1995	393.0	67.0	63.0	59.5	39.0	32.0	21.0	4.0	36.0	27.5	34.0	75	106
TOTAL		3815.68	4373.09	5386.58	4598.40	4193.00	3193.97	3597.52	4126.17	5102.61	5984.50	5617.77	3835.03
AVERAGE	611.64	43.36	49.69	61.21	52.25	47.65	36.30	40.88	46.89	57.98	68.01	63.84	43.56
* Estimated reading													

SAND RIVER DAM DAILY RAINFALL

1996	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0	0	0	3	0	0	0	0	0
2	0	0	20	0	1	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	4	0
5	0	0	0	0	1	0	20	16	0
6	0	3	0	0	0	0	3	3	0
7	0	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	2	0	0	0	0	2
10	0	0	0	0	0	0	0	0	1
11	0	4	0	0	0	0	0	0	1
12	0	0	0	0	0	0	0	0	6
13	0	0	0	0	0	0	0	1	7
14	9	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	8	0	0
16	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	7
18	13	0	0	0	0	0	0	6	11
19	0	0	0	0	0	0	0	2.5	0
20	12	0	0	0	0	0	0	0	0
21	0	0	2	0	0	0	0	0	0
22	0	0	0	0	0	0	0.8	0	0
23	3	0	0	0	0	0	0	0	0
24	2	0	0	0	4	0	0	0	0
25	3.6	0	0	0	0	0	0	0	0
26	15	7	0	0	0	0	0	4	0
27	0	0	2	0	0	0	0	0	0
28	0	2	6	0	0	0	0	0	0
29	1	0	0	0	0	0	0	0	0
30	0		0	0	0	0	0	0	0
31	0		2		2		0	0	
Total	58.6	17	32	5	8	0	31.8	36.5	35

APPENDIX 5

OPEN WATER EVAPORATION
(GROENDAL AND LOERIE DAMS)

Potential Evaporation (mm) - Groendal Dam

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1975	183	132	124	108	91	64	76	104	76	149	150	154
1976	187	155	108	95	75	77	68	83	80	105	181	210
1977	190	123	136	82	71	68	81	101	88	138	132	195
1978	168	133	129	92	72	71	63	86	127	135	172	160
1979	159	148	146	99	75	73	75	70	109	144	171	187
1980	183	166	152	117	101	63	80	84	103	156	148	178
1981	170	121	125	104	60	53	77	67	115	156	139	172
1982	193	149	119	80	78	75	60	101	87	133	163	226
1983	208	154	136	105	96	78	97	97	99	113	138	186
1984	198	185	127	124	107	81	77	90	116	141	164	216
1985	164	105	146	111	92	70	69	101	114	130	121	157
1986	176	155	128	92	96	81	73	80	122	112	148	147
1987	178	140	112	100	91	63	81	92	72	117	152	173
1988	165	131	111	90	73	63	71	90	101	123	134	162
1989	186	123	135	81	66	58	89	92	106	138	119	183
1990	189	151	96	90	74	65	68	89	109	131	135	135
1991	135	135	138	133	103	62	75	83	121	104	132	178
1992	198	142	125	95	92	89	101	92	95	131	138	185
1993	188	157	146	111	78	68	92	82	106	117	160	162
1994	142	127	125	109	84	104	78	67	120	137	171	163
1995	166	121	106	84	79	75	105	103	101	125	138	130
Average	177.4	140.6	127.1	100.1	83.52	71.48	78.86	88.29	103.2	130.2	147.9	174.2

1995/96	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0	4.8	4	6.5	5	6.4	2.4	6	3	2	2	4
2	4.5	3.5	7	5	6	5	3	1.1	2	3.5	3	4.5
3	2.5	2	6	6	7.5	6.8	4	2.5	2	4	2.3	4.5
4	2	4	4.6	8	6.5	3	4	2.5	2	4.5	1.1	4
5	6	5.5	8	8	7.5	5.5	5	1.2	2.5	2	1.2	5.5
6	6	5.5	5.5	1.4	6.1	7	4.5	2	4	1	1	4.5
7	4	6.5	3.8	4	7	5.5	4	3	4.5	1	2	4
8	3.2	3	2.5	7	7	2	3.5	2	2	1.5	3	5.5
9	0.2	1.5	5.5	6	3.5	1	4.5	5	2	2	6	2.2
10	2	5	3	6	1.4	3	2	3	2	2.5	4	0.5
11	6	8	6	5.3	2.1	7.5	2.5	3	4.5	4	2	1.2
12	2.8	6	7	1.5	8.5	4	3	2.5	2.5	5.5	4	3.8
13	4.5	7	4	0.9	4.5	3.5	3	3	3.5	2.5	4	0
14	4.5	6.5	1	7.6	3	4	3	2	5.5	3	2.5	1.5
15	4	6	2.2	6	3.5	4.5	4	2	7	2.2	3.5	3.5
16	4.5	3	0.3	5	3.5	2	3	2	6	2	2.2	3
17	5.5	4.5	0	7	6.6	4.5	3	2	3	2	3	0.9
18	6	2	5.9	1	2	5	1.5	2.5	2	2.5	3.5	2
19	1.6	6	4.5	2	8	5	4.5	4	3	2.5	1.7	4
20	4	6	5.5	4.4	2.5	2	3	4.5	1.5	1.5	1	6
21	3	5	2.2	4.5	5	4	3.5	3	2	2	3	5
22	1.5	6.8	2.4	5.5	3	5	3	3	4.5	1	3	2
23	2.2	1.4	0	3.5	2	7	3.5	2.5	5	1.5	4	4
24	2.8	6.5	3.3	3	0.5	2	3	0.2	2	2	3	5
25	6.8	1.7	3.4	0.6	1.1	5	2.5	1.5	2	1.5	4	7
26	6	3.5	4.5	1.7	0.4	5	2.5	1.5	3	1.5	4.8	5.5
27	6	6.5	4.5	5	5	1.5	3	3.5	2.5	3	3.5	4.5
28	5.5	4.5	4.1	5	4.5	0	2.5	2.5	3	2	3.5	7
29	5.5	1.9	6.5	6.4	3.5	1.5	3.5	4.5	5.5	2.5	3	5
30	6	4.2	7	5		3.5	6	4.5	4.5	2	6.5	4.5
31	6		5.5	7		0.6		1.9		2	3	
Total	125.1	138.3	129.7	145.8	126.7	122.3	100.4	84.4	98.5	72.7	94.3	114.6

Potential Evaporation (mm) - Loerie Dam

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1975	194	161	136	105	95	47	64	75	59	159	157	147
1976	182	143	114	87	59	65	75	63	61	96	166	193
1977	172	129	130	93	68	68	70	80	81	134	126	171
1978	191	171	135	96	73	52	46	75	103	128	114	182
1979	181	158	142	85	64	60	66	61	103	138	182	195
1980	190	171	146	110	95	56	67	74	102	141	153	176
1981	185	135	130	94	54	55	60	56	114	141	149	180
1982	191	151	118	88	75	57	60	85	86	140	181	234
1983	213	159	137	107	103	61	83	82	100	119	124	180
1984	193	182	123	115	96	67	66	80	99	143	170	185
1985	161	117	148	104	73	56	48	79	101	109	138	173
1986	193	172	148	88	86	69	69	61	105	106	148	169
1987	190	139	121	99	82	59	73	86	99	158	192	215
1988	207	173	140	110	89	64	71	91	121	155	180	213
1989	231	166	164	115	95	62	78	92	118	150	175	195
1990	215	168	160	120	98	61	80	96	122	154	165	198
1991	205	170	157	128	103	60	84	99	117	156	155	203
1992	221	185	136	110	97	77	90	75	104	135	150	171
1993	213	161	154	114	81	89	66	86	106	115	172	191
1994	173	167	136	115	76	72	60	104	102	149	179	165
1995	178	135	127	88	66	38	78	76	85	137	144	168
Average	194.24	157.76	138.19	103.4	82.29	61.67	69.24	79.81	99.43	136.33	158.1	185.9

1995/96	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT
1	0	0.6	6	9	5.5	5.8	1.5	4	3	2	2	3
2	3	4	5.5	4	6.5	5	4.5	2.5	3	2.5	2	4
3	3.4	2.5	5.5	6.5	7.7	3.4	4	2	2	2.3	1.8	4
4	3.5	5.8	4.8	8.5	7	4	5	2.4	2	3	3.1	3.5
5	4.5	5	7	8	9.5	6	4	2	3	2.3	0.3	6.5
6	6.5	5	4.6	3	5.5	5	4.2	2.5	2	0	1	5
7	4.5	5	6.5	5.5	6.6	5	4	3	2.5	1	2	4
8	3.8	4.5	4.5	5.5	6.5	1.3	4.8	1.5	3	1	2.5	4
9	1	5	5	7	5.3	1	5.2	3.5	3	1	3.5	1.3
10	3	5	3.1	6.5	4.2	4.5	2	3	2	2	3	1.1
11	3	7	6.5	6	4.2	5.5	4	2.5	0.7	4	3	1
12	3.1	6	6	4.5	6.5	3.5	4	1.5	2	3	3	1.8
13	4	6	8.3	2	5.5	8.1	3	2.5	3	2	3.6	1
14	5	5.5	3.2	5	2.5	4	3.5	3	4.5	3	1.5	3
15	5	4.7	4	5.5	5.5	4	4.5	2	4.5	2.1	4	4.5
16	4	5.6	5.6	8.8	4.7	5	4	5	6	1	2.4	2.9
17	6	5	2.8	7	2.1	5.5	3.5	3.1	3.5	3	3	1.8
18	6	3	5.3	2.6	6	5.5	3.5	3.1	2	2	5.1	3.2
19	3.6	5.5	7.1	9	1.5	6.5	3.5	2.6	2.5	1.5	3	3
20	3	7	8.5	2.6	5	2	3.5	2.6	2	1.5	0.6	4
21	11.7	5	4	6.5	6.5	5	1.5	2	1	1	4.5	4
22	2.3	4.5	2.2	4	3.5	4.5	2	2.5	5	1	2.5	4
23	1.8	4.3	3.9	4.4	4	5	3	2	1	2	3.5	3
24	2.2	7.1	4.4	3.9	1	7	2	0	1	3	3.5	5
25	6.1	3.2	3.4	0.9	2	5	2.8	2	2.5	0.8	3	5.3
26	4	4	5.4	5.3	3.1	3	3	2.5	3	1	3.6	5
27	6	6	3.7	4	3	6.4	3	2.5	1.5	3	3	5
28	6	3.5	5	4	7.5	2	3	3	2	2.5	3	5
29	6.5	5	6	6	4	1.7	4	4	4	1.3	3	4.5
30	5.5	3.6	7.5	7		4	4.5	4.5	1	2.5	6	1.7
31	9.3		12.5	6.5		1.6		1.3		2.5	3	
Total	137.3	143.9	167.8	169	142.4	135.8	105	80.6	78.2	-60.8	89	105.1

APPENDIX 6

WEIR CONSTRUCTION REPORT

TOESTEMMING OM EIENDOM TE BETREE

Hiermee gee ek, die ondergetekende,

NAAM: L. WONKHORE

ADRES: "FIRGROVE" ROOKLANDS.

