AN EXPERIMENTAL STUDY OF THE EFFECT OF *Acacia mearnsii* (BLACK WATTLE TREES) ON STREAMFLOW IN THE SAND RIVER, EASTERN CAPE.

BY

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ABSTRACT

This thesis explores the effect of *Acacia mearnsii* on streamflow in the Eastern Cape. There is a need for data on the localised effects of removing alien trees from the riparian zones within the Fynbos Biome. Fynbos catchments throughout the Western and Eastern Cape yield large quantities of good quality water which is an essential resource in the region. To convince local land owners to manage their riparian zones, small scale experimental results will prove invaluable to assure them of the immediate advantages for themselves and for downstream water users.

Three permanent weirs were built 500 m apart to monitor the effect of removing *A. mearnsii* on streamflow in the Sand River, Eastern Cape. Consecutive weirs allowed for the comparison of streamflow between a cleared and uncleared section of the river without significant differences in riparian conditions, channel morphology and vegetation densities. A site survey confirmed comparable densities of *A. mearnsii* in both sections. A sample of trees was weighed and a relationship was found between diameter at breast height and above ground wet biomass. Between the first two weirs, 2.5 ha of riparian zone was cleared amounting to approximately 160t/ha.

Streamflow was monitored from the 10th of January 1996 to the 9th of September 1996. The average streamflow reduction for the duration of the experiment was 15.1m^3/ha/day or 551mm per annum. Initially, after a period of above average rainfall, streamflow was augmented by discharge from the riparian zone but as conditions dried out, there was a net uptake of water with the highest average uptake of 23.7m^3/ha/day in June. A comparison between weather conditions and streamflow reduction indicated there is a complex relationship, with evidence of *A. mearnsii* exhibiting control of water loss during dry conditions.

Acacia mearnsii trees in the riparian zone have been shown to cause significant streamflow reduction. Permanent weirs were found to be appropriate for this type of study. There is a need for further research on the effect of alien trees in riparian zones around South Africa as there is potential for significant increases in streamflow.

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LIST OF ACRONYMS

A. mearnsii	*Acacia mearnsii*
cm	Centimetre
DBH	Diameter at Breast Height
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
et al.	Latin *et alii* (and others)
ha	Hectare
HPV	Heat Pulse Velocity
IBT	Inter Basin Transfers
ICM	Integrated Catchment Management
Inc.	Incorporated
l/s	Litres per second
m^2	Square metre
m^3/d	Cubic metres per day
$m^3.ha^{-1}.yr^{-1}$	Cubic metres per hectare per year
mm	Millimetre
mS/m	Millisemens per metre
PEM	Port Elizabeth Municipality
pH	Percentage Hydroxyl
pp	Page number/s
RDP	Reconstruction and Development Plan
RSA	Republic of South Africa
t/ha	Tons per hectare
$uS.cm^{-1}$	Micro semens per cm
VPD	Vapour pressure deficit
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."**
>
> *(Gribbin, 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, 1991). 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 (Du Venage, 1992; Ninham Shand Inc., 1993).

In South Africa water shortages are a daily problem for millions of people (RSA White Paper, 1994) and it is expected that we will run out of water in the early part of the next century (Du Venage, 1992). Although such shortages are often attributed solely to droughts, 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; Versveld *et al.*, 1998). *Acacia mearnsii*, an Australian exotic and the focus of this thesis, 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; Scott and Lesch, 1995; van Wilgen *et al.*, 1996). 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 relationships (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 (Du Venage, 1992; DWA, 1986). 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 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 a deficit is a solution to meeting the needs of the growing population, industrial and agricultural demands (Petitjean and Davies, 1988). Inter Basin Transfers (IBT) 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 alternative options the Department of Water Affairs and Forestry (DWAF) exploited in the past until the Fynbos Forum, where a group of researchers decided in October 1993 to turn 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).

1.2 RESEARCH CONTEXT

The Working for Water programme has grown in three years from the original concept, almost entirely sponsored by the national RDP programme, to an inter-departmental partnership sponsored by a wide variety of organisations. The Working for Water 1996/97 annual report shows a total of 8 386 jobs created and 71 289 hectares of alien vegetation cleared (DWAF, 1997). In two years these figures have increased to 42 059 jobs created and 220 884 hectares of alien vegetation cleared (DWAF, 1998). The programme has been widely recognised for its achievements and has been presented with various conservation awards but there have been some concerns.

While job creation is one of the main focuses of the programme, water augmentation due to the removal of alien vegetation is vital for the continued success of the project. At present there are 240 project areas carefully chosen based on the presence of alien vegetation, the need for poverty relief, economic benefits and the infrastructure capable of running the programmes (DWAF, 1998). Locations of projects need to be justified when comparisons are made to potential additional areas to ensure maximum benefit on a national scale (Versveld *et al.*, 1998). In the programme leaders report, Dr. Guy Preston suggests there is a lack of research on the consequences of alien vegetation throughout the country and research should be undertaken to sustain the programme (DWAF, 1998). The present research expects to contribute to the future success of the programme by either supporting its work to increase streamflow through the removal of alien vegetation and/or offer recommendations to the ongoing success of the programme.

A recent publication, in view of the Working for Water programme, on alien invading plants and water resources in South Africa has created a framework highlighting all aspects of alien plant invasions throughout the country (Versveld *et al.*, 1998). Although the report is thorough in many aspects, the authors recognise that maximum benefit will only be reached if the data set is used as a baseline and management tool, and is regularly updated and improved (Versveld *et al.*, 1998).

It would have been ideal to set up the present study with an extensive report of this nature and focus the aims and objectives towards research priorities and gaps in the scientific knowledge. However, it was recognised from the lack of literature on the effects of *Acacia mearnsii* on streamflow, the present study would be relevant and beneficial to the broader body of information currently available. The report confirmed that research is needed for aspects of the biology of individual alien invasive species and further information is required to improve water use estimates (Versveld *et al.*, 1998).

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). On a catchment scale the effect of alien species on streamflow has been investigated in various parts of the country (Smith and Bosch, 1989; Dye and Poulter, 1995b; Le Maitre *et al.*, 1996; Versveld *et al.*, 1998), but not specifically *Acacia mearnsii* which accounts for a large proportion of alien invasions in the riparian zones of Eastern Cape rivers.

Alien invasions are found throughout South Africa and the vast majority of catchments, of which *Acacia mearnsii* is ranked as the worst invader in South Africa (Versveld *et al.*, 1998). Alien invasions in South Africa cover a condensed area (total invaded area with different percentage cover, adjusted to bring cover to 100%) of 1.7 million hectares in South Africa and 151 258 hectares condensed area in the Eastern Cape (Versveld *et al.*, 1998). *A. mearnsii* covers a condensed area of 131 341 hectares throughout the country and 49 022 hectares in the Eastern Cape (Versveld *et al.*, 1998). Combined alien plant invasions are estimated to use in excess of 3 300 million m^3 of water per year throughout South Africa and 558 million m^3 of water in the Eastern Cape (Versveld *et al.*, 1998). The authors recognise these estimates lack precision for reasons such as riparian vegetation enjoying access to water during dry periods when trees in the surrounding catchment would be limited (Versveld *et al.*, 1998). It is hoped results from the present study will verify and update conclusions and estimates of water use to aid decision makers when prioritizing catchments and areas planned for clearing programmes.

In the Eastern Cape, *Acacia mearnsii* has invaded the riparian zones along river courses and, to a far lesser degree, on a catchment scale (Ninham Shand Inc., 1993; Palmer and Hintsa, 1996). Ninham Shand Inc. (1993) investigated the effect of *A. mearnsii* in the Krom and Kouga catchments in the Eastern Cape, but had to use a general value for the water consumption of the trees taken from catchment experiments worldwide. The effect of clearing invasive trees (*Pinus patula* and *Acacia mearnsii)* in the riparian zone has been investigated in Mpumalanga (Dye and Poulter, 1995b), but there has been no field research undertaken in the Eastern Cape. There is a need for further research on the effects of clearing alien vegetation from catchments in the Eastern Cape, and more specifically, the effect on streamflow of clearing *A. mearnsii* from riparian zones.

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 Chapter 2. Chapter 2 highlights the need for a broader body of information on individual exotic species, such as biomass, age distribution, the effect of different catchment and climatic conditions and how these factors affect streamflow response to clearing invasive trees.

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. The task group noted the Elands River catchment, part of the Zwartkops River catchment, was heavily infested by invader tree species, especially *Acacia mearnsii*. Subsequently, the area of alien invasions in the catchment has been mapped to a condensed area of 11 358 hectares (Versveld *et al.*, 1998). It would thus be a suitable river in which to monitor the effect of the 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 and Rhodes University was contracted to carry out the research itself.

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 Working for Water programme has been initiated in the neighbouring Kouga and Krom River catchments as they contribute to the main supply dams for the greater Port Elizabeth region (Ninham Shand Inc., 1993), but with results obtained in the present research, a motivation could be put forward for the programme to extend to the Zwartkops catchment. However, even if the Working for Water programme does not extend into the Zwartkops catchment, the results can still 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; Versveld *et al.*, 1998). A principle conclusion from the report on alien invading plants and water resources in South Africa explains that public awareness and participation in the management of invaders is essential for the future success of any government initiated programmes (Versveld *et al.*, 1998). Integrated Catchment Management (ICM) is a relatively new concept in South Africa that has been adopted around the world to manage water resources effectively. Mitchell and Pigram (1989) defines 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 provides 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 resultant commitment to any resolutions achieved.

In South Africa, Mackay (1994) used a localised community on the Chatty River flood plain in Port Elizabeth to develop a technique for ICM. The Chatty River is a tributary of the Zwartkops catchment and therefore is not a direct example of ICM, but covers a tributary catchment which affects the downstream ecology and water users. The study and management of the area were successful in that social, economic and environmental aspects were drawn together in the project and local beneficiaries played a significant role in the project design and planning. The Chatty River Flood plain Project was completed for the Mzingini Development Trust. It serves as a good example of the way the ICM can work for water managers, the environment and most notably the local communities involved. This study will, therefore, provide useful input into such an ICM plan.

The aim of the present study is to determine the effect on streamflow of *Acacia mearnsii* in the riparian zone. On completion of the project, ICM will serve as an ideal management plan for solving problems within catchments and will be effective in coordinating the control of alien invasions. The ZRWRMP has a functional committee and task group and, with meaningful results, the communities will be shown the effects of removing *Acacia 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 *Acacia 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, Le Maitre *et al.*, 1995; Scott *et al.*, 1998). 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. To convince local land owners to manage their riparian zones, small scale experimental results will prove invaluable to convince them of the immediate advantages 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:

1) To determine the effect on streamflow of *Acacia mearnsii* in the riparian zone.

The secondary aim of this research is:

1) To examine additional impacts of *Acacia mearnsii* within the riparian zone.

1.4.2 Research Objectives

The following primary objectives have been 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 weather conditions in the area.
5) To assess the effect of alien vegetation on soil moisture.

The following secondary objectives have been identified:

1) To monitor water quality within the areas before and after clearing.
2) To assess the effect of *Acacia mearnsii* on channel stability.

1.5 THE STUDY SITE

The Zwartkops River Water Resources Management Plan (ZRWRMP) oversees the Zwartkops river catchment, inland of Port Elizabeth in the Eastern Cape Province, South Africa (Figure 1.1 and Figure 1.2). The catchment encompasses two tributaries, the KwaZunga and Elands rivers combining to form the Zwartkops river which flows into the ocean approximately 10km north of Port Elizabeth (Figure 1.2). 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 *Acacia mearnsii.* Together with the present researcher, an initial experimental site was identified on a tributary of the Elands River, the Sand River, approximately 500m downstream from the Sand River Dam (Figure 1.3). Various factors were taken into consideration in determining the location of the study site, other than the presence of *Acacia mearnsii* in the riparian zone and the river in the Zwartkops catchment. These will be discussed in greater detail in Chapter 4.

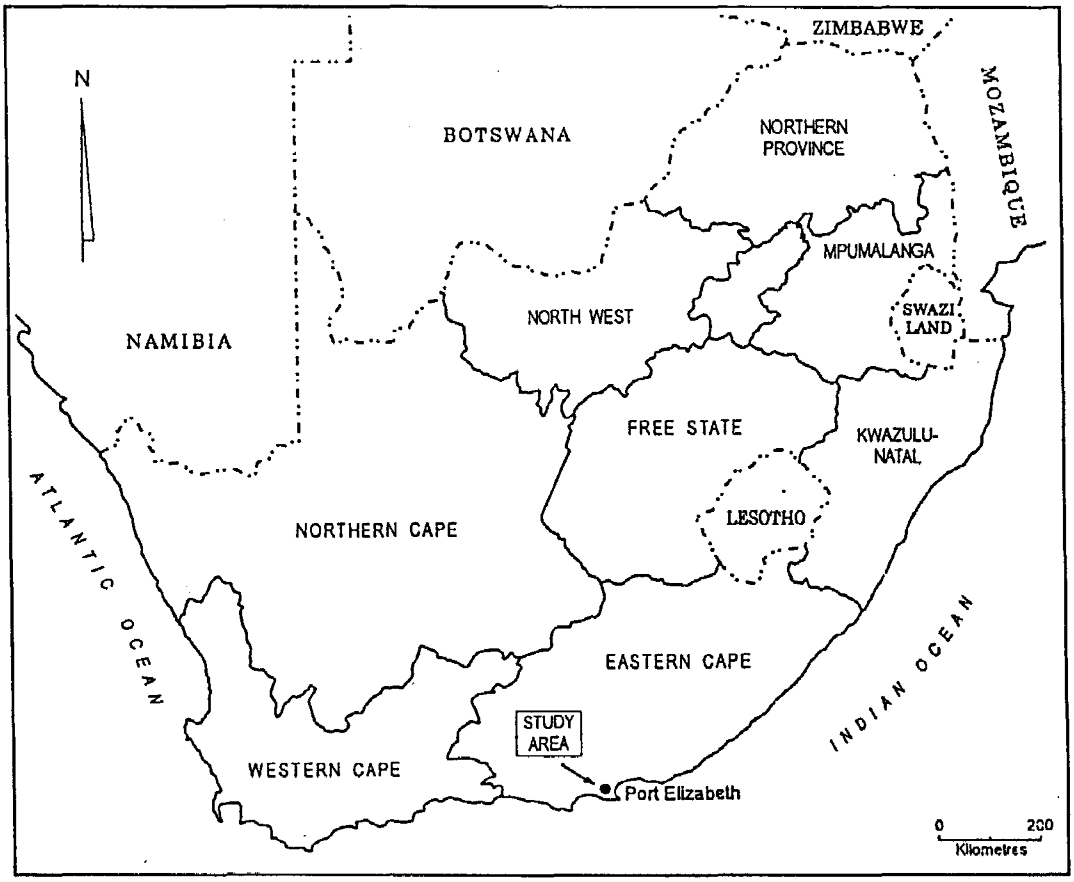


Figure 1.1: Location of the study site within the Republic of South Africa.