TELEFOON: 9555876

as eienaar/gevolmagtigde van eienaar van die eiendom:

PLAAS:

OMGEWING: UITENHAGE

die Direkteur-generaal van die Departement van Waterwese en Bosbou of sy gevolmagtigdes, toestemming om bogenoemde eiendom te betree met die nodige vervoermiddel en toerusting ten einde ondersoeke te doen na die geskiktheid van terreine vir die oprig van meetstruktuur(e).

Toestemming word ook verleen vir die reg van toegang vir die maak van toegangspad en oprig van die struktuur, indien die terrein geskik is. Reg van toegang word ook behou vir onderhoud, waarneming en enige ander verbandhoudende werke in verband met die struktuur.

Alle uitheemse plantegroei wat vir navorsingdoeleindes verwyder word, moet op hope gepak word waar die hout vir enige doel aangewend kan word.

GETEKEN op die 18 dag van OKTOBER 1995

te UITENHAGE

EIENAAR/GEVOLMAGTIGDE

GETUIE 1 GETUIE 2

TOESTEMMING OM EIENDOM TE BETREE

Hiermee gee ek, die ondergetekende,

NAAM: BADEN D. RUSSOUW

ADRES: DEEL 374 TRISHA FARM ELANDSRIVIER DIST. UITENHAGE.

TELEFOON: 041-9555586

as eienaar/~~gevolmagtigde van eienaar van die eiendom~~:

PLAAS: TRISHA FARM ELANDSRIVIER

OMGEWING: DIST. UITENHAGE

die Direkteur-generaal van die Departement van Waterwese en Bosbou of sy gevolmagtigdes, toestemming om bogenoemde eiendom te betree met die nodige vervoermiddel en toerusting ten einde ondersoeke te doen na die geskiktheid van terreine vir die oprig van meetstruktuur(e).

Toestemming word ook verleen vir die reg van toegang vir die maak van toegangspad en oprig van die struktuur, indien die terrein geskik is. Reg van toegang word ook behou vir onderhoud, waarneming en enige ander verbandhoudende werke in verband met die struktuur.

Alle uitheemse plantegroei wat vir navorsingdoeleindes verwyder word, moet op hope gepak word waar die hout vir enige doel aangewend kan word.

GETEKEN op die 17de dag van OKTOBER 1995

te UITENHAGE

EIENAAR/GEVOLMAGTIGDE

RUSSOUW

GETUIE 1 GETUIE 2

NOTES

1) Design capacity = 0.247 m^3/s

2) Weir limit = 0.200m

3) Low notch to be manufactured of 5mm mild steel.

4) The low notch are to be sealed with "THIOFLEX 600" to the concrete.

5) Concrete strength = 20 MPa

6) Concrete mix ratio = 1 : 3 : 5

7) Where possible the walls have to be anchored with Dowels

8) Dowels = 400mm R12, 200mm sunk.

9) Steel reinforcement of the walls = REF 245

10) Concrete mixer to be used.

11) Ready Mix only to be used when assured that no flora will be damaged.

12) The low notch will be manufactured by an outside institution.

13) All construction waste to be removed at completion of project.

14) No trees, shrubs or plants may be removed or damaged during construction.

15) All neccesary materials will be supplied by this office.

16) All construction and clearance works must be completed by 15 Desember 1995.

17) All construction works to be done under supervision.

18) The weir sites will be shown to the Superintendent

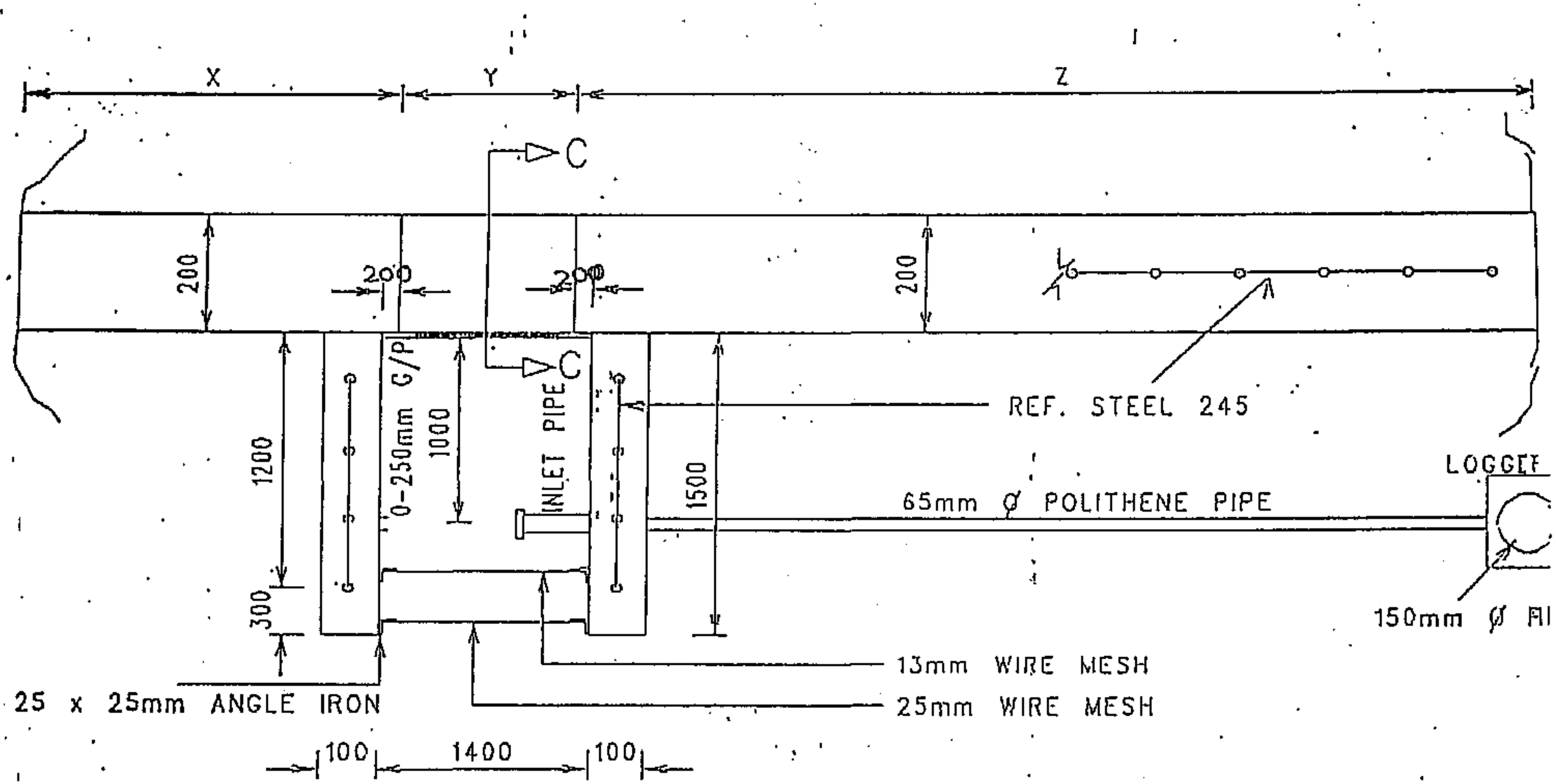
19) Permission to enter private property to be acquired before construction commenses.

20) The low notches must be kept clean using wire mesh as seen on the plan section.

21) The wire mesh frame must have an opening of 100mm above ground level to ensure that the debris will have no effect on the flow.