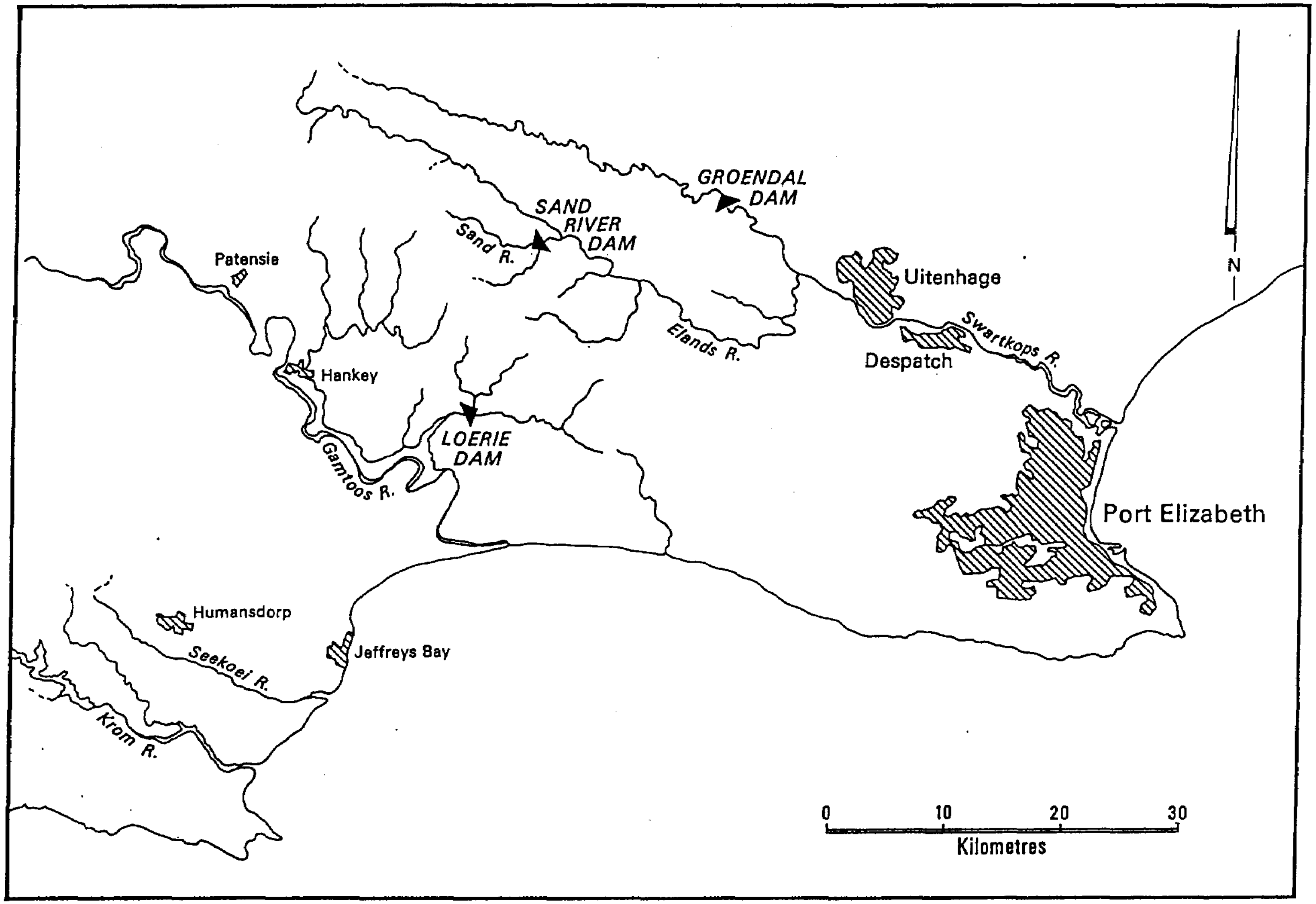


Figure 1.2: Location of the study site within the Eastern Cape.

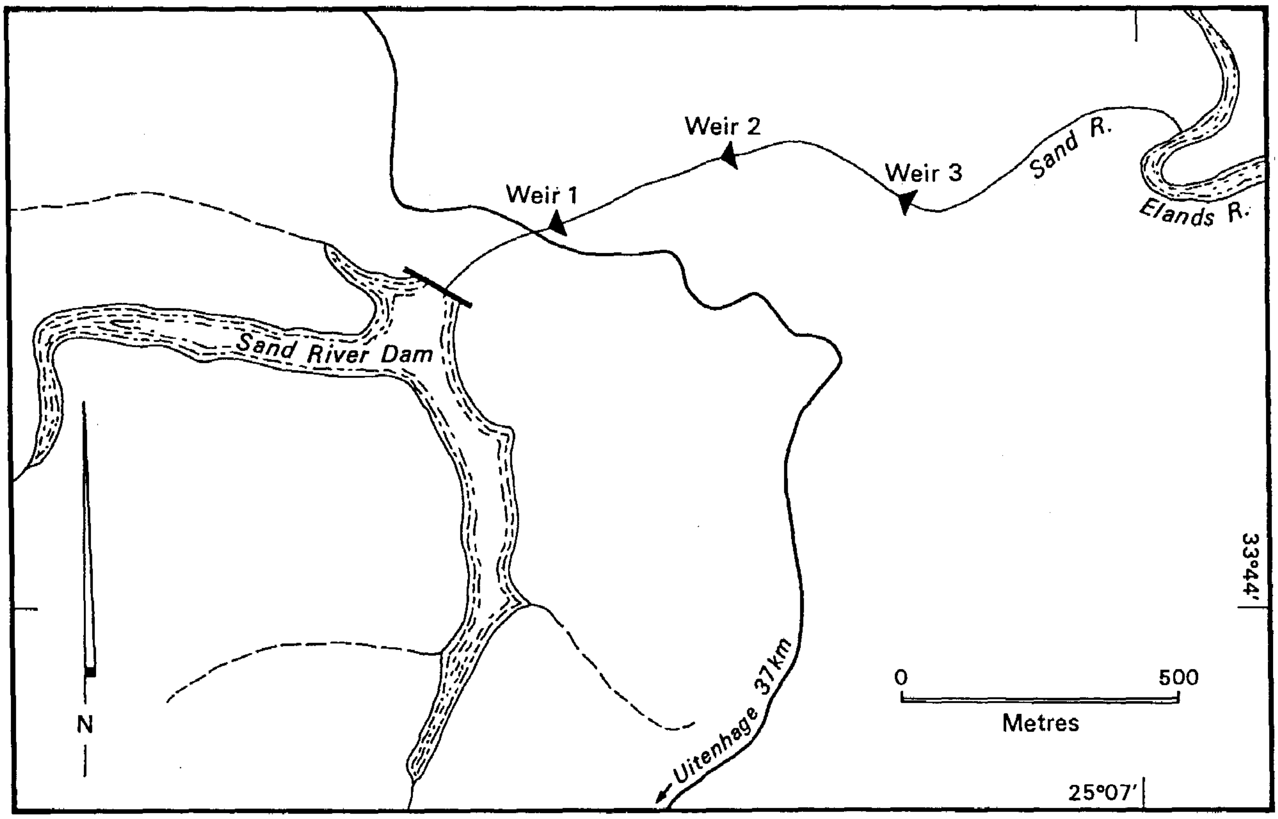


Figure 1.3: Location of the study site and weir positions on the Sand River.

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 a 0.02 slope. 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 1. Weather conditions for the duration of the experiment will be discussed in greater detail in Chapters 4 and 5.

1.5.1 Vegetation

The majority of the Sand and upper Elands River catchments and adjacent to the study site below the dam wall is characterised as South Coast Renosterveld, part of the Fynbos Biome (Belcher, 1996; Low and Rebelo, 1996). Renosterveld is one of two major vegetation groupings in the Fynbos Biome, the other being Fynbos (Low and Rebelo, 1996). Renosterveld is dominated by members of the Daisy Family (Asteraceae), specifically Renosterbos *Elytropappus rhinocerotis*, from which the vegetation type gets its name (Low and Rebelo, 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 and Rebelo, 1996). The above classification would form the natural riparian vegetation on the river banks if it were not for the invasion of the *A. mearnsii* trees.

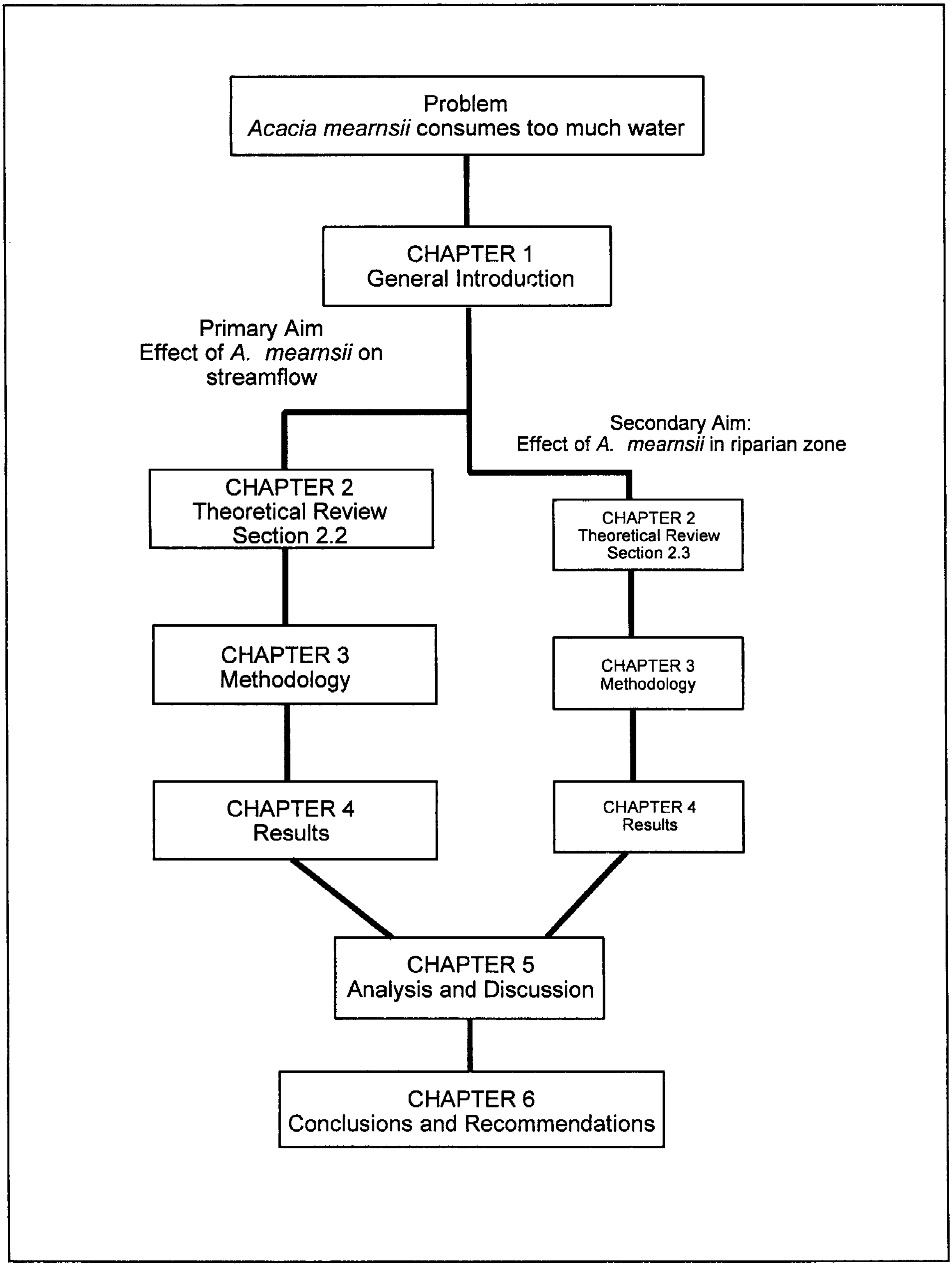
1.5.2 Geology and Soils

The geology forms part of the Cape Supergroup, Bokkeveld group and Ceres subgroup. The soils derived from these groups are undifferentiated shales and sandstones (Rust, 1988; Toerien and Hill, 1989). The shales are carbonaceous and virtually black when fresh as opposed to the sandstones which can form prominent ridges which are generally fine grained, impure, felspathic and dark (Toerien and Hill, 1989). Intact sandstone bedrock is impermeable to water but fractures in the rock are common (Rust, 1988; Toerien and Hill, 1989; Newson, 1994). Observations in the field confirmed this description of sandy loamy soils within the riparian zone, which is expected from weathered table mountain sandstones in the surrounding hills. The soils in the area have a negligible percentage clay content which means the soils are permeable, increasing as more cobbles are found originating from the surrounding sandstones. The sandy loamy soils in the area are characteristically permeable (Rust, 1988).

1.6 THESIS OUTLINE

A summary of the thesis structure is presented in Figure 1.4. Chapter 2 provides a theoretical background to the invasion of *Acacia mearnsii* and the framework within the present research is conducted. Previous research on the water use of trees on a catchment scale is reviewed and the relatively small amount of investigations on the effect of alien vegetation in the riparian zone on streamflow are discussed in more detail. General effects of *A. mearnsii* invasions in the riparian zone are also discussed. Chapter 3 explains the reasons for the research design and the methodology used in attempting to achieve the aims and objectives. Results of field work and analysis of data are presented in Chapter 4. All factors determining the effects of *A. mearnsii* in the riparian zone and specifically the effects on streamflow are synthesised and discussed in Chapter 5. Chapter 6 serves as a conclusion to the study, and discusses study problems and limitations, the contribution of the study to the subject and further research recommendations.

Figure 1.4: Flow Diagram Indicating the Structure of Research



CHAPTER 2

THEORETICAL REVIEW

2.1 INTRODUCTION

"The trouble with trees is they drink too much" (Stober, 1992, pp19). Trees need water to survive, but the issue is rather the amount of water they should be allowed to use (Stober, 1992). 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 von Gadow, 1990; Scott *et al.*, 1998; 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, 1995, van Wilgen *et al.*, 1996; Versveld *et al.*, 1998).

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 (Bosch and Marais, 1995; 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 apposed 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 (Acocks, 1988; Low and Rebelo, 1996). 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 it is essential to have an understanding of the history of the introduced species, and the factors to consider when researching the effect of *Acacia mearnsii* trees on streamflow in the riparian zone (Dye *et al.*, 1994).

Acacia 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). Literature explains 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 introduction 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 from Australia, in Cape Town, 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, *Acacia 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). In the Cape the trees were not planted on the same scale as Natal, but have spread throughout the Cape, 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 between intentional introduction of invader species and the unintentional creation of disturbed environments 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 the most impacted ecosystems in southern Africa are riparian zones and give various reasons why stream banks are particularly prone to invasions compared to terrestrial environments. These include 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; Low and Rebelo, 1996). Fynbos shrubs rely on, and exploit, the brief period after a fire, but then lack the capacity as individuals or as a community to optimise resource use later in stand development (Richardson *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).

Acacia 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, and form dense thickets in the burnt areas (De Beer, 1986; Macdonald, 1987). The availability of water close to the soil surface in riparian zones makes it a favourable area for plants and trees to grow (Le Maitre *et al.*, 1995). *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 *Acacia 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.