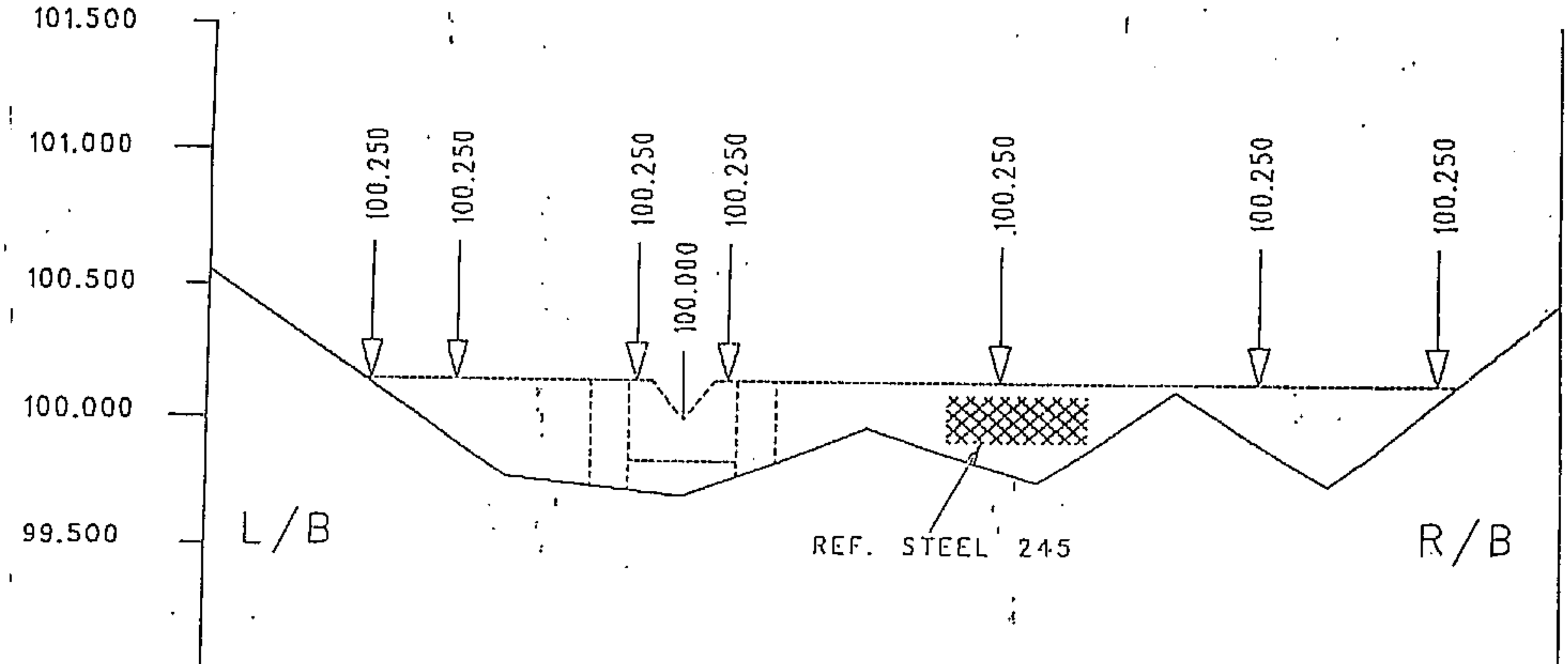
PRELIMINARY COSTING LIST

MATERIAL	AMOUNT	COST/ UNIT	COST FINAL
CEMENT (2000 kg)	41 BAGS	R 20,00	R 820,00
BUILDING SAND	6.5 m^3	R 45,00	R 292,50
STONE (19mm)	7.0 m^3	R 68,00	R 476,00
STEEL REINFORCING (R12)	60 m	R 1,35	R 81,00
DOLLY STEEL (6mm)	60 m	R 0,67	R 40.20
ANGLE IRON (40 x 40mm)	11.4 m	R 30,00	R 342,00
DEALS (3" x 4")	108m	R 10,00	R1080,00
BOARDS SHUTTER STANDARD	15 SHEETS	R150,00	R2250,00
NAILS ROUND (50mm)	10 kg	R 5,00	R 50,00
NAILS ROUND (100mm)	10 kg	R 5,50	R 55,00
NAILS ROUND (150mm)	10 kg	R 6,00	R 60,00
WIRE (5 kg)	1 ROLL	R 25,00	R 25,00
WIRE (50 kg)	1 ROLL	R200,00	R 200,00
STEEL ROUND (R20)	60 m	R 5,00	R 300,00
BOLTS & NUTS & WASHERS	24 SETS	R 4,00	R 96,00
ANGLE GRINDER BLADES	2	R 17,00	R 34,00
CUTTING BLADES	2	R 10,00	R 20,00
INLET PIPE 100mm ø	3 m	R 47,00	R 141,00
RING FLANGE 100mm ø	3	R 30,00	R 90,00
BLANK FLANGE 100mm ø	3	R 35,00	R 105,00
GAUGE PLATE (0-0,250m)	3	R 10,00	R 30,00
HILTI ANCHORS M12 x 70mm	40	R 2,98	R 119,20
BAGS EMPTY	50	R 0,50	R 25,00
		TOTAL COSTS =	R6923,90



TOP VIEW SECTION 1, 2 & 3

SCALE: N.T.S



CHAINAGE (m)	0.000	3.900	6.200	8.600	10.800	12.600	14.600	18.000
REDUCED LEVEL (m)	100.584	99.854	99.700	99.962	99.770	100.117	99.759	100.450