2.2 WATER USE BY TREES

Research has been undertaken to quantify how much more water invasive trees and plants use, but there is still a need for further research (Bosch and Hewlett, 1982; Dye and Poulter, 1995b; Poulter *et al.*, 1994; Scott *et al.*, 1998). The effect of vegetation changes on water yield has been investigated in all parts of the world on 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; Nanni, 1972). In South Africa, research has focussed on regions where forestry stations were established, and several long term experiments were laid out 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; Smith and Bosch, 1989; Van Wyk, 1987).

Results from research at the forestry stations have been used to model the water use of vegetation and have established relationships between cover, biomass and their resultant effect on streamflow reduction (Le Maitre *et al.*, 1996; Scott and Smith, 1997; Scott *et al.*, 1998). There have been a number of models published and/or previous models reviewed since the start of the Working for Water programme (Section 1.2) to assist decision makers for prioritization of potential clearing projects, of which the most notable is a preliminary assessment of alien invading plants and water resources in South Africa (Versveld *et al.*, 1998). These models have used actual water use values from experimental results to derive estimates which are used on a larger scale, in different geographical regions and for different plant species (Versveld *et al.*, 1998). It would constitute a project in itself to review all the models with relevance to the results from the present study and it was therefore decided to use original catchment experiments in the comparisons. In addition, there is a lack of data pertaining to the effects of wattles on streamflow and specifically *Acacia mearnsii* (Le Maitre *et al.*, 1997; Scott *et al.*, 1998). As a result wattles have not been included in models to date and would therefore be relevant to present the data as it was recorded as apposed to modelling.

However, the preliminary assessment of alien invading plants and water resources in South Africa has been described as a baseline and framework for all present and future research to utilize (Versveld *et al.*, 1998). The model used to estimate the effect of alien invaders on water use was established by Le Maitre *et al.* (1996 and 1997) where a relationship was found between biomass and streamflow reduction (Section 2.2.2) (Versveld *et al.*, 1998). The total water use of alien invaders in South Africa over a condensed area of 1.7 million hectares is estimated to be 3 300 million m^3 per year. In the Eastern Cape alien plants cover a condensed area of 151 258 hectares and it is estimated they use 558 million m^3 of water per year (Versveld *et al.*, 1998). *Acacia meurnsii* is recognised in the report as one of the worst invaders in the South Africa and covers a condensed area of 131 341 ha and 49 022 ha in the Eastern Cape (Versveld *et al.*, 1998). This amounts to 576.58 million m^3 and 215.2 million m^3 water use for alien plant invaders in South Africa and the Eastern Cape respectively (Versveld *et al.*, 1998). Some values of water use were adjusted by the authors to account for periods of no flows but it was recognised that this would not take into account riparian vegetation which might still be able to access water in the saturation zone. The average values of water used in the report for all alien plants derived from the Le Maitre *et al.* (1996 and 1997) model was 190mm in South Africa, 369mm in the Eastern Cape, and 354mm in the PE Coast, Swartkops and Coega catchments (Versveld *et al.*, 1998).

It is standard practice for plantation managers to avoid planting trees in the riparian zones to avoid 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; Le Maitre *et al.,* 1995; Ninham Shand Inc., 1993; Scott and Lesch, 1995, 1996). Trees growing in the riparian zone have direct access to the water feeding the streams and are able to transpire freely and meet evaporative demand whereas trees further away from streams are limited by soil water availability (Le Maitre *et al.*, 1995).

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 (Dunne and Leopold, 1978a; Kramer, 1983) whereas evaporation refers to the loss of water directly to the atmosphere from a surface water source (Smith, 1990). Interception of rain by a vegetated surface forms part of the process and also contributes to loss of runoff due to the increased surface area where evaporation can take place. 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).

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 and Whitfield, 1981). Smith *et al.* (1992) verified the technique for *Acacia mearnsii*, concluding that the technique 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 and it was suggested that long term experiments need to be carried out to ensure reliable results.

Smith *et al.* (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* exhibiting early control of water loss as the vapour pressure deficit (VPD) increases and the air dries out (Figure 2.1). Smith *et al.*, (1992) studied the technique in Jonkershoek near Stellenbosch in September where measurements were taken between 12pm and 4pm on the single tree on a cloudless day. Poulter *et al.*, (1994) used two trees in the Sabie River catchment (Mpumalanga) for a 31 day period between late October and November. HPV provides useful information about the water use characteristics of trees

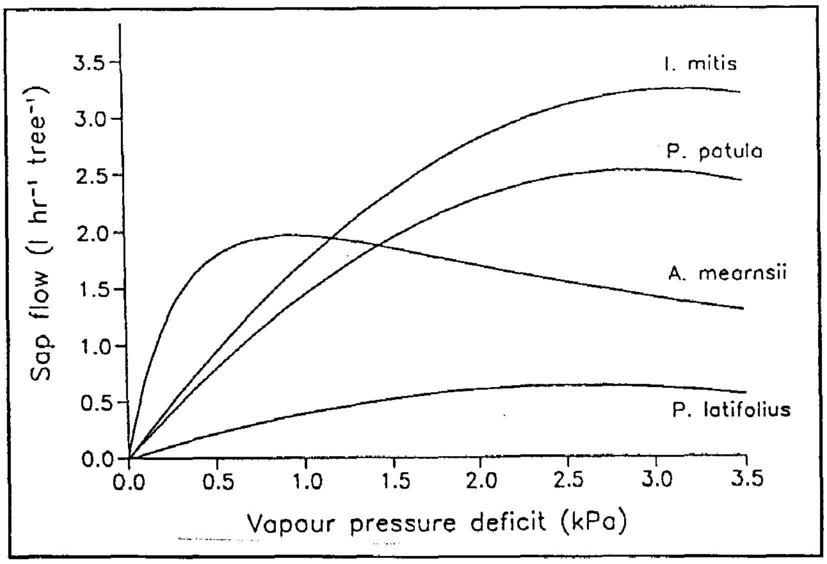


Figure 2.1: *Acacia mearnsii* exhibiting control of water loss as VPD increases and the air dries out. (Poulter *et al.*, 1994, pp24)

(Poulter *et al.*, 1994) and the technique has been verified for *Acacia mearnsii* (Poulter *et al.*, 1994; Smith *et al.*, 1992). However, further research is recommended by the authors and suggest the choice of species grown in riparian zones could lead to important differences in streamflow characteristics.

In all the literature reviewed, only one reference was made to the possibility of certain tree species in the riparian zone not using water directly from the stream channel (Dawson and Ehleringer, 1991). It is suspected, however, that trees in the riparian zone use potentially more water than trees further away from the channel. Dawson and Ehleringer (1991), using hydrogen isotope ratio analyses, were able to conclude that mature stream side trees do not use water from the channel. In a catchment near Salt Lake City where a scrub oak-maple (*Quercus-Acer)* is common in the riparian zone, the authors were able to identify isotopes from different water sources and show that mature trees were using water from deeper soil strata and not from the surface stream water (Dawson and Ehleringer, 1991). No reference of this type of study was found for South African conditions and/or tree species but it is an interesting possibility to determine the exact movement of water within the riparian zone. The knowledge that different tree species in the riparian zone might be accessing different sources of water could create different impacts on streamflow characteristics.

2.2.1 Alien Trees in Catchments Affecting Streamflow

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; Versveld *et al.*, 1998). Bosch and Hewlett (1982) reviewed 94 catchment experiments worldwide to investigate the effect of vegetation changes on water yield. The assimilation of information allowed the authors 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 (Bosch and Hewlett, 1982). It was shown that the results from catchment experiments are influenced by certain general trends of which precipitation is the most significant. Results in extreme low or high rainfall regions showed greatest increases or decreases in water yield in response to vegetation changes. Topography, climate and soils were also recognised as affecting the outcome of results and should be used as factors to consider when deciding on the size and design of an experimental site (Bosch and Hewlett, 1982). If a site is too small it was suggested that the results may not represent the catchment as a whole. However, it is difficult to control treatments, estimate precipitation and measure streamflow accurately as an experimental catchment increases in size (Bosch and Hewlett, 1982).

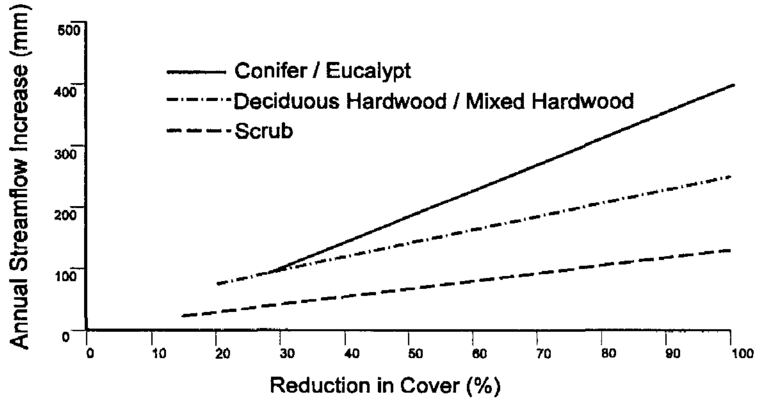


Figure 2.2: Water yield changes following changes in vegetation cover (Adapted from Bosch and Hewlett, 1982)

The authors were able to conclude that coniferous and eucalypt cover types have the greatest influence on water yield, followed by deciduous and mixed hardwoods and finally scrub or grasslands (Figure 2.2). *Acacia mearnsii* specifically was not studied 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 the authors to conclude that valuable information is available and can be used as a general guideline for practical purposes in catchment management around the world (Bosch and Hewlett, 1982). Ninham Shand Inc. (1993) used these estimates of reduced streamflow (Figure 2.2)to complete a report on the effect of *Acacia mearnsii* in the Krom and Kouga River catchments (Section 2.2.2).

Results presented by Bosch and Hewlett (1982) depict an average of 94 catchment experiments worldwide, which included 10 South African examples (Figure 2.2). It was emphasised that specific functions relating water yield change to forestry practices should be approached with caution due to the wide variety of catchment conditions reviewed (Bosch and Hewlett, 1982). In view of their statement, selected results from reviews of catchment experiments within the Fynbos Biome have been summarised in Table 2.1 (Van Wyk, 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.

Table 2.1: Results from catchment experiments within the Fynbos Biome

Reduced streamflow ($m^3.ha^{-1}.month^{-1}$)	**Percentage of catchment afforested**	**Plantation species**	**Experiment Duration**	**Source**
207.5 (249 mm/a)	57%	*Pinus patula*	28 years	Van Wyk (1987)
260.8 (313 mm/a)	98%	*Pinus patula*	20 years	Van Wyk (1987)
142.5 (171 mm/a)	36%	*Pinus patula*	16 years	Van Wyk (1987)
154.2 (185 mm/a)	89%	*Pinus patula*	8 years	Van Wyk (1987)

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, 1987; Bosch and von Gadow, 1990). 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, and thereafter the density of the alien plants increased dramatically, in addition to the trees invading 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).

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 2.3) and a relationship between mean annual rainfall and run-off (Figure 2.4) 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).

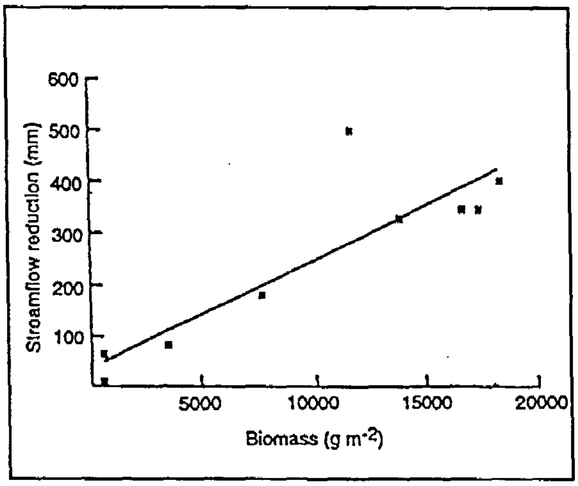


Figure 2.3: Relationship between Above Ground Biomass and Reduced Streamflow (Le Maitre *et al.*, 1996).

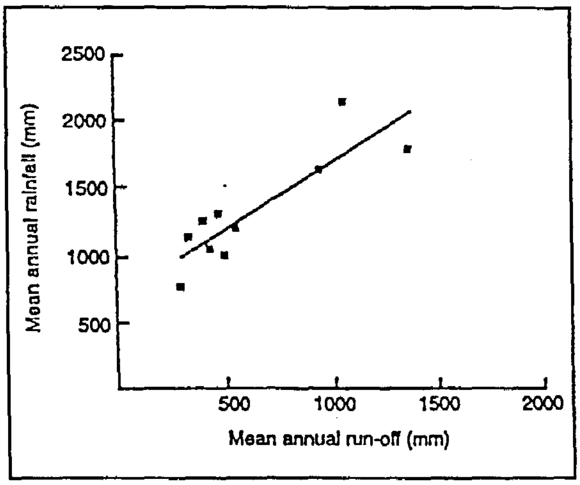


Figure 2.4: Relationship between mean annual rainfall and run-off (Le Maitre *et al.*, 1996)

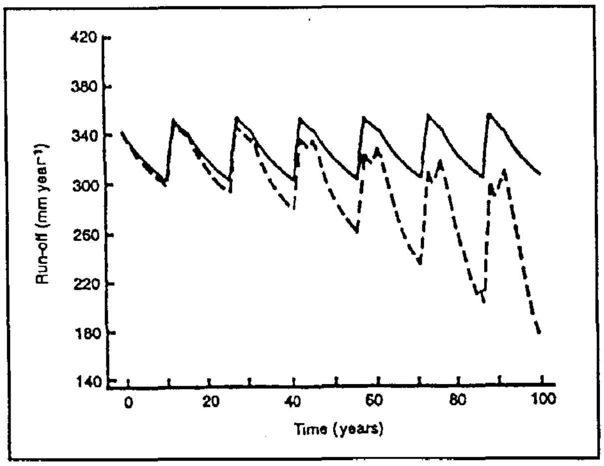


Figure 2.5: Simulations of annual run-off with alien trees absent (——) and alien trees present (-----) with a fire return interval of 15 years. (Le Maitre *et al.*, 1996)

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 2.5).

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 347m^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 347m^3.ha^{-1}.yr^{-1} (34.7mm) is based on an area of 250 000 hectares. The percentage loss of water would be considerably higher in areas below the average rainfall, which ranges between 600mm and 1900mm, 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).

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 *Acacia mearnsii,* where invasion is worst in the riparian zone, further research is necessary at a smaller scale within riparian zones around the country.

2.2.2 Alien Trees in the Riparian Zone Affecting Streamflow

The few field demonstrations that have been undertaken to investigate the effect of clearing indigenous and invasive vegetation in riparian zones have shown increases in streamflow (Dye and Poulter, 1995a, 1995b; Nanni, 1972; Rowe, 1963; Scott and Lesch, 1995, 1996). Dye and Poulter (1995b) investigated the effect on streamflow of clearing mixed stands of *Pinus patula* and *Acacia mearnsii* in the riparian zone, but no field demonstrations on clearing homogeneous stands of *Acacia mearnsii* have been conducted.

Dye and Poulter (1995b) demonstrated the effect on streamflow of clearing invasive *Pinus patula* and *Acacia mearnsii* from a riparian zone in an afforested catchment in the 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 2.6). Dye and Poulter (1995b) found clearing of the trees accounted for a 120% increase in streamflow, equivalent to 30.5m^3/day/2.5ha or 438mm per annum.

The authors concluded that the trees in the riparian zone exerted a strong influence on the streamflow as seen by the daily fluctuations recorded as a consequence of transpiration by the trees, taking place only during the hours of daylight (Figure 2.6). 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 2.6). Dye and Poulter (1995b) concluded that invasive exotic trees should be removed from riparian zones to increase streamflow from afforested catchments. It was stated there is a need for more information on the effects of individual species, density and age distribution, as well as catchment characteristics, before the effect on streamflow responses of clearing invasive trees can be considered reliable.

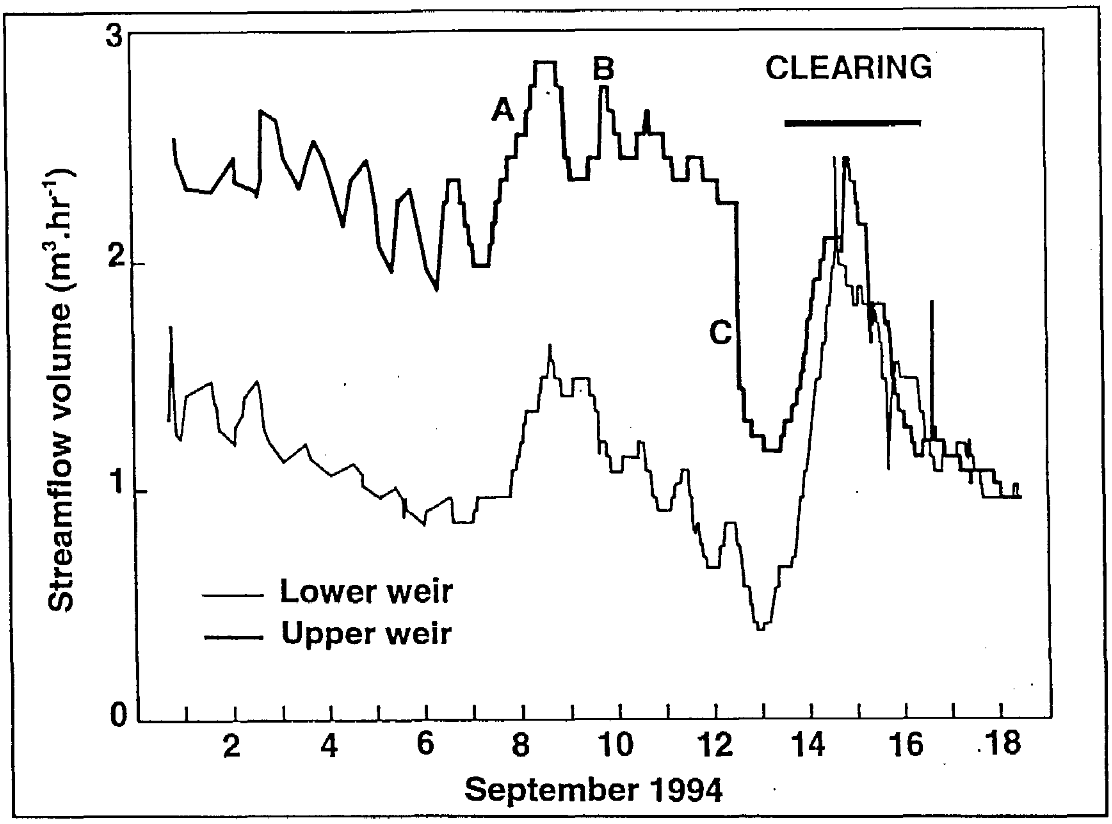


Figure 2.6: Streamflow recorded at the upper and lower weirs for the duration of the experiment. Point A marks an increase in the streamflow due to overcast weather. The upper weir was partially blocked at B and cleared at C. (Dye and Poulter, 1995b).

The technique using two portable weirs to measure streamflow was first used by Nanni (1972) to study the effect of clearing indigenous riparian vegetation on water use at Cathedral Peak. There were no exotic trees present in the Nanni (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. Nanni (1972) showed that although changes in streamflow were small in response to the clearing indigenous riparian vegetation there was a measurable response. 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. Nanni (1972) also concluded that this type of experiment would be successful during dry periods, and light rainfall events, and 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 of riparian vegetation is higher than that of 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 South Western Cape Province 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 southern Cape *Pinus 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 increase in annual streamflow (55mm), 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 to 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).

Water use estimates from the Bosch and Hewlett (1982) review (Section 2.2.1) were 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 300mm of annual streamflow (3000m^3 of water per hectare per year) water usage of mixed hardwoods, to estimate the effect of *Acacia mearnsii* in the Kouga and Krom catchments and were able to provide future management suggestions.

Using digitised data of the Kouga and Krom catchments it was found that riparian zones equal to an area of 3170ha were invaded with *Acacia mearnsii* trees (Ninham Shand Inc. 1993). Palmer and Hintsa (1996) used satellite imagery (Landsat TM imagery) to examine the extent of alien vegetation in the same area and concluded 3200ha or 5% of the relevant 1:50 000 topographical map (3324CC) is invaded by *Acacia mearnsii*. On examination of the reclassified image, the distribution of *Acacia mearnsii* invasions follows the river lines (Palmer and Hintsa, 1996) and therefore corresponds with the figure Ninham Shand Inc. (1993) used. These figures amount to 9.5 million m^3 of water per annum used by *Acacia mearnsii* in riparian zones, in this area (Ninham Shand Inc., 1993). In a cost versus benefit analysis the authors concluded that alien vegetation control should be considered as a first option to solving the regions water problems (Ninham Shand Inc., 1993).

The majority of international literature found on the general subject of riparian zones and water use deals more specifically with the health of riparian zones as apposed to the potential increase in streamflow as a result of removing vegetation (Gresswell *et al.*, 1989). However, a pilot study showing streamflow increases after removing indigenous woodland-riparian vegetation in southern California was located (Rowe, 1963). The riparian vegetation consisted mainly of deep rooted mixed oak-woodland, in a catchment characterised by highly permeable sandy-loamy soils with an average rainfall of 25.5 inches (653mm) (Rowe, 1963). Historical data was available for streamflow in adjacent catchments and was used in a comparison before and after the clearing of 38 acres (15ha) of riparian vegetation in one of the catchments. The cleared area was approximately 1.3 miles (2km) long and 100 - 400 feet (30-120m) wide.

While the focus of the conclusions was not concerned with quantity of increased streamflow, the highest recorded increase in a season amounted to an average 14.4 inches (369mm). This increase in streamflow was recorded during dry conditions with the least rainfall. The main conclusions from the study state that streamflow increases can be expected in areas where the water supply is adequate to exceed evapotranspiration losses after treatment. In addition, the saturation zone should be in reach of the riparian vegetation and the riparian soils should be sufficiently deep to permit reduction in evapotranspiration if the deep rooted vegetation is removed (Rowe, 1963).

In conclusion, research on the effect of exotic trees on streamflow in riparian zones is 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 (Bosch and Marais, 1995; Dye and Poulter, 1995b; Scott and Lesch, 1995, 1996).

2.3 GENERAL EFFECTS OF *A. mearnsii* IN THE RIPARIAN ZONE

Acacia mearnsii has no natural enemies in South Africa and it is known to have widespread effects on ecosystems which it invades (Barrett, 1996; Macdonald and Richardson, 1986). Conservationists have been attempting, however, to eradicate *A. mearnsii* from Fynbos catchments for years (Barrett, 1996; Macdonald and Richardson, 1986). The control of *A. mearnsii* has received an abundance of attention recently with 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 (Section 2.1). This reduction in species richness is well documented in literature and Macdonald and Richardson (1986) summarised how plant species richness was reduced in Fynbos communities dominated by alien plants relative to uninvaded

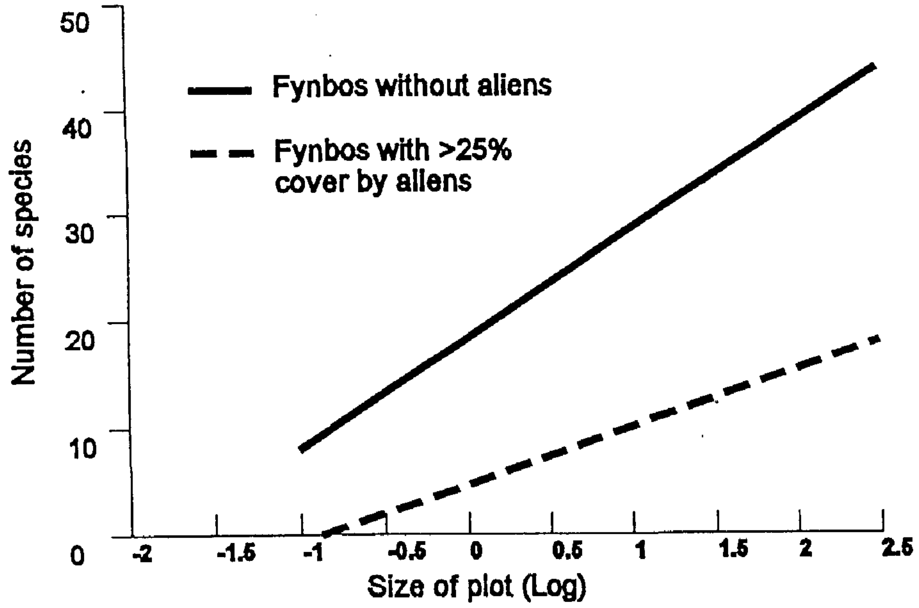


Figure 2.7: The relationship between the number of indigenous plant species and size of plot in Fynbos areas densely infested by alien woody plants and in uninfested areas. (Adapted from Macdonald and Richardson, 1986)

indigenous Fynbos communities (Figure 2.7).

It has been discussed how *A. mearnsii* out competes natural Fynbos vegetation, forming dense stands of trees (Section 2.1). 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; Seydack and Bekker, 1995). 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 Wilgen and Kruger, 1985).

2.3.1 Channel Form and Stability

Vegetation has often been played down as a significant variable in channel stability, partly because it is difficult to quantify effectively. Fluvial geomorphologists are, however, increasingly recognising its importance in controlling channel processes and form (Gregory and Gurnell, 1988; Murgatroyd and Ternan, 1983; Rowntree, 1991; Thorne, 1990). 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 (Gregory and Gurnell, 1988; Gurnell and Gregory, 1984). 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 *Acacia 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 the majority 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. Two adjacent catchments in the Kouga river system, the Rachels and Huis rivers, have completely different channel morphologies (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 *Acacia mearnsii*, but not on the Huis river which has indigenous vegetation in the riparian zone. 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 *Acacia 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 the study that the invasive vegetation on the Rachels river played a major role in the damage caused to the river channel during the flood event (Figure 2.8). In comparison the Huis river showed no signs of bank instability and 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 *Acacia mearnsii* has also invaded the riparian zone (Rowntree, 1990). The results of Mooi river study (Rowntree, 1990) also show the marked difference in size of the channel (Figure 2.9), only in this case it is on the same river and not a comparison between rivers which have different vegetation types. Rowntree (1990) noted that a reach of the Mooi river invaded by *Acacia mearnsii* had a decreased width-depth ratio, but had a larger cross-section compared to that of a grassy reach (Figure 2.9).

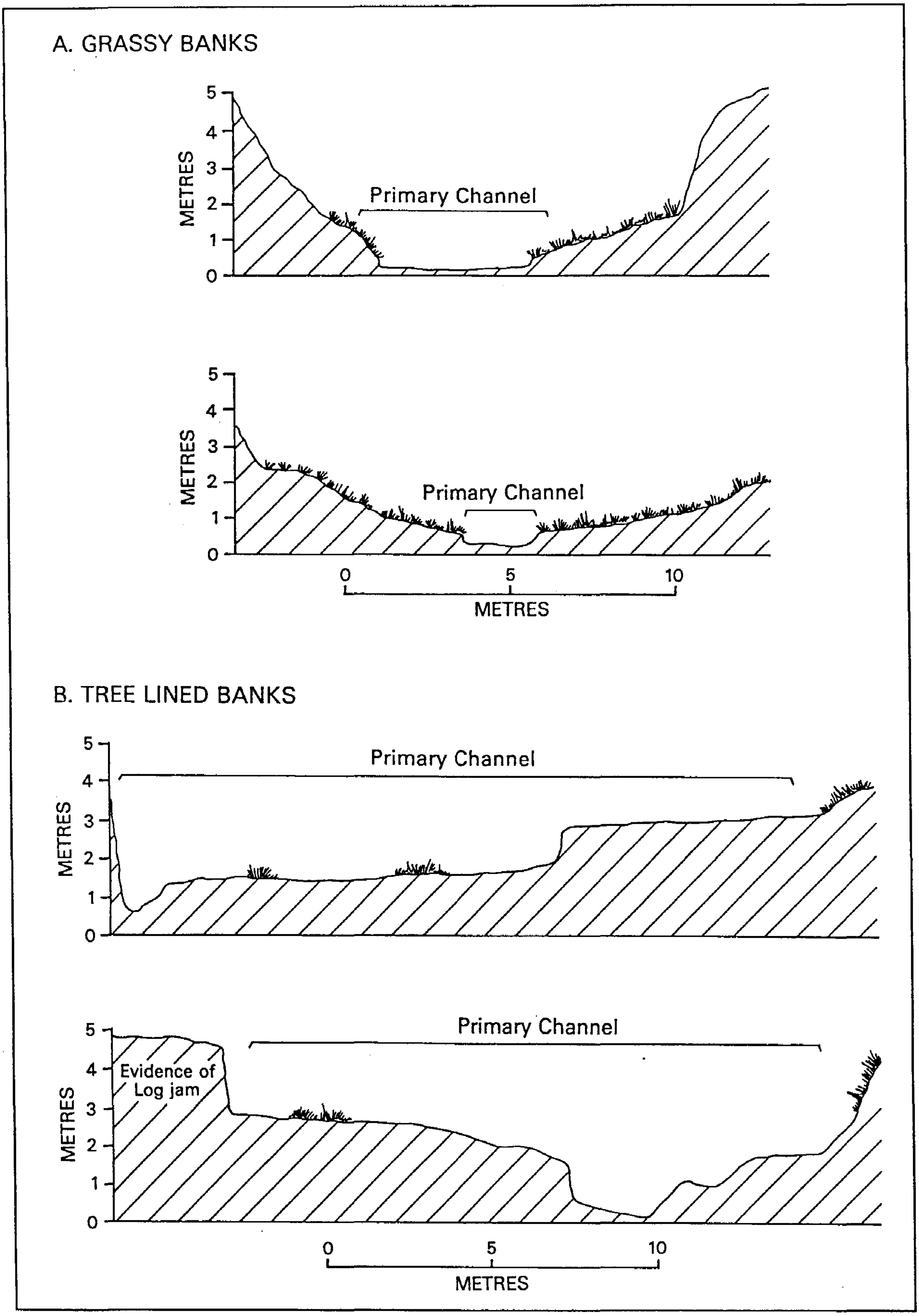


Figure 2.8: The effect of invasion by *Acacia mearnsii* in contrast to grassy banks on channel morphology of the Huis and Rachels rivers. (Beyers, 1994)