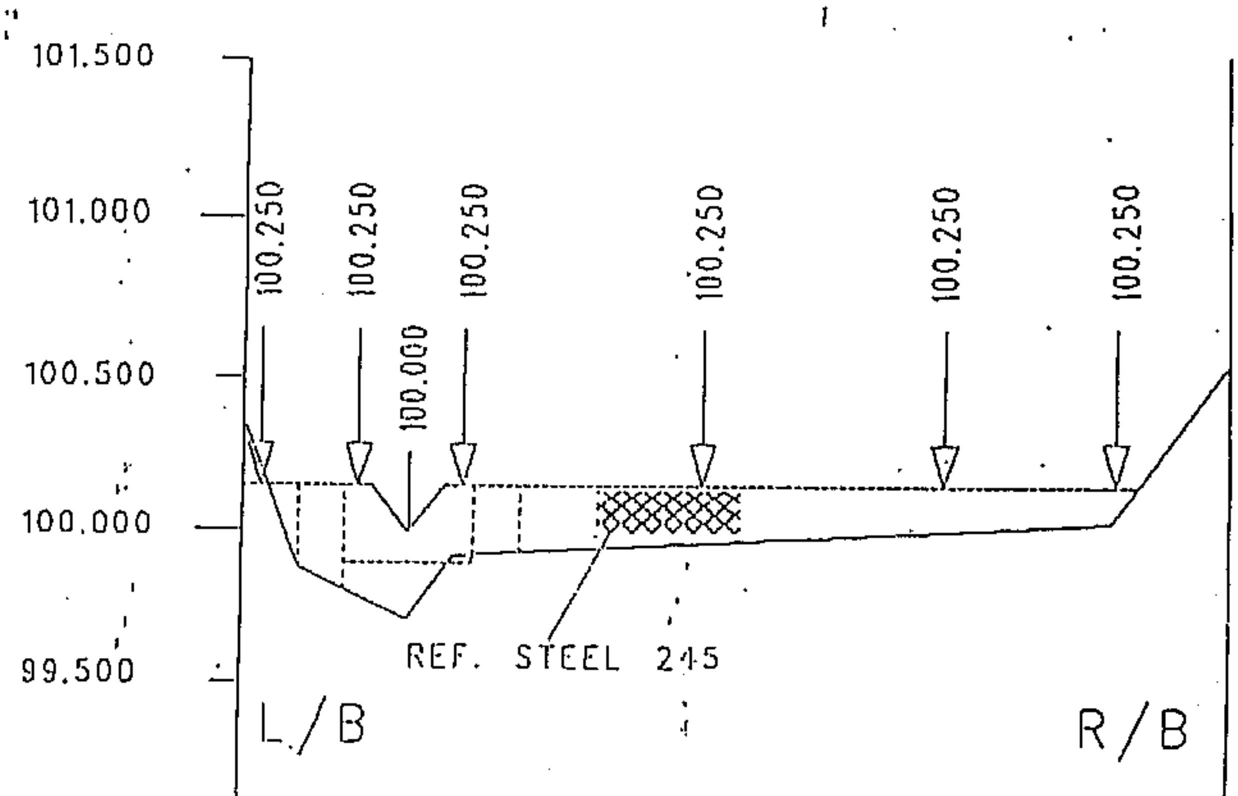
SECTION 1

CHAINAGE = 0.000m

SCALE: HOR 1:100
VERT 1:25

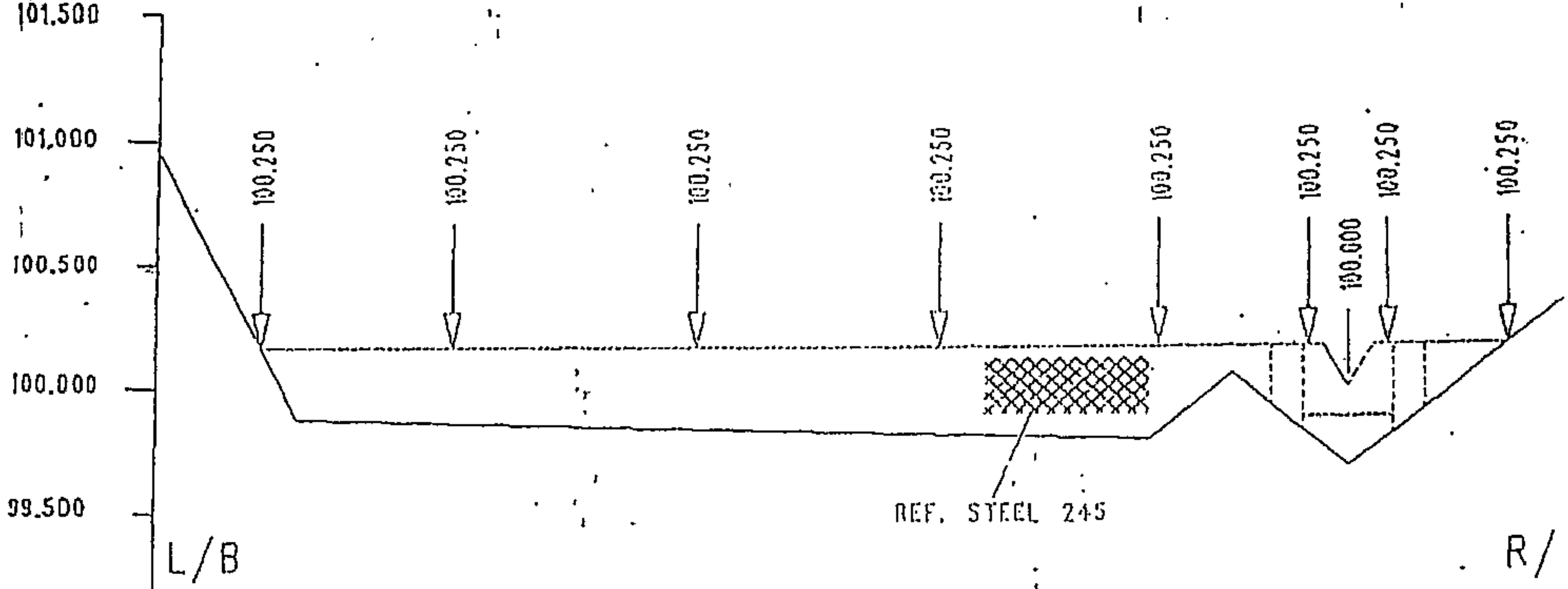
SECTION 2

SCALE: HOR 1:100
VERT 1:25



CHAINAGE AFSTAND (m)	REDUCED LEVEL (m)
0.000	100.348
0.600	99.869
1.800	99.700
2.300	99.925
9.300	100.071
10,600	100.547

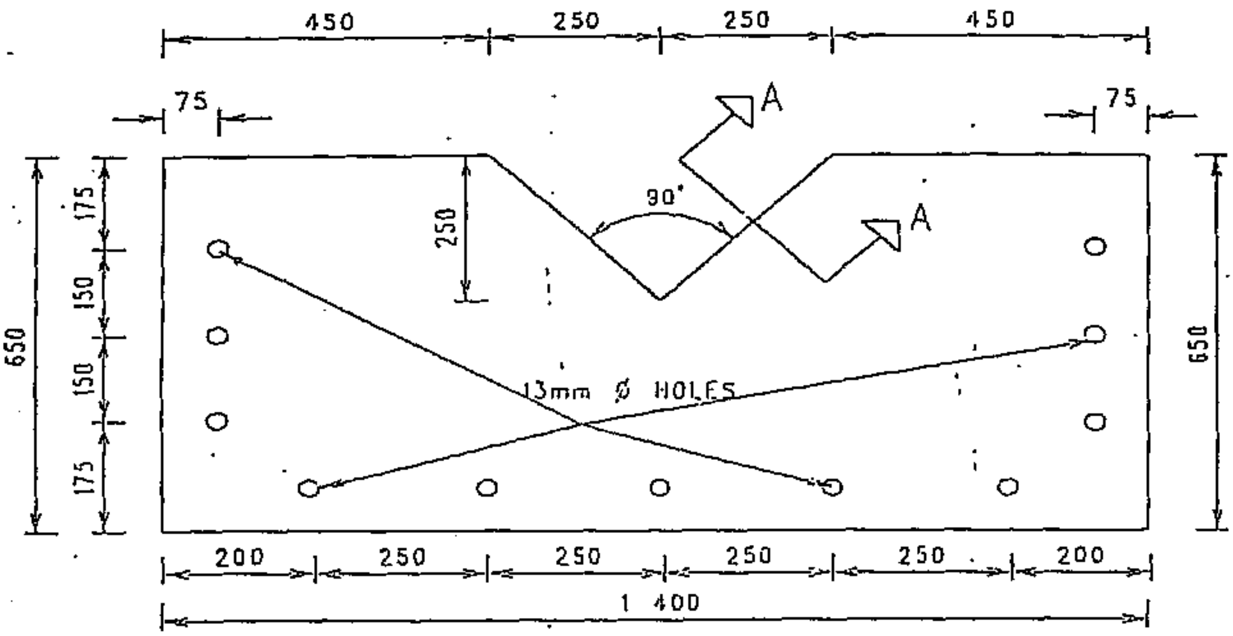
CHAINAGE = 500m



CHAINAGE (m)	0.000	2.300		15.900	17.200	13.000	
REDUCED LEVEL (m)	100.997	99.837		99.817	100.074	99.700	

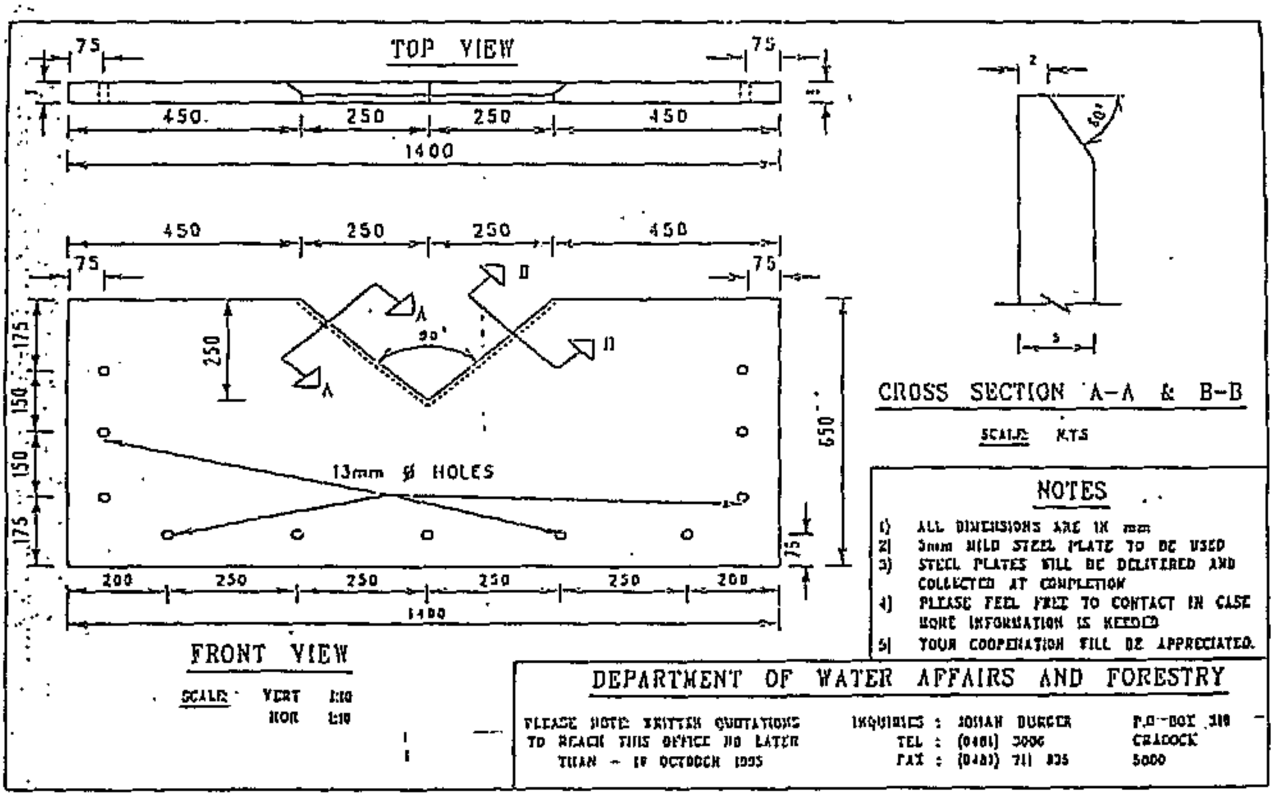
SECTION 3 CHAINAGE = 1000m

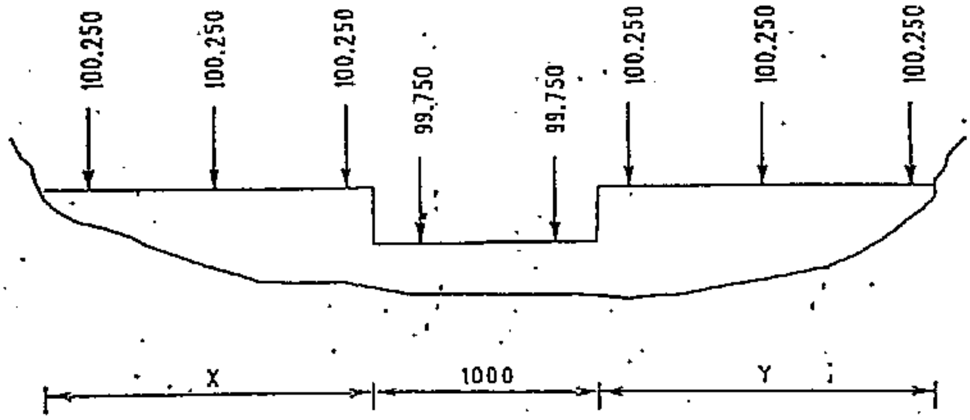
SCALE: HOR 1:100
VERT 1:25



LOW NOTCH

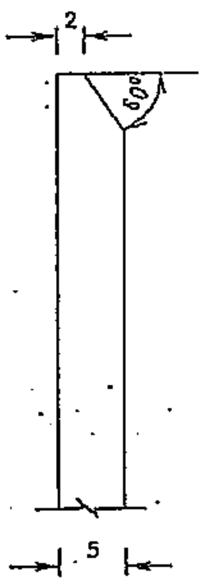
SCALE: HOR 1:10
VERT 1:10



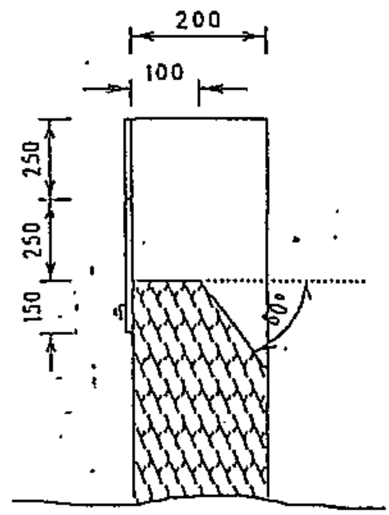


WEIR CONSTRUCTION
SECTIONS 1, 2 & 3

SCALE: N.T.S

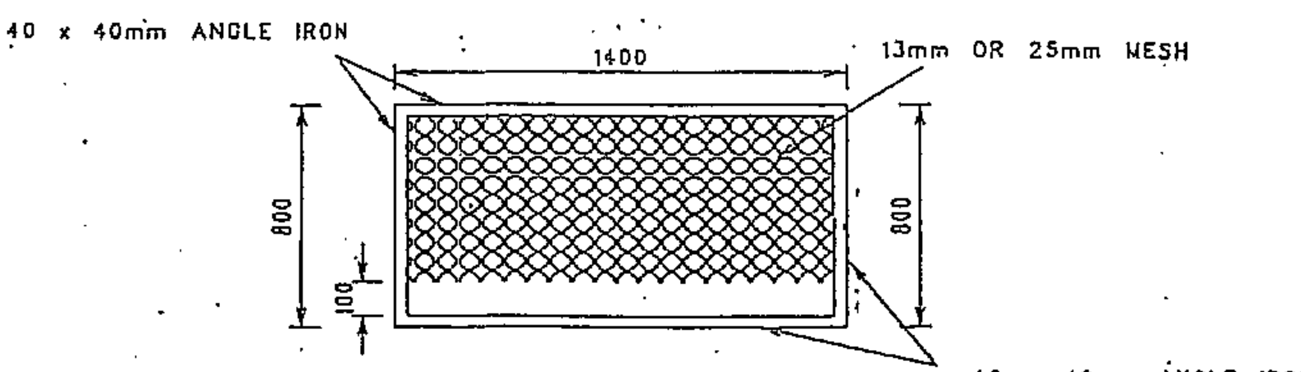


CROSS SECTION A–A



SECTION C–C

SCALE: N.T.S



OBSTRUCTION IN FRONT OF THE LOW NOTCHES

SCALE: N.T.S

APPENDIX 7

EXAMPLE OF RAW STREAMFLOW DATA

WEIR 1

SANDRIV001 000000S001 WATERVLAK
15/01/96 0.053 03:00 0.029 11:24

000000S001	0001	15/01/96	00:12	0.049
000000S001	0001	15/01/96	00:24	0.045
000000S001	0001	15/01/96	00:36	0.048
000000S001	0001	15/01/96	00:48	0.044
000000S001	0001	15/01/96	01:00	0.049
000000S001	0001	15/01/96	01:12	0.045
000000S001	0001	15/01/96	01:24	0.044
000000S001	0001	15/01/96	01:36	0.044
000000S001	0001	15/01/96	01:48	0.046
000000S001	0001	15/01/96	02:00	0.047
000000S001	0001	15/01/96	02:12	0.046
000000S001	0001	15/01/96	02:24	0.049
000000S001	0001	15/01/96	02:36	0.051
000000S001	0001	15/01/96	02:48	0.051
000000S001	0001	15/01/96	03:00	0.053
000000S001	0001	15/01/96	03:12	0.049
000000S001	0001	15/01/96	03:24	0.049
000000S001	0001	15/01/96	03:36	0.052
000000S001	0001	15/01/96	03:48	0.051
000000S001	0001	15/01/96	04:00	0.051
000000S001	0001	15/01/96	04:12	0.047
000000S001	0001	15/01/96	04:24	0.047
000000S001	0001	15/01/96	04:36	0.047
000000S001	0001	15/01/96	04:48	0.048
000000S001	0001	15/01/96	05:00	0.045
000000S001	0001	15/01/96	05:12	0.044
000000S001	0001	15/01/96	05:24	0.044
000000S001	0001	15/01/96	05:36	0.048
000000S001	0001	15/01/96	05:48	0.044
000000S001	0001	15/01/96	06:00	0.044
000000S001	0001	15/01/96	06:12	0.042
000000S001	0001	15/01/96	06:24	0.044
000000S001	0001	15/01/96	06:36	0.040
000000S001	0001	15/01/96	06:48	0.044
000000S001	0001	15/01/96	07:00	0.042
000000S001	0001	15/01/96	07:12	0.044
000000S001	0001	15/01/96	07:24	0.040
000000S001	0001	15/01/96	07:36	0.044
000000S001	0001	15/01/96	07:48	0.041
000000S001	0001	15/01/96	08:00	0.042

WEIR 2

SANDRIV002 0000000002 WATERVLAK

15/01/96 0.058 01:36 0.047 14:24

0000000002	0001	15/01/96	00:12	0.056
0000000002	0001	15/01/96	00:24	0.057
0000000002	0001	15/01/96	00:36	0.056
0000000002	0001	15/01/96	00:48	0.057
0000000002	0001	15/01/96	01:00	0.057
0000000002	0001	15/01/96	01:12	0.057
0000000002	0001	15/01/96	01:24	0.055
0000000002	0001	15/01/96	01:36	0.058
0000000002	0001	15/01/96	01:48	0.056
0000000002	0001	15/01/96	02:00	0.055
0000000002	0001	15/01/96	02:12	0.058
0000000002	0001	15/01/96	02:24	0.058
0000000002	0001	15/01/96	02:36	0.057
0000000002	0001	15/01/96	02:48	0.057
0000000002	0001	15/01/96	03:00	0.057
0000000002	0001	15/01/96	03:12	0.057
0000000002	0001	15/01/96	03:24	0.056
0000000002	0001	15/01/96	03:36	0.057
0000000002	0001	15/01/96	03:48	0.056
0000000002	0001	15/01/96	04:00	0.055
0000000002	0001	15/01/96	04:12	0.055
0000000002	0001	15/01/96	04:24	0.055
0000000002	0001	15/01/96	04:36	0.055
0000000002	0001	15/01/96	04:48	0.055
0000000002	0001	15/01/96	05:00	0.055
0000000002	0001	15/01/96	05:12	0.055
0000000002	0001	15/01/96	05:24	0.054