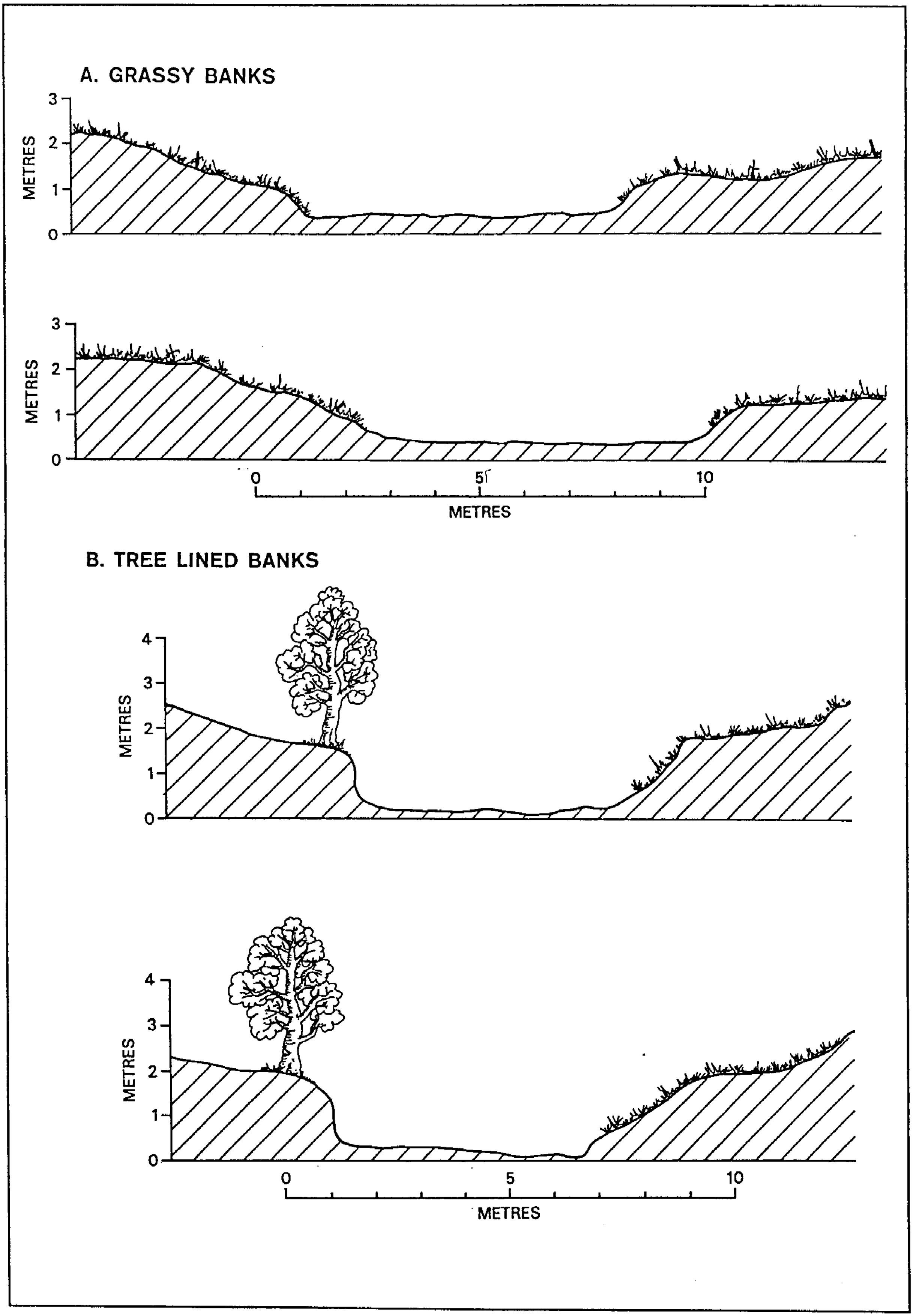


Figure 2.9: Results of the effect of invasion by *Acacia mearnsii* on channel morphology of the Mooi river, north eastern Cape (Rowntree, 1991).

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). Rowntree (1991) discusses the important distinction between grassy and woody vegetation in terms of their effects on bank stability. 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.*

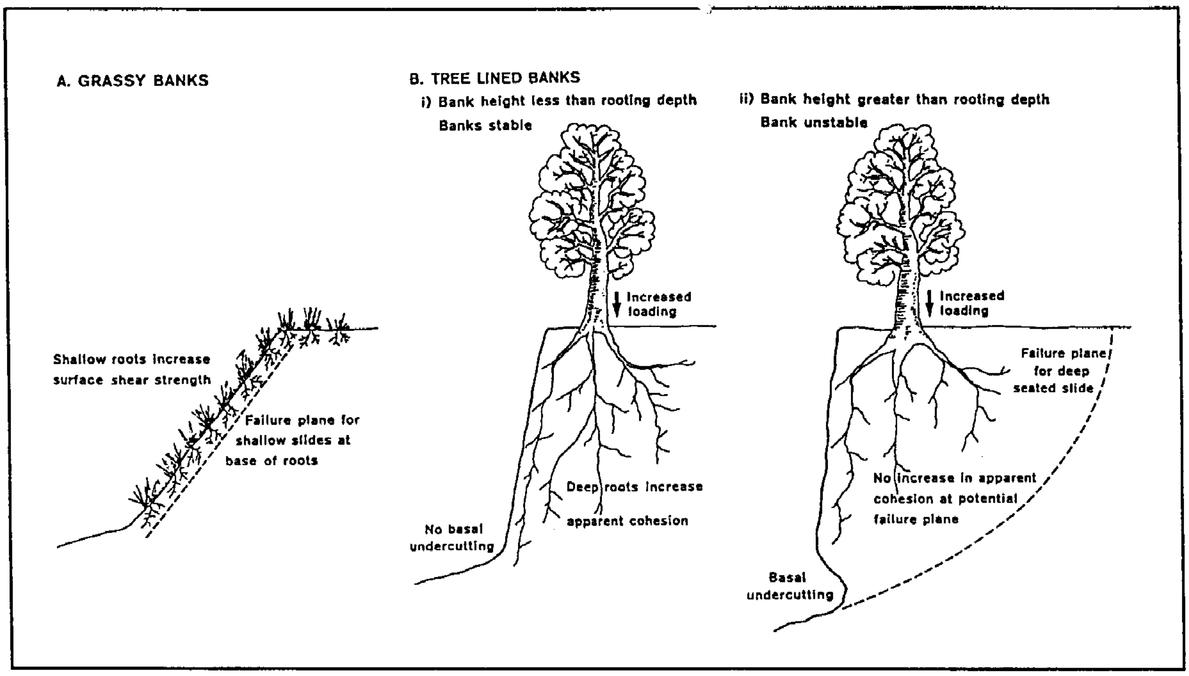


Figure 2.10: The effect of vegetation on bank stability (Rowntree, 1991).

On the Rachels river trees were not close to the banks but rather growing a little distance away. There were however small seedlings on the banks, which suggests there were trees on the river bank before the recent floods, increasing bank strength and allowing 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 what looked like 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 a log step higher up in the river during a flood event could potentially increase the energy of a body of water by a damming effect. When the pressure exceeds the logs holding capacity, the water and logs burst downstream causing more damage in the form of erosion and scour, than there ordinarily would have been (Keller and Swanson, 1979; Marston, 1982).

2.3.2 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. *Acacia mearnsii* formed a large proportion of the alien vegetation on the invaded rivers in the survey. During the survey, the Rachels river (section 2.3.1) 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's 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

The theoretical review in Chapter 2 confirms that the effect on streamflow of removing *Acacia mearnsii* from the riparian zone needs further research. Catchment experiments have, in the past, focussed on forestry practices. Due to the lack of extensive forestry practices in the Fynbos region of the Eastern Cape, previous experimental studies on the effect of vegetation, either at a catchment scale or within the riparian zone, are lacking for this geographical area (Section 2.2).

The ZRWRMP task group 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). After further investigation of the catchment by the present researcher, the site was confirmed as a suitable location for various reasons. These included, the proximity of the dam wall above the site to control streamflow through the system, to protect the weirs in case of floods and to augment flow during dry periods. Secondly, staff of Port Elizabeth Municipality (PEM) based at the Sand River Dam could assist for the duration of the experiment; 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. Finally, the site allowed for the establishment of two sections of similar morphology and vegetation density.

Previous studies on the effect of riparian vegetation on streamflow used paired catchments (Section 2.2.1) or two temporary weirs on a section of river over a short period of time (Section 2.2.2). To facilitate a longer term study to compare seasonality of streamflow response to the removal of riparian vegetation, permanent weirs would be constructed. Once permanent weirs were in place, long term studies could be initiated and/or intensive short term studies could be undertaken without the expense of rebuilding weirs. The construction and layout of the weirs will be discussed in greater detail in Section 3.4.

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). Three weirs were constructed approximately 500m apart from each other (Figure 3.1). This would allow two adjacent sections to be compared without having vast differences in catchment conditions, channel morphology and vegetation densities.

The northern bank of the river is steep hillslope, invaded by *Acacia mearnsii* (Figure 3.1). The trees in the northern riparian zone were observed and briefly sampled to confirm no marked differences in density between the two sections. Due to the steep hillslope on the northern side of the river, there is no defined riparian zone except for an area of half a hectare of gradual slope, 100m downstream from weir 1. In comparison to the riparian zone on the southern bank with areas of approximately 2.5 hectares in each section, it was felt for the purposes of the present study the riparian zone north of the study site would not be cleared due to time constraints.

Streamflow was monitored from the 10th to the 22nd of January 1996 before clearing and between the 22nd and 26th of January 1996 when the riparian zone south of the river, between weir 1 and 2, was cleared. The data loggers were removed from all three weirs between the 27th of January and the 6th of February as a precaution when the Sand River Dam over flowed due to heavy isolated rainfall elsewhere in the catchment. By using three weirs, the streamflow in a cleared section (between weir 1 and 2) could be compared to an uncleared (control) section (between weir 2 and 3) over the duration of the year. Streamflow was monitored after clearing until the 9th of September when the data loggers were removed by DWAF.

Experimental design was the sole responsibility of the present researcher, whereas the time frame of the project including the removal of data loggers and the clearing of trees, was coordinated by the ZWRMP task group. Availability of equipment and personnel provided by the Department of Water Affairs and Forestry and the Department of Agriculture were taken into account. The following sections discuss the methodological approach of the study in attempting to achieve the aims and objectives laid out in Section 1.4, using past research as a framework for the study (Chapter 2).

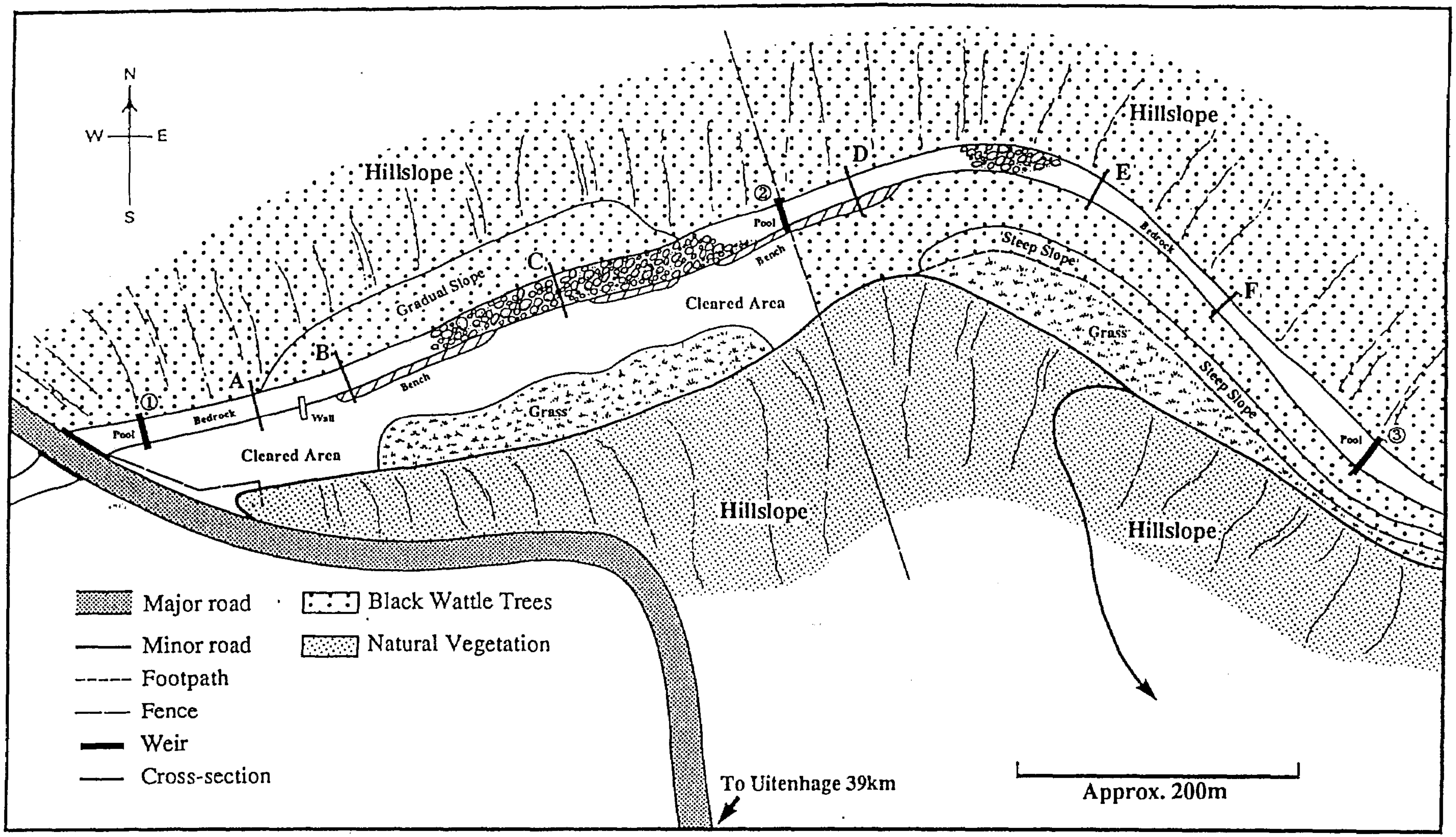


Figure 3.1: Layout of the Sand river study site

3.2 VEGETATION SURVEY

Le Maitre *et al.* (1996) was able to show a relationship between above ground biomass and reduced streamflow (Figure 2.3). In past research when above ground biomass has been compared to reduced streamflow, *Acacia mearnsii* has not been included in these calculations due to the lack of data (Le Maitre *et al.*, 1995). 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 *Acacia mearnsii* in the riparian zone was sampled. Brower *et al.* (1990) state that plot or quadrant 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.