0000000002	0001	15/01/96	05:36	0.055
0000000002	0001	15/01/96	05:48	0.055
0000000002	0001	15/01/96	06:00	0.054
0000000002	0001	15/01/96	06:12	0.054
0000000002	0001	15/01/96	06:24	0.055
0000000002	0001	15/01/96	06:36	0.054
0000000002	0001	15/01/96	06:48	0.054
0000000002	0001	15/01/96	07:00	0.054
0000000002	0001	15/01/96	07:12	0.053
0000000002	0001	15/01/96	07:24	0.053
0000000002	0001	15/01/96	07:36	0.053
0000000002	0001	15/01/96	07:48	0.053
0000000002	0001	15/01/96	08:00	0.054

WEIR 3

SANDRIV003 000000S003 WATERVLAK

15/01/96 0.082 13:36 0.068 23:48

000000S003	0001	15/01/96	00:12	0.075
000000S003	0001	15/01/96	00:24	0.076
000000S003	0001	15/01/96	00:36	0.076
000000S003	0001	15/01/96	00:48	0.077
000000S003	0001	15/01/96	01:00	0.077
000000S003	0001	15/01/96	01:12	0.076
000000S003	0001	15/01/96	01:24	0.074
000000S003	0001	15/01/96	01:36	0.075
000000S003	0001	15/01/96	01:48	0.078
000000S003	0001	15/01/96	02:00	0.077
000000S003	0001	15/01/96	02:12	0.078
000000S003	0001	15/01/96	02:24	0.077
000000S003	0001	15/01/96	02:36	0.077
000000S003	0001	15/01/96	02:48	0.078
000000S003	0001	15/01/96	03:00	0.078
000000S003	0001	15/01/96	03:12	0.078
000000S003	0001	15/01/96	03:24	0.079
000000S003	0001	15/01/96	03:36	0.078
000000S003	0001	15/01/96	03:48	0.078
000000S003	0001	15/01/96	04:00	0.078
000000S003	0001	15/01/96	04:12	0.080
000000S003	0001	15/01/96	04:24	0.080
000000S003	0001	15/01/96	04:36	0.078
000000S003	0001	15/01/96	04:48	0.077
000000S003	0001	15/01/96	05:00	0.078
000000S003	0001	15/01/96	05:12	0.078
000000S003	0001	15/01/96	05:24	0.077
000000S003	0001	15/01/96	05:36	0.078
000000S003	0001	15/01/96	05:48	0.076
000000S003	0001	15/01/96	06:00	0.077
000000S003	0001	15/01/96	06:12	0.077
000000S003	0001	15/01/96	06:24	0.077
000000S003	0001	15/01/96	06:36	0.077
000000S003	0001	15/01/96	06:48	0.077
000000S003	0001	15/01/96	07:00	0.076
000000S003	0001	15/01/96	07:12	0.076
000000S003	0001	15/01/96	07:24	0.076
000000S003	0001	15/01/96	07:36	0.076
000000S003	0001	15/01/96	07:48	0.077
000000S003	0001	15/01/96	08:00	0.078

APPENDIX 8

EXAMPLE OF CONVERTED STREAMFLOW DATA

DATE	TIME	WEIR 1	WEIR 2	WEIR 3
15/01/96	00:12	0.049	0.056	0.075
	00:24	0.045	0.057	0.076
	00:36	0.048	0.056	0.076
	00:48	0.044	0.057	0.077
	01:00	0.049	0.057	0.077
	01:12	0.045	0.057	0.076
	01:24	0.044	0.055	0.074
	01:36	0.044	0.058	0.075
	01:48	0.046	0.056	0.078
	02:00	0.047	0.055	0.077
	02:12	0.046	0.058	0.078
	02:24	0.049	0.058	0.077
	02:36	0.051	0.057	0.077
	02:48	0.051	0.057	0.078
	03:00	0.053	0.057	0.078
	03:12	0.049	0.057	0.078
	03:24	0.049	0.056	0.079
	03:36	0.052	0.057	0.078
	03:48	0.051	0.056	0.078
	04:00	0.051	0.055	0.078
	04:12	0.047	0.055	0.08
	04:24	0.047	0.055	0.08
	04:36	0.047	0.055	0.078
	04:48	0.048	0.055	0.077
	05:00	0.045	0.055	0.078
	05:12	0.044	0.055	0.078
	05:24	0.044	0.054	0.077
	05:36	0.048	0.055	0.078
	05:48	0.044	0.055	0.076
	06:00	0.044	0.054	0.077
	06:12	0.042	0.054	0.077
	06:24	0.044	0.055	0.077
	06:36	0.04	0.054	0.077
	06:48	0.044	0.054	0.077
	07:00	0.042	0.054	0.076
	07:12	0.044	0.053	0.076
	07:24	0.04	0.053	0.076
	07:36	0.044	0.053	0.076
	07:48	0.041	0.053	0.077
	08:00	0.042	0.054	0.078
	08:12	0.039	0.054	0.075
	08:24	0.042	0.054	0.074
	08:36	0.039	0.053	0.074
	08:48	0.038	0.053	0.075
	09:00	0.042	0.053	0.077
	09:12	0.041	0.052	0.075
	09:24	0.039	0.053	0.074
	09:36	0.038	0.052	0.074
	09:48	0.038	0.052	0.074
	10:00	0.041	0.053	0.075
	10:12	0.038	0.053	0.074
	10:24	0.041	0.054	0.073
	10:36	0.039	0.052	0.074
	10:48	0.037	0.053	0.075
	11:00	0.04	0.053	0.076
	11:12	0.031	0.054	0.074
	11:24	0.029	0.053	0.069
	11:36	0.036	0.053	0.07
	11:48	0.042	0.054	0.075
	12:00	0.035	0.053	0.072

TIME	WEIR 1	WEIR 2	WEIR 3
12:12	0.033	0.054	0.072
12:24	0.032	0.054	0.072
12:36	0.035	0.054	0.073
12:48	0.035	0.054	0.074
13:00	0.042	0.05	0.07
13:12	0.032	0.05	0.075
13:24	0.04	0.049	0.081
13:36	0.037	0.049	0.082
13:48	0.038	0.051	0.082
14:00	0.035	0.049	0.082
14:12	0.033	0.049	0.08
14:24	0.039	0.047	0.08
14:36	0.039	0.049	0.079
14:48	0.035	0.049	0.078
15:00	0.031	0.049	0.079
15:12	0.039	0.049	0.078
15:24	0.036	0.049	0.082
15:36	0.034	0.049	0.078
15:48	0.041	0.051	0.079
16:00	0.031	0.051	0.081
16:12	0.031	0.049	0.079
16:24	0.04	0.051	0.078
16:36	0.036	0.049	0.078
16:48	0.037	0.05	0.078
17:00	0.035	0.05	0.079
17:12	0.031	0.05	0.078
17:24	0.033	0.051	0.079
17:36	0.032	0.05	0.078
17:48	0.034	0.051	0.078
18:00	0.033	0.051	0.076
18:12	0.034	0.05	0.078
18:24	0.032	0.051	0.076
18:36	0.032	0.051	0.076
18:48	0.031	0.051	0.076
19:00	0.033	0.051	0.074
19:12	0.032	0.051	0.076
19:24	0.033	0.051	0.074
19:36	0.034	0.05	0.075
19:48	0.031	0.051	0.074
20:00	0.031	0.052	0.073
20:12	0.033	0.051	0.074
20:24	0.032	0.052	0.075
20:36	0.032	0.05	0.073
20:48	0.032	0.05	0.072
21:00	0.031	0.051	0.073
21:12	0.032	0.052	0.073
21:24	0.033	0.052	0.071
21:36	0.031	0.052	0.071
21:48	0.031	0.051	0.071
22:00	0.032	0.049	0.071
22:12	0.031	0.05	0.072
22:24	0.032	0.05	0.071
22:36	0.031	0.049	0.072
22:48	0.033	0.05	0.071
23:00	0.033	0.052	0.071
23:12	0.031	0.051	0.07
23:24	0.032	0.049	0.07
23:36	0.032	0.049	0.07
23:48	0.031	0.05	0.068
24:00	0.031	0.049	0.069

APPENDIX 9

DAILY FLOW DATA AND WATER USE ESTIMATES

mean daily flow litres/sec			total daily flow m*3				flow increment m*3/day		water use m*3/day
w1	w2	w3	w1	w2	w3		a=w2-w1	b=w3-w2	a-b
0.68	2.30	5.96	59.14	198.58	514.95	Jan 10	139.44	316.37	-176.93
0.58	1.86	3.90	50.28	160.37	337.11		110.09	176.75	-66.66
0.56	1.40	2.80	48.30	121.04	242.14		72.74	121.10	-48.36
0.49	1.08	2.07	41.94	93.24	179.01		51.30	85.76	-34.47
0.42	0.95	1.72	36.63	82.20	148.92		45.57	66.72	-21.15
0.42	0.88	2.18	36.43	75.74	188.44		39.31	112.70	-73.39
0.22	0.69	1.48	18.70	59.20	128.09		40.51	68.89	-28.38
0.18	0.58	1.09	15.65	49.81	94.59		34.17	44.78	-10.61
0.38	0.53	1.26	32.68	45.42	108.69		12.74	63.27	-50.53
0.88	0.48	1.86	75.75	41.10	160.67		-34.65	119.57	-154.22
0.24	0.50	1.53	20.50	43.23	131.90		22.73	88.67	-65.94
0.28	0.59	1.65	23.81	50.95	142.27		27.14	91.33	-64.19
0.14	0.54	1.14	12.01	46.76	98.58		34.75	51.82	-17.07
0.12	0.49	0.93	10.41	42.60	80.14		32.19	37.54	-5.35
0.09	0.41	0.87	7.95	35.71	74.89		27.76	39.18	-11.41
0.11	0.35	0.84	9.53	29.96	72.52		20.43	42.56	-22.13
0.73	0.31	1.00	63.14	26.92	86.06	Jan 26	-36.21	59.13	-95.35
0.52	1.25	1.82	44.76	107.68	157.55	Feb 6	62.92	49.86	13.06
0.49	1.04	1.36	42.45	89.58	117.55		47.13	27.98	19.15
0.40	0.92	0.98	34.56	79.32	84.76		44.76	5.44	39.32
0.43	0.82	0.85	37.19	70.98	73.68		33.79	2.71	31.08
0.39	0.69	0.89	33.58	59.72	76.77		26.14	17.05	9.10
0.22	0.63	0.80	18.73	54.61	69.34		35.88	14.73	21.16
0.14	0.54	0.51	11.67	46.70	44.14		35.03	-2.55	37.58
0.12	0.43	0.36	10.77	37.47	31.36		26.71	-6.11	32.82
0.06	0.35	0.32	4.91	30.34	27.72		25.42	-2.62	28.04
0.04	0.31	0.28	3.35	27.21	23.79		23.86	-3.42	27.29
0.03	0.29	0.25	2.95	25.24	21.37		22.29	-3.87	26.17
0.03	0.25	0.19	3.01	21.19	16.78		18.19	-4.41	22.60
0.05	0.21	0.19	4.07	18.15	16.34		14.08	-1.81	15.89
0.03	0.18	0.14	2.33	15.67	11.79		13.34	-3.89	17.23
0.03	0.17	0.11	2.78	14.42	9.74		11.64	-4.67	16.31
0.02	0.14	0.07	2.15	12.06	6.28		9.91	-5.78	15.70
0.02	0.12	0.05	1.99	10.06	4.55		8.07	-5.51	13.58
0.03	0.11	0.05	2.23	9.24	3.96		7.01	-5.28	12.29
0.03	0.11	0.05	2.81	9.21	4.53		6.40	-4.68	11.08
0.10	0.14	0.10	8.80	12.23	8.41		3.43	-3.82	7.25
0.02	0.09	0.10	1.31	7.58	8.59		6.28	1.01	5.27
0.00	0.11	0.08	0.39	9.70	6.59		9.31	-3.11	12.41
0.01	0.12	0.07	0.55	10.38	5.68		9.83	-4.70	14.53
0.01	0.13	0.06	0.89	10.94	4.99	Mar	10.05	-5.95	16.00
0.01	0.10	0.04	1.20	8.50	3.44		7.30	-5.06	12.36
1.26	0.18	0.18	108.77	15.20	15.18		-93.57	-0.02	-93.55
0.04	0.17	0.15	3.80	15.06	13.06		11.26	-2.00	13.26
0.02	0.29	0.07	1.99	24.78	6.32		22.79	-18.46	41.25
0.01	0.30	0.05	1.18	26.14	4.51		24.96	-21.62	46.58
0.01	0.27	0.03	0.79	23.74	2.94		22.95	-20.80	43.75
0.01	0.22	0.02	0.99	19.10	1.73		18.11	-17.37	35.48
0.01	0.18	0.01	1.04	15.68	1.03		14.64	-14.65	29.29

0.01	0.13	0.01	0.78	11.17	0.92		10.39	-10.25	20.64
0.01	0.11	0.01	0.75	9.87	1.01		9.12	-8.86	17.98
0.01	0.10	0.00	0.99	8.82	0.34		7.83	-8.47	16.30
0.01	0.10	0.00	1.14	8.49	0.12		7.35	-8.37	15.72
0.01	0.08	0.00	1.00	6.54	0.01		5.54	-6.52	12.06
0.01	0.05	0.00	0.95	4.06	0.00		3.12	-4.06	7.18
0.01	0.04	0.00	0.93	3.09	0.00		2.16	-3.09	5.24
0.01	0.03	0.00	0.68	2.47	0.00		1.79	-2.47	4.27
0.01	0.03	0.00	0.66	2.20	0.00		1.55	-2.20	3.75
0.00	0.01	0.00	0.21	1.19	0.00		0.98	-1.19	2.18
0.00	0.01	0.00	0.29	0.46	0.00		0.17	-0.46	0.63
0.01	0.00	0.00	0.70	0.33	0.00		-0.37	-0.33	-0.04
0.00	0.00	0.00	0.03	0.01	0.17		-0.02	0.16	-0.18
0.00	0.00	0.00	0.01	0.00	0.00		-0.01	0.00	-0.01
0.00	0.00	0.00	0.00	0.00	0.00		-0.00	0.00	-0.00
0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00
0.02	0.00	0.00	1.78	0.00	0.00		-1.78	0.00	-1.78
0.00	0.00	0.00	0.34	0.00	0.00		-0.34	0.00	-0.34
0.00	0.00	0.00	0.07	0.00	0.00		-0.07	0.00	-0.07
0.01	0.00	0.00	0.69	0.00	0.00	Apr	-0.69	0.00	-0.69
0.01	0.00	0.00	0.60	0.00	0.00		-0.60	0.00	-0.60
0.00	0.00	0.00	0.16	0.00	0.00		-0.16	0.00	-0.16
15.61	4.61	0.00	1349.12	397.89	0.00		-951.23	-397.89	-553.34
18.36	14.26	6.83	1586.31	1232.38	589.74		-353.93	-642.64	288.71
18.41	16.77	14.31	1590.51	1448.65	1236.45		-141.86	-212.20	70.34
18.65	17.81	15.61	1611.76	1538.87	1348.90		-72.89	-189.97	117.08
18.72	18.25	16.03	1617.50	1576.79	1384.70		-40.71	-192.09	151.38
10.56	14.83	14.40	912.08	1281.65	1244.17		369.58	-37.48	407.06
0.49	5.52	5.63	42.71	476.79	486.29		434.08	9.49	424.59
0.24	3.62	3.32	21.14	312.47	286.81		291.33	-25.66	316.99
0.15	2.52	2.10	13.02	217.62	181.80		204.60	-35.82	240.43
0.12	1.87	1.47	10.33	161.43	127.31		151.10	-34.12	185.22
0.09	1.27	1.00	8.07	109.40	86.52		101.33	-22.89	124.21
0.06	0.96	0.66	5.57	82.65	56.78		77.08	-25.86	102.94
0.05	0.80	0.32	4.41	68.80	27.66		64.39	-41.14	105.53
0.26	0.72	0.31	22.14	62.16	26.86		40.03	-35.30	75.33
2.05	0.62	0.23	176.86	53.72	19.57		-123.15	-34.15	-89.00
0.31	0.67	0.15	26.46	57.64	12.53		31.18	-45.11	76.29
0.14	0.72	0.10	12.42	61.84	8.62		49.42	-53.22	102.64
0.11	0.67	0.11	9.19	58.24	9.53		49.05	-48.71	97.75
0.09	0.60	0.13	7.54	52.14	11.07		44.61	-41.08	85.69
0.07	0.53	0.12	6.18	45.73	10.69		39.55	-35.04	74.59
0.28	0.50	0.11	24.60	42.99	9.29		18.40	-33.70	52.10
0.34	0.48	0.09	29.23	41.89	8.10		12.65	-33.79	46.44
0.33	0.46	0.07	28.58	39.96	5.74		11.38	-34.22	45.60
0.29	0.44	0.04	25.21	37.97	3.51		12.76	-34.46	47.22
0.20	0.45	0.03	17.58	38.89	2.48		21.31	-36.42	57.73
0.16	0.45	0.02	14.03	38.91	1.87		24.88	-37.04	61.92
0.12	0.43	0.02	10.24	37.07	1.65		26.83	-35.42	62.25