The extent of the vegetation within the two sections of the study site is established in plates 1,2 and 3 respectively. 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 represents the centre of four compass directions (N,S,E,W), which divides the sampling site into four quarters (Figure 3.2). In each quarter the distance was measured from the centre point, to the centre of the nearest tree. One tree per quarter is measured so that a total of four trees is recorded for each point sampled (Figure 3.2). Smith (1990) recommends a large number of sample points, with a minimum of 50 points, to give an accurate estimate of the number of trees in the sampled area. In excess of 750 point to plant measurements were recorded on data sheets (Appendix 2).

The area of each section south of the river was calculated from measurements during the site survey and topographical maps. The individual areas of both the cleared and uncleared section were both found to be approximately 2.5ha respectively. The point to plant distances and area were used to calculate the total number of trees and the numbers of each size class (Table 4.1) within the cleared and uncleared section of the riparian zone south of the river (Figure 3.1). To calculate the total number 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).

Plate 1: Study site before felling of trees.

Plate 2: Study site - one day after felling of trees was completed.

Plate 3: Study site - a few months after felling of trees.

The amount of trees in each size class were calculated by dividing the total number of trees in all DBH classes into the number of trees for each individual DBH class and multiplying by 100. The amount of trees in each DBH class was then calculated by dividing the number of the class by 100 and multiplying by the total number of all trees (Smith, 1990). The amount of trees in 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 the 22th and 26th of January, samples in the different size classes were weighed (Table 4.2). Larger trees were cut into manageable sizes and then weighed with the use of a spring scale. A comparison was made between the DBH of each size class and above ground biomass (Figure 4.1). The average weight of each class was multiplied by their respective densities to obtain a total wet above ground biomass value of trees removed in the cleared and uncleared section of the study site (Section 4.1).

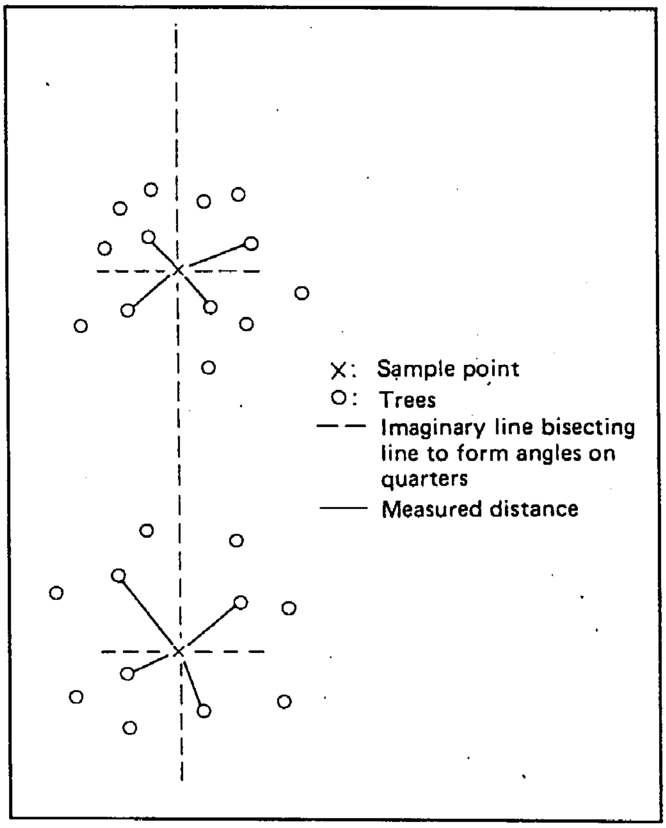


Figure 3.2: Plotless sampling technique - point quarter sampling method (Smith, 1990).

3.3 MEASUREMENT OF STREAMFLOW

Following the survey of the study site, the location for the construction of three permanent weirs was 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 3). All three weirs had the same design except for the length of the weir wall across the river channel (Plates 4 and 5). A 90° v-notch weir was mounted in front of a settling pool with a small orange stage plate for manual readings and wire mesh to stop debris from blocking the notch and interfering with the flow of water (Appendix 3) (Plate 6). To ensure accuracy of readings, the weirs were checked on a daily basis for blockages and at regular intervals throughout the day while clearing took place. During the initial two months of monitoring there were no blockages and the weirs were checked regularly either by Port Elizabeth Municipality staff or the present researcher for the duration of the monitoring period. A pressure probe was placed behind the v-notch in the settling pond and data loggers recording values from the probe were placed in secure boxes close to the river bank (Appendix 3) (Plates 4 and 5).

Three weirs were used in the study to allow for a comparison between a cleared and uncleared section of the riparian zone (Figure 3.1) (Plates 2 and 3). An ODS pressure probe was used to measure the streamflow height, which was recorded by an Ott:Log data logger every 12 minutes for 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 ensure continuous accuracy. Water flow at all weirs was extremely low and stopped completely on some days towards the end of March. It was decided to release water from the dam to continue monitoring as it could now be assumed there was no recharge from the river banks and/or the amount of recharge was insufficient to induce flows.

Plate 4: Above weir 1 looking down river before felling of trees.

Plate 5: Above weir 1 looking down river after felling of trees.

Plate 6: Weir 2 showing the design of the settling pool.

3.4 ANALYSIS OF STREAMFLOW

Data was received in ASCII text format (Appendix 4) and converted into spreadsheets (Appendix 5). Due to the large data set (83 520 values), a combination of Quattro Pro and Sigma Plot spreadsheet packages were used in a time-consuming process to convert raw data to a format facilitating further analysis. The ASCII text values from the data loggers were measurements of streamflow height flowing through the v-notch at the individual weirs. Data logger streamflow heights were converted into discharge using $Q=1.35.h^{2.5}$ (Dunne and Leopold, 1978a) where Q is the discharge measured in cubic metres and h is the streamflow 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 . The daily means were presented in a time series for the duration of the monitoring period (Figure 4.2). A comparison of discharge between weirs (the difference between weir 2 and 1 and weir 3 and 2) to determine the volume of water released or consumed in either section is presented in Figure 4.3. The mean daily differences were used to calculate the total consumption or release of water for each month and were included as a table on Figure 4.3.

The total net uptake of water by *A. mearnsii* was calculated as the sum of the water released from the cleared section and the measured uptake of water from the uncleared section. Table 4.3a shows the streamflow reduction (net uptake of water by *A. mearnsii*) for the different months. During April the streamflow reduction is significantly higher than the other months over the monitoring period (Table 4.3a). On the 4th of April it was decided to release a steady flow of water from the dam as the natural flow of the river had ceased. The initial release of water caused a noticeable increase in streamflow (Figure 4.2) but stabilised towards the end of the month. For this reason the streamflow values for April were not used in calculations of the total streamflow reduction due to the clearing of *Acacia mearnsii* in the riparian zone.

Figures 4.2 and 4.3 show atypical flood peaks at weir 1 in comparison to weir 2 and 3. These were considered to be a result of increased runoff generated from the nearby road. As the purpose of the study was to compare differences between the weirs it was felt these days should be removed from the analysis (Table 4.3b). In addition, when flow stopped completely and when there were periods of unsteady flow, data for all three weirs on the specific day and if necessary subsequent days were removed and calculations for streamflow reduction were reworked with the decrease in number of days (Table 4.3b). A complete data set of daily flows at each weir and calculations of water use and/or water released between weirs is included in Appendix 6.

3.5 ANALYSIS OF WEATHER CONDITIONS

Bosch and Hewlett (1982) state that weather conditions are an 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 1). Mean monthly rainfall was compared to actual monthly rainfall to contextualise the rainfall for the duration of the monitoring period (Figure 4.4). Although monitoring commenced on the 10th of January, rainfall was analysed for 3 months prior to the experiment in order to understand conditions leading up to the period of monitoring (Figure 4.4). To interpret the moisture status in the riparian zone before and during the monitoring period, the difference between monthly rainfall during the monitoring period and the mean monthly rainfall was analysed (Figure 4.5).

There was no evaporation pan at the site, but data was available from Groendal and Loerie Dams, in the north-east and south-western catchments respectively (Figure 1.2). The Department of Water Affairs and Forestry (Pretoria) supplied daily and monthly potential open water pan evaporation (hereafter referred to as evaporation) data, measured at the respective dams (Appendix 7). Mean monthly evaporation for the past 20 years was compared to the monthly evaporation rates to contextualise the evaporation for the duration of the monitoring period (Figure 4.6). In order to relate streamflow to the weather conditions, the combined daily evaporation measured at Groendal and Loerie Dams (Appendix 7) and daily rainfall measured at the Sand River Dam (Appendix 1) is presented in a time series graph (Figure 4.7).

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 2.2.2). In an attempt to observe daily fluctuations in streamflow due to evaporative demand, three days were chosen from Figure 4.2 during periods with no rainfall in January (before clearing)(Figure 4.8a), February (after clearing)(Figure 4.8b) and June (driest month of the year)(Figure 4.8c). It was not possible to compare more sample days due to rainfall and extremely low or high streamflow measurements at one or more of the weirs during the monitoring period.

To identify possible relationships between the weather conditions and the effect of *Acacia mearnsii* on streamflow reduction, evaporative demand (the difference between evaporation and rainfall) was compared to streamflow reduction (Figure 4.9). The mean daily streamflow reduction for each month (Figure 4.9) was calculated using the data from Table 4.3b.

In the theoretical review (Chapter 2) it was suggested that weather conditions are directly related to streamflow responses. To examine a possible relationship between evaporative demand and streamflow reduction, correlation analyses were carried out for different time frames and some examples of these are shown in Appendix 8. Correlation coefficients were included on the graphs (Appendix 8).

3.6 SOIL MOISTURE MONITORING

Ground water is a vital component in the understanding of the relationship between streamflow and vegetation changes. Although Dye *et al.* (1994) explains 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 to the required depth. 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 be taken.

To investigate soil moisture changes, surface soil samples were taken from the cleared section and separate samples were taken from the uncleared section 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 shallow 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 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 4.4). A time series of the samples is presented in Figure 4.10 and the average percentage moisture content before and after clearing is shown in Figure 4.11.

3.7 ADDITIONAL EFFECTS OF CLEARING *Acacia mearnsii*

3.7.1 Water Quality

Conductivity can be used as a basic measure of water quality (Dallas *et al.*, 1994; DWAF, 1993; Franson *et al.*, 1985, Golterman *et al.*, 1978, Kempster *et al.*, 1982) and was successfully used by Cambray and de Moor (1995) to show the difference of water quality between rivers with riparian zones invaded and those clear of *Acacia 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 4.5). The average conductivity readings before and after clearing are shown in Figure 4.12.

3.7.2 Channel Survey

Researchers agree that alien woody species in the riparian zone adversely affect the channel morphology of a river (Section 2.3.1). With a view to monitoring the effect of bank clearance on channel stability, three representative cross-sections of the channel in the cleared section (Figure 4.13) and three in the uncleared section (Figure 4.14) were surveyed. 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.

The cross sections were drawn up by taking measurements from stretching a tape measure across the width of the channel and taking depth readings using a surveying pole at half metre intervals or at smaller intervals when there were smaller features to be taken into account (Appendix 9).

3.7.3 Rehabilitation and Restoration

As part of the research a workshop was funded on 'the environmental impact of alien tree eradication along river courses and its rehabilitation' which was arranged by Eastern Cape Nature Conservation. From this workshop a detailed report will be published outlining clearing techniques, rehabilitation and restoration. For the purposes of the present study a localised rehabilitation and restoration programme was initiated at the study site.

The vegetation growing below *Acacia mearnsii* trees is out-competed during the invasion process (Section 2.1), making it necessary to try and stabilise the soil once all trees have been cleared. Different species of lime coated grass seed (Appendix 10) were sown in the cleared section of the study site at the on the 16th of March. The lime coating ensures a higher rate of germination by controlling the time of germination until there is sufficient available water to penetrate the coating. Once this has occurred, and germination is successful, the lime coating is used by the seed for nutrients. The types of grasses were chosen for various characteristics such as palatability, due to potential small scale grazing in the area and erosion control.

CHAPTER 4

RESULTS

4.1 VEGETATION AND SITE SURVEY

The overall layout of the study site, location of weirs and cross-sections, the distribution of vegetation types and general topographical features in the area were shown in Figure 3.1.

The homogeneous stands of *Acacia mearnsii* within the cleared and uncleared sections were sampled and results from this survey are presented in Table 4.1. The total number of trees in the cleared section amount to 11263 and the uncleared section 10209. There is a difference of 1054 trees of which 77% of this figure is accounted for in trees with a diameter at breast height (DBH) of up to 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, with well developed root systems, resulting in both sections having similar tree densities. This allowed for a comparison of the effects of the trees on streamflow between the two sections.

Table 4.1: Number of *A. mearnsii* in respective size classes in the cleared and uncleared sections (area = 2.5ha for each section).

Cleared section

Size Class (DBH)	0 - 2.5cm	2.5 - 5cm	5 - 10cm	10 - 15cm	15 - 20cm
Number	3970	3309	2562	1239	183

Uncleared section

Size Class (DBH)	0 - 2.5cm	2.5 - 5cm	5 - 10cm	10 - 15cm	15 - 20cm
Number	3307	3165	2539	1198	208

The weights of the sampled trees and average weights of the size classes are presented in Table 4.2. The number of trees in each size class in the sections (Table 4.1) were multiplied with the average weight of the corresponding size class to obtain an approximate wet above ground biomass estimate of 160 t/ha (16 000 g/m^2) for an area of 2.5ha in both the cleared and uncleared sections. The relationship between the wet above ground biomass and DBH of the individually weighed samples is clearly shown in Figure 4.1.

Table 4.2: Sample and average weights of trees in the different DBH size classes.

Size Class	DBH (cm)	Weight (kg)	Ave Wt (kg)	Size Class	DBH (cm)	Weight (kg)	Ave Wt (kg)
0 - 2.5cm	0.4	0.8		5 - 10cm	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 - 5cm	2.5	6.3		10 - 15cm	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 - 20cm	15.5	258	
DBH - Diameter at breast height					16.4	249	
Ave Wt - Average weight of trees measured					16.6	256	
					18	281	
					19.4	292	267.2

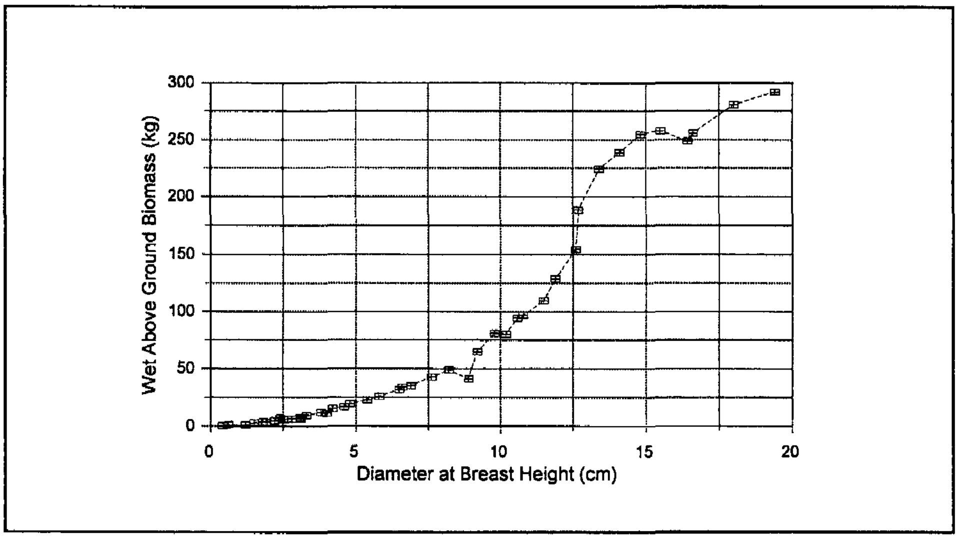


Figure 4.1: Relationship between wet above ground biomass and DBH.