0.09	0.41	0.02	8.18	35.24	1.74	May	27.05	-33.50	60.56
0.08	0.40	0.03	7.05	34.71	2.22		27.65	-32.49	60.14
0.08	0.39	0.05	7.34	34.10	4.23		26.76	-29.88	56.64
0.06	0.39	0.04	5.58	33.69	3.69		28.11	-30.01	58.12
0.06	0.37	0.04	4.86	32.36	3.05		27.51	-29.31	56.81
0.05	0.33	0.03	4.29	28.16	2.24		23.87	-25.92	49.79
0.04	0.28	0.02	3.24	24.12	1.41		20.88	-22.71	43.59
0.03	0.31	0.01	2.36	26.69	1.29		24.34	-25.40	49.74
0.03	0.33	0.02	2.66	28.34	1.36		25.68	-26.97	52.65
0.03	0.30	0.01	2.56	25.66	1.09		23.09	-24.57	47.66
0.02	0.29	0.01	1.67	25.32	0.79		23.65	-24.53	48.18
0.02	0.30	0.01	2.01	25.57	0.48		23.55	-25.09	48.64
0.01	0.22	0.00	1.15	19.33	0.19		18.19	-19.15	37.33
0.01	0.15	0.00	0.98	13.12	0.07		12.14	-13.05	25.18
0.01	0.13	0.00	0.58	11.64	0.01		11.06	-11.62	22.68
0.00	0.12	0.00	0.40	10.35	0.01		9.95	-10.34	20.28
0.00	0.16	0.00	0.36	13.76	0.04		13.39	-13.72	27.11
0.00	0.13	0.00	0.32	11.39	0.15		11.07	-11.25	22.32
0.00	0.19	0.01	0.27	16.07	0.47		15.81	-15.60	31.41
0.00	0.13	0.01	0.39	10.94	0.47		10.55	-10.47	21.01
0.00	0.10	0.04	0.37	8.43	3.15		8.05	-5.28	13.33
0.00	0.10	0.04	0.38	8.33	3.15		7.96	-5.18	13.14
3.03	0.10	0.05	262.01	9.02	4.55		-252.99	-4.47	-248.53
0.09	0.30	0.05	8.00	25.98	4.45		17.99	-21.53	39.52
0.03	0.49	0.02	2.86	42.57	2.09		39.71	-40.48	80.19
0.02	0.54	0.03	1.43	46.80	2.86		45.36	-43.94	89.30
1.28	0.44	0.06	110.72	38.18	4.89		-72.54	-33.28	-39.26
2.08	0.44	0.09	179.44	38.42	7.78		-141.02	-30.64	-110.37
0.42	0.74	0.13	36.37	63.84	11.01		27.47	-52.82	80.29
0.44	0.76	0.17	37.66	66.04	15.05		28.38	-50.99	79.36
0.41	0.74	0.12	35.07	64.02	10.52		28.95	-53.49	82.44
0.48	0.70	0.00	41.84	60.21	0.00	June	18.37	-60.21	78.58
0.47	0.68	0.00	40.84	58.54	0.00		17.70	-58.54	76.24
0.38	0.64	0.00	32.69	54.91	0.15		22.22	-54.76	76.99
0.29	0.60	0.02	25.05	51.57	1.60		26.52	-49.97	76.49
0.24	0.55	0.05	20.87	47.64	4.30		26.76	-43.34	70.10
0.22	0.50	0.05	19.04	43.08	4.42		24.04	-38.66	62.70
0.20	0.49	0.04	16.90	42.20	3.51		25.30	-38.69	63.99
0.16	0.45	0.03	13.65	38.70	2.65		25.05	-36.05	61.09
0.16	0.42	0.02	14.18	36.43	1.44		22.26	-34.99	57.25
0.17	0.39	0.01	14.68	33.27	0.92		18.59	-32.34	50.93
0.16	0.36	0.01	14.08	31.35	0.79		17.27	-30.56	47.84
0.17	0.35	0.01	14.34	30.46	1.30		16.13	-29.17	45.29
0.18	0.34	0.04	15.54	28.95	3.26		13.40	-25.69	39.09
0.14	0.31	0.04	12.48	26.92	3.22		14.44	-23.69	38.13
0.14	0.45	0.03	12.40	38.73	2.19		26.33	-36.53	62.86
0.35	0.70	0.02	30.48	60.25	1.65		29.77	-58.60	88.37
0.61	0.80	0.01	52.39	68.82	1.00		16.43	-67.83	84.26
0.40	0.31	0.01	34.33	27.09	0.62		-7.24	-26.47	19.23
0.02	0.21	0.01	1.94	17.97	0.44		16.03	-17.54	33.57
1.38	0.18	0.00	119.39	15.16	0.18		-104.23	-14.99	-89.24
1.53	0.19	0.00	132.16	16.35	0.07		-115.80	-16.28	-99.52
0.26	0.35	0.00	22.39	30.47	0.01		8.08	-30.46	38.54

0.25	0.47	0.00	21.32	40.36	0.00		19.04	-40.36	59.41
0.23	0.50	0.00	19.89	42.92	0.00		23.03	-42.92	65.95
0.23	0.51	0.00	19.72	43.79	0.00		24.07	-43.79	67.85
0.23	0.45	0.00	20.24	39.16	0.00		18.93	-39.16	58.09
0.23	0.41	0.00	19.53	35.49	0.01		15.96	-35.48	51.44
0.24	0.39	0.00	20.57	33.99	0.07		13.42	-33.92	47.34
0.21	0.38	0.00	18.05	32.88	0.22		14.82	-32.66	47.48
0.16	0.38	0.01	14.21	32.77	0.44		18.56	-32.32	50.88
0.17	0.39	0.01	14.99	33.31	0.81	July	18.32	-32.50	50.82
0.16	0.36	0.01	13.58	31.26	0.98		17.68	-30.28	47.97
0.14	0.36	0.01	12.33	31.39	1.18		19.06	-30.21	49.26
0.19	0.34	0.01	16.59	29.63	1.09		13.03	-28.54	41.57
1.60	0.40	0.04	138.60	34.38	3.27		-104.22	-31.11	-73.11
2.15	0.66	0.89	185.38	57.02	76.61		-128.37	19.59	-147.96
0.44	1.10	0.70	37.75	94.86	60.42		57.11	-34.44	91.54
0.39	1.12	0.67	33.68	96.43	57.53		62.75	-38.90	101.65
0.37	0.87	0.64	32.39	75.26	55.22		42.87	-20.04	62.91
0.34	0.74	0.52	29.59	63.74	45.21		34.15	-18.52	52.67
0.33	0.66	0.43	28.37	57.02	37.41		28.65	-19.61	48.26
0.32	0.58	0.37	27.30	50.30	31.70		23.00	-18.61	41.61
0.32	0.52	0.31	27.49	44.68	26.53		17.19	-18.15	35.35
0.25	0.46	0.27	21.40	40.13	23.71		18.73	-16.42	35.14
0.24	0.43	0.22	20.38	37.11	18.98		16.73	-18.13	34.87
0.70	0.48	0.44	60.37	41.76	38.20		-18.61	-3.56	-15.05
0.24	0.45	0.40	20.43	39.21	34.37		18.78	-4.84	23.62
0.12	0.47	0.27	10.45	40.56	23.45		30.10	-17.11	47.21
0.09	0.43	0.24	7.51	37.39	20.99		29.88	-16.40	46.29
0.07	0.39	0.21	6.27	33.61	18.49		27.34	-15.12	42.45
0.07	0.36	0.21	5.88	30.70	18.50		24.82	-12.20	37.02
0.06	0.32	0.20	5.21	27.39	17.70		22.17	-9.68	31.85
0.05	0.29	0.20	4.55	25.03	17.15		20.47	-7.88	28.35
0.04	0.25	0.17	3.42	21.18	14.73		17.76	-6.45	24.21
0.03	0.22	0.16	2.96	19.42	13.44		16.46	-5.98	22.44
0.03	0.20	0.14	2.87	17.62	12.49		14.75	-5.13	19.88
0.03	0.18	0.12	2.88	15.96	10.25		13.08	-5.71	18.79
0.04	0.19	0.11	3.15	16.20	9.48		13.06	-6.72	19.78
0.03	0.15	0.09	2.86	13.22	7.70		10.36	-5.52	15.88
0.03	0.12	0.07	2.61	10.61	6.07		8.00	-4.55	12.55
0.03	0.11	0.06	2.31	9.24	4.89		6.94	-4.36	11.29
0.03	0.10	0.05	2.34	8.26	4.63	Aug	5.91	-3.63	9.54
0.03	0.12	0.05	2.85	9.99	4.60		7.14	-5.39	12.53
0.04	0.11	0.06	3.19	9.39	5.23		6.20	-4.16	10.36
0.04	0.12	0.09	3.76	10.46	7.55		6.70	-2.91	9.60
0.76	0.19	0.67	66.09	16.41	58.11		-49.69	41.70	-91.39
2.00	0.74	0.52	172.98	63.53	45.11		-109.45	-18.42	-91.03
0.10	0.89	0.39	8.88	77.09	33.47		68.21	-43.63	111.84
0.08	0.61	0.20	6.69	53.11	16.89		46.42	-36.23	82.65
0.06	0.58	0.15	5.25	50.14	12.64		44.88	-37.50	82.38
0.05	0.49	0.18	3.89	42.71	15.91		38.82	-26.80	65.62
0.05	0.41	0.18	4.63	35.70	15.78		31.08	-19.93	51.00
0.04	0.36	0.17	3.76	30.89	14.45		27.14	-16.44	43.58
0.04	0.30	0.16	3.83	25.86	13.45		22.03	-12.41	34.44

0.04	0.32	0.16	3.21	27.28	13.44		24.06	-13.83	37.90
0.03	0.28	0.13	2.92	24.56	11.41		21.65	-13.16	34.80
0.04	0.25	0.11	3.45	21.51	9.70		18.06	-11.82	29.88
0.34	0.43	0.21	29.60	36.87	18.14		7.27	-18.73	26.01
0.04	0.15	0.16	3.84	12.87	13.99		9.04	1.12	7.92
0.11	0.33	0.20	9.49	28.47	16.90		18.99	-11.57	30.56
0.05	0.35	0.17	4.23	30.17	15.08		25.94	-15.09	41.02
0.03	0.34	0.13	2.90	29.35	11.65		26.45	-17.71	44.16
0.03	0.36	0.11	2.32	31.32	9.08		29.00	-22.24	51.24
0.02	0.36	0.09	1.99	30.97	7.90		28.98	-23.07	52.05
0.02	0.35	0.09	1.53	30.62	7.89		29.09	-22.73	51.82
0.02	0.36	0.09	1.60	31.11	7.38		29.51	-23.73	53.24
0.01	0.37	0.08	1.26	31.57	7.02		30.31	-24.55	54.86
0.05	0.53	0.18	4.64	45.97	15.17		41.33	-30.80	72.13
0.04	0.46	0.19	3.37	39.97	16.24		36.60	-23.73	60.33
0.03	0.45	0.20	2.79	38.83	17.06		36.04	-21.77	57.81
0.03	0.43	0.20	2.24	36.86	17.35		34.62	-19.51	54.12
0.02	0.42	0.18	1.50	36.32	15.38		34.82	-20.94	55.75
0.02	0.39	0.10	1.34	33.89	8.92	Sept	32.55	-24.97	57.53
0.01	0.35	0.06	0.67	30.64	5.41		29.97	-25.23	55.19
0.00	0.30	0.04	0.03	25.81	3.71		25.78	-22.10	47.89
0.00	0.24	0.02	0.00	21.09	2.13		21.09	-18.96	40.04
0.00	0.20	0.02	0.00	17.44	1.34		17.44	-16.11	33.55
0.00	0.17	0.01	0.00	14.59	1.08		14.59	-13.51	28.10
0.00	0.12	0.01	0.00	10.08	0.51		10.08	-9.57	19.65
0.00	0.07	0.00	0.00	6.28	0.26		6.28	-6.03	12.31
0.00	0.04	0.00	0.00	3.48	0.03	Sep 9	3.48	-3.46	6.94

APPENDIX 10

GRASS TYPES AND AMOUNTS SOWN IN CLEARED AREAS

Grass seeds sown on Saturday March 16th 1996 over an area of 3 hectares

Eragrostis curvula (6kg)
Varity - Ermelo
Germination specification % 70 -79

Cynodon (6kg)
Varity - Kweek
Germination specification % 80-89

Panicum maximum (C) (9 kg)
Variety - Cutter
Germination specification % 20-29

Chloris gayana (C) (9kg) (Rhodes grass)
Variety - Katambora
Germination specification % 20-29

Digitaria eriantha (C) (9kg) (Smuts)
Variety - Irene
Germination specification % 20-29

Chenchrus cilaris (C) (3kg) (Bloubuffel)
Variety - Molopo
Germination specification % 20-29

DW 1

DEPARTEMENT VAN WATERWESE EN BOSBOU
DEPARTMENT OF WATER AFFAIRS AND FORESTRY
REPUBLIEK VAN SUID-AFRIKA / REPUBLIC OF SOUTH AFRICA

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Verwysing: / Reference: 7/2/271

The City Engineer
Port Elizabeth Municipality
PO Box 7
PORT ELIZABETH
6000

Attention : DA Raymer

Dear Dave

TASK GROUP ON THE CONTROL OF INVADER PLANT SPECIES : EXPERIMENT TO MONITOR THE WATER CONSUMPTION OF WATTLE TREES IN THE ZWARTKOPS RIVER CATCHMENT

The site visit dated 30 January and various telephone discussion between Mr DA Raymer and myself, refer.

The experimental site where wattle trees were removed is now to be rehabilitated to prevent erosion and the re-establishment of wattle seedlings. The Port Elizabeth Municipality (PEM) has agreed to assist with the preparation of a seed bed for and the distribution of grass seed delivered at your premises during the site visit. Please receive the following specification in this regard.

1. **Preparation of the seed bed**

   Most of the areas to be seeded are covered with organic material which necessitates no special preparation for a seed bed and the grass seed may be distributed directly on such areas. The hardened surfaces are to be scarified by means of a hand pick parallel to the contours. Areas with an existing grass cover of more than 50 % do not need to be prepared for grassing.

2. **Distribution of grass seed**

   The attached table indicates the required grass seed mixture and sowing rate. Also refer to the attached document on methods of grassing which is an extraction from a DWAF document on grassing guidelines.

3. **Spreading of organic material over the seeded area**

Leaves and branches with a diameter smaller than 20 mm and derived from the felled wattle trees, are to be spread on the seeded areas. The purpose of this "mulch" is to act as a protection to the grass seedlings and will assist in retaining moisture in the soil.

4. **Maintenance of grassed area**

No maintenance except the removal of wattle seedlings is foreseen. When required this could possibly be arranged with Mr D Joubert of the Department of Agriculture: Resources Conservation.

Of great importance though is that for at least one year period after seeding, no domestic animals are allowed on the rehabilitated area. When grazing animals are eventually allowed a grazing procedure must be worked out carefully to prevent erosion of the sensitive river bank.

5. **Time of sowing**

It was suggested by various members of the ZRWRMP Task Group that the grass seeding be done in the late summer or early winter. It is recommended that it be done during April 1996.

As requested please provide me with the detail information on the tags attached to the bags of seed which were delivered at your premises on 30 January 1996.

The commitment of PEM to participate in the above rehabilitation is appreciated.

Yours sincerely

Chairman : Task Group on the Control of Invader Plant Species
Date : 13.03.96

TABLE 1 : GRASS SEED MIXTURE AND SOWING RATE FOR THE EXPERIMENTAL SITE ALONG THE SAND RIVER

GRASS SEED	DISTRIBUTION kg / ha	TOTAL FOR 3 ha kg
Cenchrus ciliaris 'Molopo' Bloubuffelgras	1	3
Chloris gayana Rhodesgras	3	9
Cynodon dactylon 'Bermuda' Kweekgras	2	6
Digitaria eriantha Smutsfingergras	3	9
Eragrostis curvula 'Ermelo'	2	6
Panicum maximum	3	9
TOTAL	14	42

3.2 METHODS OF GRASSING AND PLANTING

3.2.1 Broadcasting

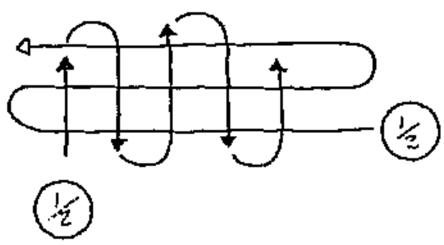
This is probably the cheapest method of distributing seed and can be done either by hand, by a hand held spreader or by a tractor mounted seed spreader.

a. By hand and hand held spreader

Broadcasting by hand is particularly suited to sowing on wet soils and where the terrain is unsuitable for mechanical seeding. One of the problems with hand seeding, however, is the uneven distribution of the seed over the whole area and the necessity of calibrating the spreader to give approximately the correct density of seed.

Some ways of distributing the seed evenly are:

i) divide the seed into two equal parts and use each lot to cover the entire area moving in different directions during the sowing process;

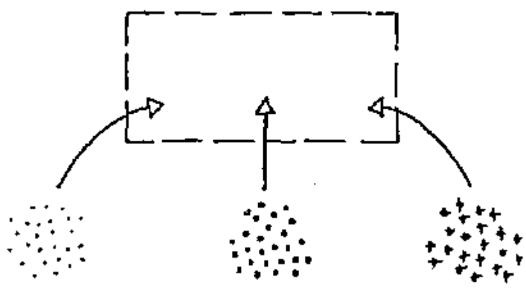


SEED DIVIDED INTO TWO EQUAL PARTS

ii) mix small seeds with sand to give it a bulkier parcel with which to work;

SMALL SEED MIXED WITH SAND

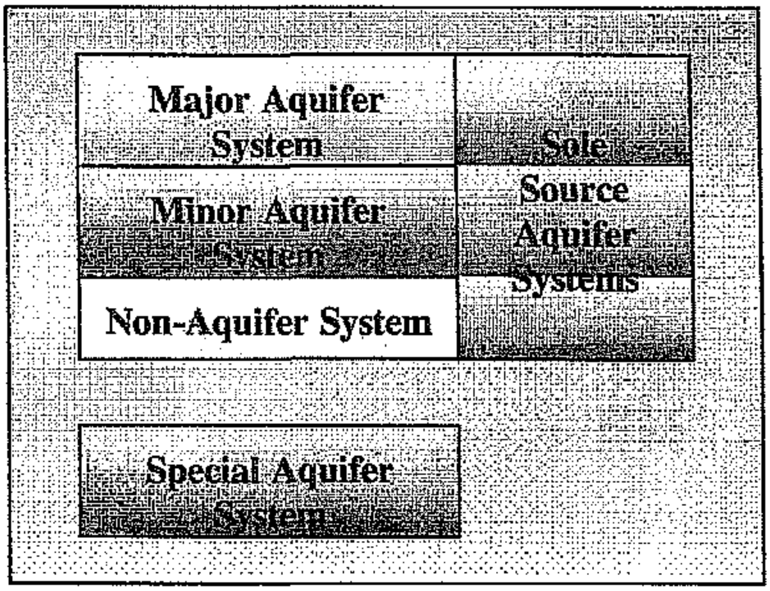
iii) sow each seed type, in the case of mixed seeding, separately to prevent the heavier seeds from moving to the bottom of the container.



SEPERATE SEEDING

Classification System

Aquifer System Management classification



Definitions of Aquifer System Management classes.

Sole Source Aquifer System	An aquifer which is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
Major Aquifer System	Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.
Non-Aquifer System	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.