4.2 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 the following figures. The daily mean flows as observed at the three weirs (Figure 4.2) and the volume of water either released from the banks (flow augmentation between the weirs) or uptake of water (flow depletion between the weirs) (Figure 4.3).

During the night of the 26th of January there was heavy rainfall over the upper Sand River catchment which caused the Sand River Dam to overflow, in spite of the dam water level being kept well below capacity in order to stop minor floods like this from interfering with the experiment. As a precautionary measure to prevent damage or loss, the data loggers were removed for 10 days until the flow had subsided sufficiently (Figure 4.2). The dam was later used in the experiment to augment the flow between the 4th of April and the 17th of July. This period was unusually dry for the region and it was necessary to augment the flows to ensure a base flow for the duration of the monitoring period (Figure 4.2).

Before clearing took place at the end of January, it can be seen that both sections of river were being augmented by flows from the banks. This was in fact greatest from the downstream section (a total of 1586m^3 as compared to 640m^3) (Figure 4.3). It should be noted that December was a wet month so that alluvium in the valley bottom would have been recharged with rainwater. Despite three reasonably heavy storms during January, the flow levels continued to decline in line with normal recession curves.

After clearing took place, flow levels continued to decline (Figure 4.2). By mid February minimal flow was entering the top of the system, but some flow augmentation continued due to bank releases in the cleared section. Flow augmentation from the riparian zone in the lower section soon ceased completely and was replaced by a reduction in flows representing uptake by the riparian trees. The inset table in Figure 4.3 shows in February that flow augmentation from the cleared area (left hand column) amounted to 502m^3 and from the uncleared area (right hand column) only 53m^3. Thereafter, the cleared area continued to release water whilst the lower uncleared section registered a net uptake of water. The total uptake of water by *A. mearnsii* can be calculated as the sum of the water released from the cleared section and the measured uptake of water from the uncleared section. This is seen to be highest in June at 1431m^3 (305 + 1126) or 48m^3 per day from a 500m length of channel cleared on one side only, for an area of 2.5ha. Maximum water consumption is seen to take place following a prolonged dry period with moderate evaporation rates. This is also the time when catchment water reserves are at a minimum.

Tables 4.3a and 4.3b outline streamflow reduction on a monthly basis. Table 4.3a is a literal representation of the recorded values at each weir for the duration of the monitoring period. April has been highlighted as these values are extremely high due to the release of water from the Sand River Dam and were not used in any analyses. In addition it was felt that due to the flood peaks at weir 1 caused by isolated run-off from the road (Figures 4.2 and 4.3) these periods would be excluded. The amended data and subsequent reduction in days in comparison with Table 4.3a is shown in Table 4.3b. It is interesting to note the increased streamflow reduction values in Table 4.3b as a result of removing only 20 days. In March the removal of data for one day accounted for a difference of 93m^3 between weir 1 and 2 over the month whereas there was no change in difference between weir 2 and 3. The figures from Table 4.3b will be discussed and analysed in Chapter 5.

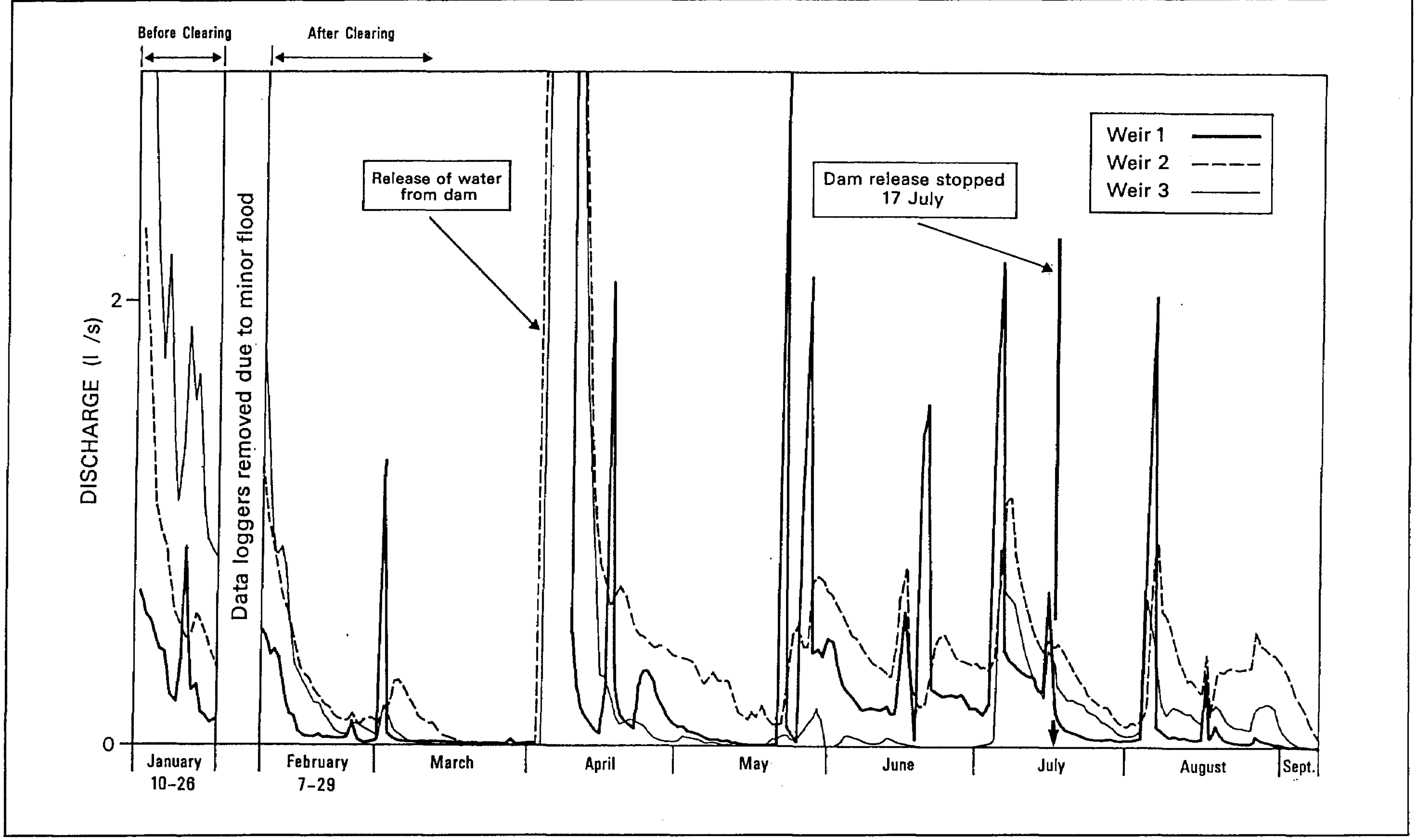


Figure 4.2: Daily mean flows as measured at the gauging weirs. Weir 1 to weir 2 is the cleared section, weir 2 to weir 3 is the uncleared section.

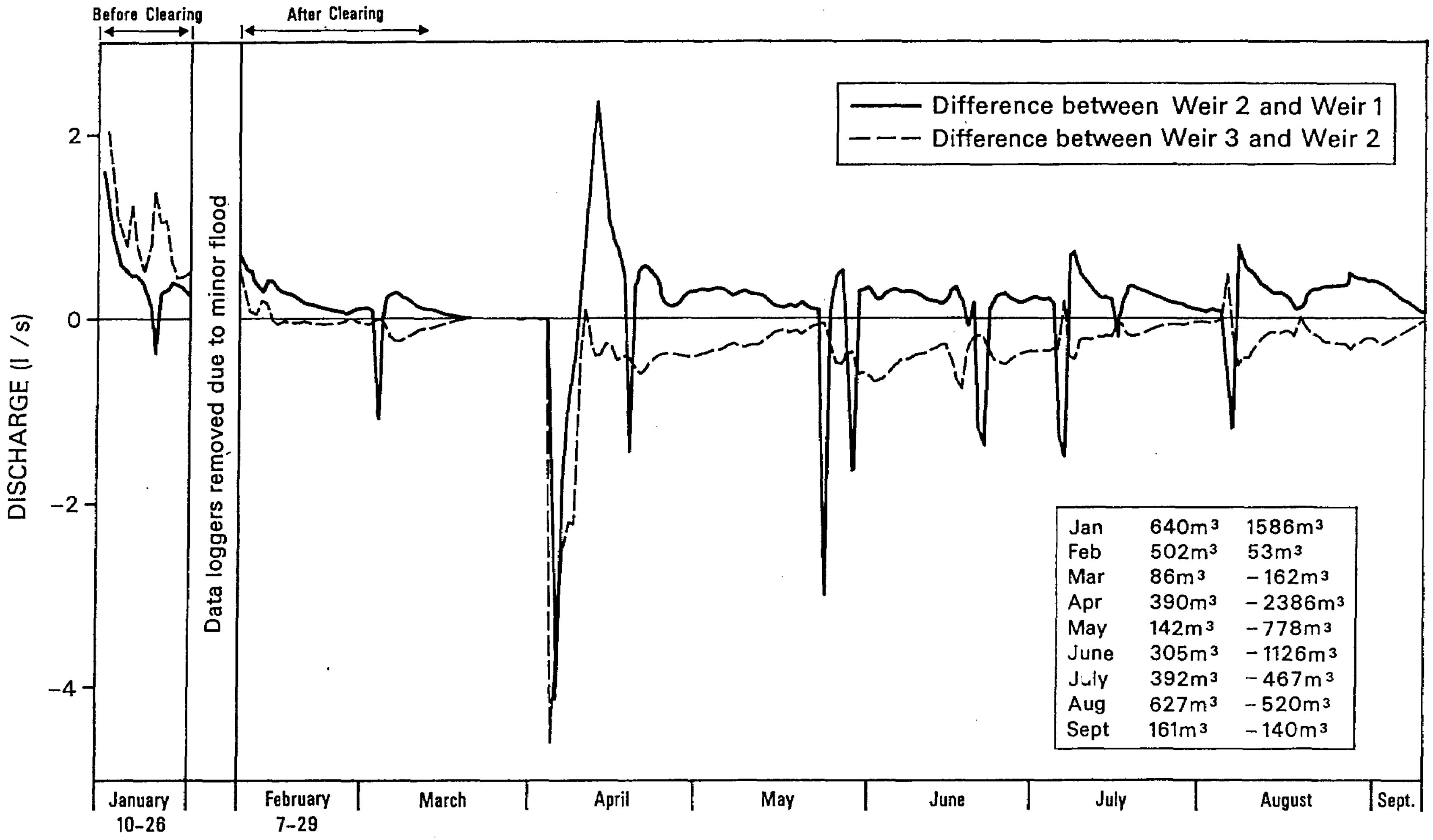


Figure 4.3: Water uptake (negative) and flow augmentation (positive) within the cleared section (—) and uncleared section (----). Inset table shows monthly values of uptake or release from the uncleared and cleared areas (left and right hand columns respectively).

Table 4.3a: Actual measurements of streamflow reduction due to uptake of water by *Acacia mearnsii*

Month	No.of days	Weir 2 - Weir 1(x) (m^3)	Weir 3 - Weir 2(y) (m^3)	Net Uptake (x-y) (m^3)	Net uptake (m^3/ day)	Net uptake (m^3/day/ha)	Streamflow Reduction as rainfall equivalent (mm per annum)
January	17	640	1586	-946	-56	-22.4	-818
February	23	502	53	450	20	8	292
March	31	86	-162	248	8	3.2	117
April	30	390	-2386	2776	93	37.2	1358
May	31	142	-778	920	30	12	438
June	30	305	-1126	1431	48	19.2	701
July	31	392	-467	859	28	11.2	409
August	31	627	-520	1147	37	14.8	540
September	9	161	-140	301	33	13.2	482

Table 4.3b: Amended measurements of streamflow reduction due to uptake of water by *Acacia mearnsii*

Month	No.of days	Weir 2 - Weir 1(x) (m^3)	Weir 3 - Weir 2(y) (m^3)	Net Uptake (x-y) (m^3)	Net uptake (m^3/ day)	Net uptake (m^3/day/ha)	Streamflow Reduction as rainfall equivalent (mm per annum)
January	14	698	1344	-646	-46	-18.5	-674
February	19	403	-12	415	22	8.7	318
March	30	179	-162	341	11	4.5	166
April	30	390	-2386	2776	93	37.2	1358
May	28	608	-709	1317	47	18.8	687
June	27	533	-1068	1601	59	23.7	866
July	28	643	-452	1095	39	15.6	571
August	28	777	-544	1321	47	18.9	689
September	9	161	-140	301	33	13.2	482

4.3 WEATHER CONDITIONS

The mean monthly rainfall was compared to monthly rainfall for the duration of the experiment (Figure 4.4 and 4.5). In the two months prior to monitoring, rainfall exceeded the 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. Figure 4.5 displays these differences above and below the average monthly rainfall. The months prior to the study are above average but from February onwards the rainfall is below average. It is assumed the wet months prior to streamflow monitoring recharged the alluvium in the riparian zone. Although there was some rain in each month except during June, the rainfall figures are all below average and it is assumed that the alluvium was not recharged from rainfall to any significant degree during the monitoring period from the 10th of January to the 8th of September.

Figure 4.6 compares the combined values of mean monthly evaporation to monthly evaporation during the monitoring period. Throughout the year there is relatively little difference between the monthly potential evaporation and mean monthly potential evaporation. Evaporation for the region is unimodal with high potential evaporation in the summer months and lower potential evaporation rates in the winter months (Figure 4.6). December and January are the only two months with a difference between monthly evaporation and mean monthly evaporation of over 20mm.

A time series of daily rainfall and potential evaporation is presented in Figure 4.7. Daily potential evaporation fluctuates 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. Rainfall is more variable with the highest recorded rainfall events of 20mm on the 2nd of March and 20th of July. Rainfall is expected all year around in this area but during 1996 there were relatively few rainfall events over the winter months with June lacking rainfall completely.

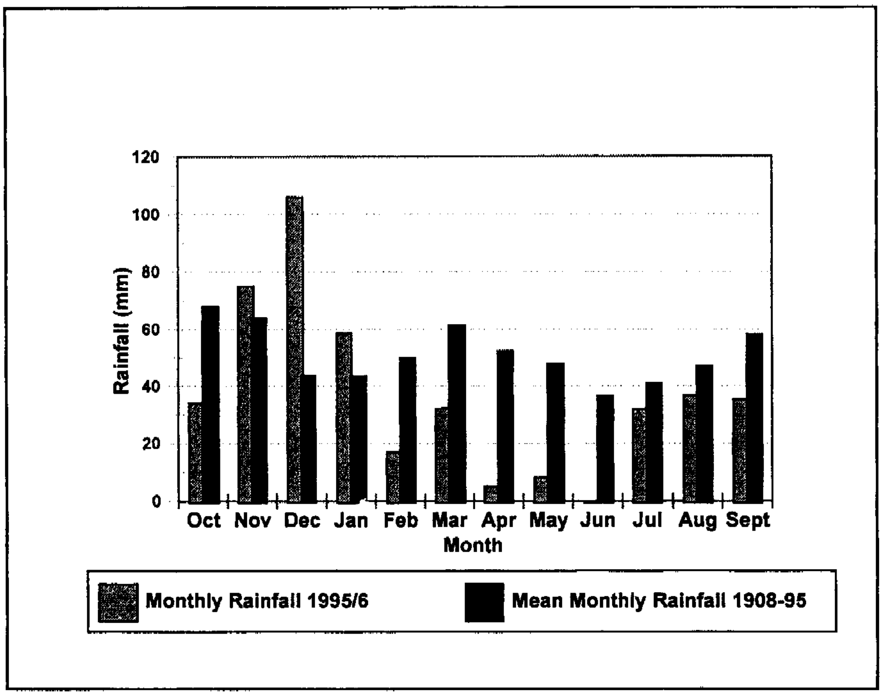


Figure 4.4: Mean monthly rainfall compared to monthly rainfall 3 months prior to monitoring and during the monitoring period.

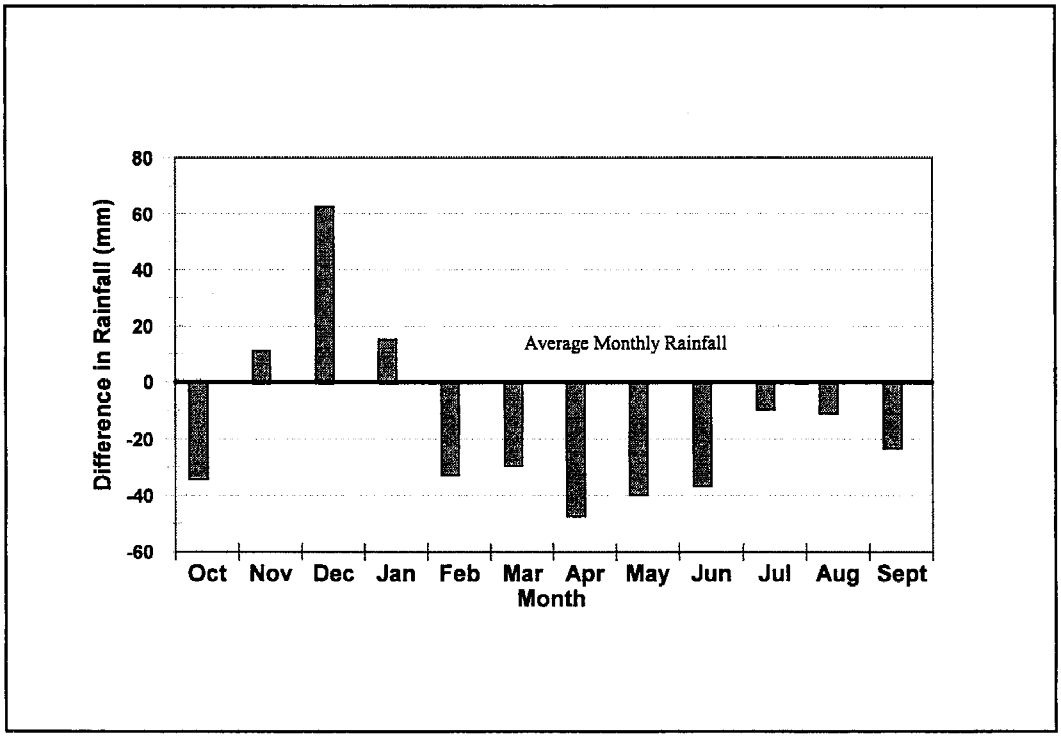


Figure 4.5: The difference between the monthly rainfall and the mean monthly rainfall.

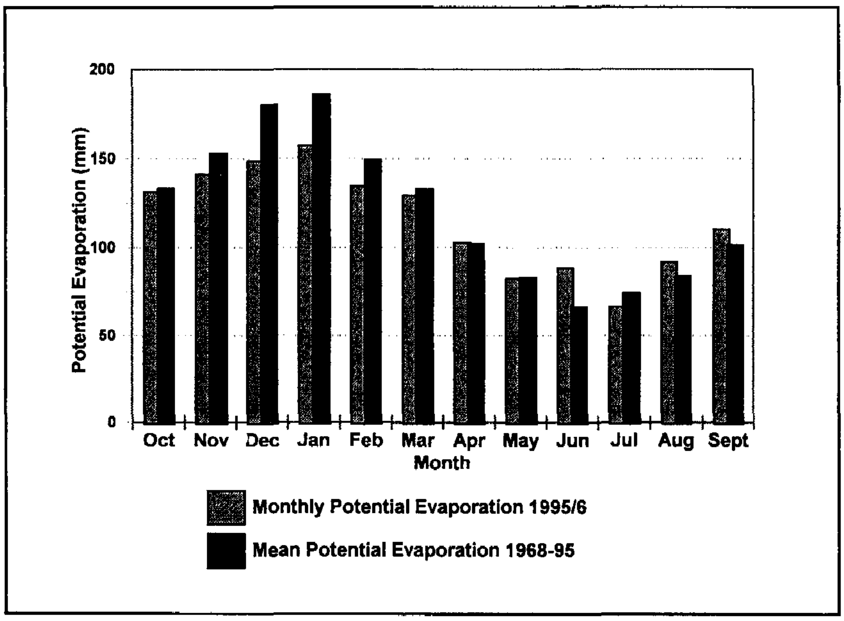


Figure 4.6: Mean monthly compared to monthly potential evaporation - Loerie and Groendal Dams combined average.

Daily fluctuations of streamflow in response to potential open water evaporation between the 10th to 12th of January, 20th to 22nd of February and 4th to 6th of June can be seen in figures 4.8a, 4.8b and 4.8c respectively. It should be noted that y-axis scales expressing discharge values are different for the separate figures. In all three figures the fluctuations in streamflow are clear with the most prominent fluctuations, indicating an increase in streamflow, occurring over midday when the evaporative demand of the air is at its highest. Although Figure 4.8b is magnified, due to the scale, it is interesting to note the fluctuation on the 21st of February which is larger than those on the preceding and following day, in line with the higher evaporation value of 5.75mm recorded on the 21st as apposed to 3.75mm recorded on the 20th and 3.25mm on the 21st. Streamflow increasing over midday when the evaporative demand of the air is higher was not expected and will be discussed further in Chapter 5.

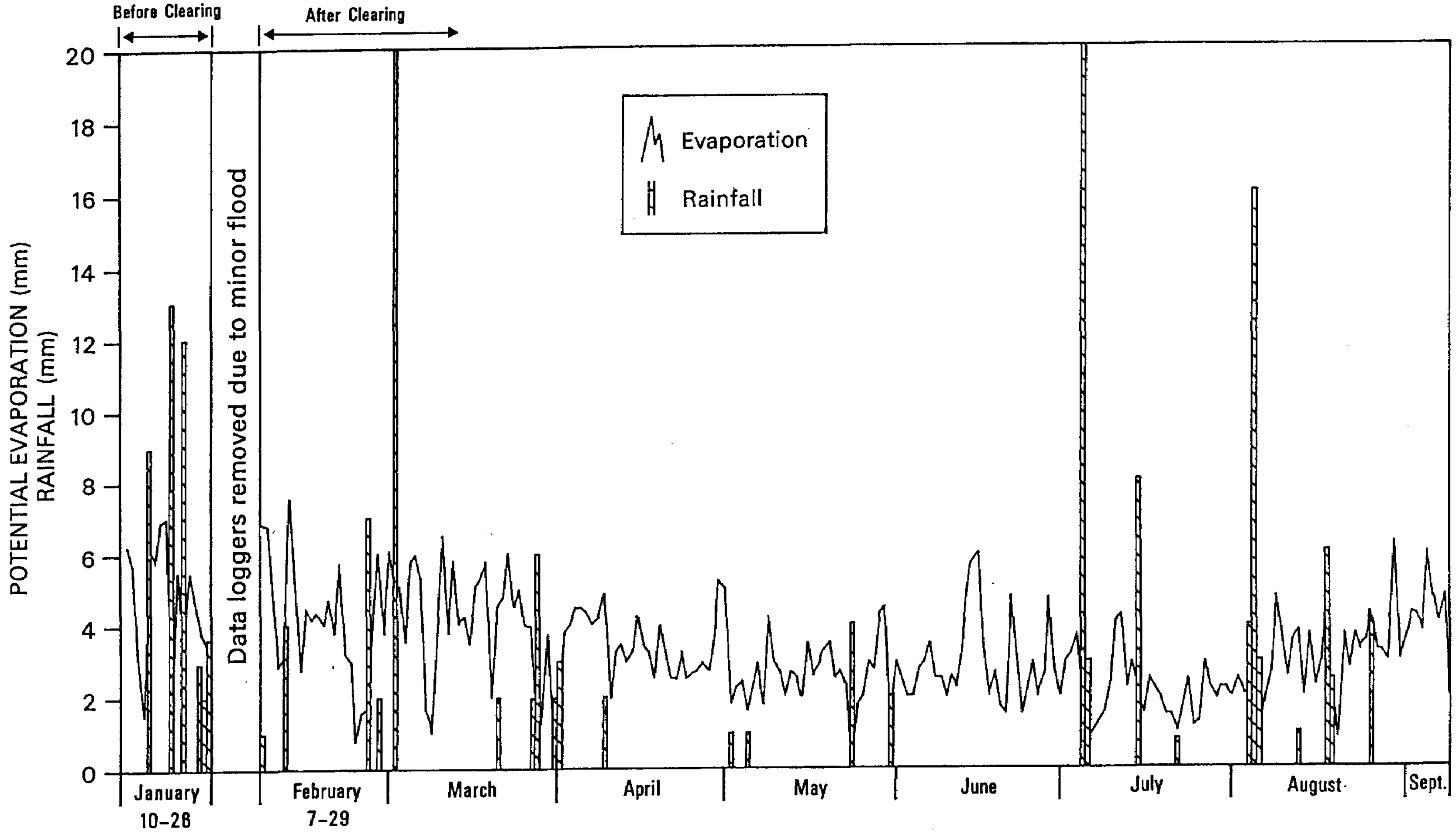


Figure 4.7: Time series graph of daily rainfall and potential open water evaporation.

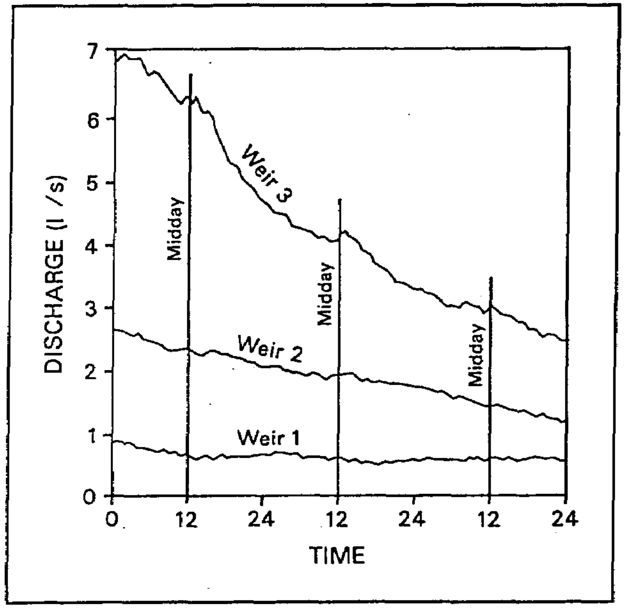


Figure 4.8a: Daily streamflow fluctuations from January 10 to 12. Potential evaporation was 6.25, 5.65 and 3 mm each day respectively.

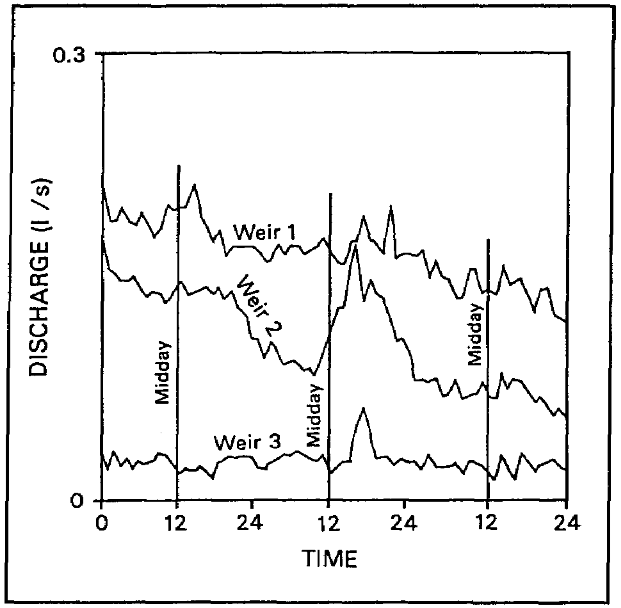


Figure 4.8b: Daily streamflow fluctuations from February 20 to 22. Potential evaporation was 3.75, 5.75 and 3.25 mm each day respectively.

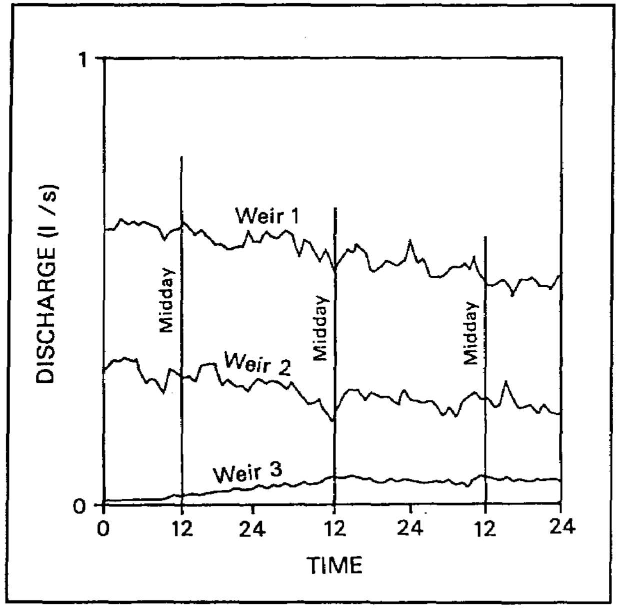


Figure 4.8c: Daily streamflow fluctuations from June 4 to 6. Potential evaporation was 2, 2.75 and 3 mm each day respectively.

A comparison between streamflow reduction and evaporative demand (the difference between evaporation and rainfall) is presented in Figure 4.9. January is the only month where streamflow reduction is negative (water was added to the system) which corresponds to the evaporative demand which is the lowest for the duration of the monitoring period, due to heavy rainfall. In February and March the evaporative demand increases substantially to over 3mm per day and streamflow reduction increases from January to February. In March both the evaporative demand and streamflow reduction decrease by a small margin. In May and June, although the evaporative demand has decreased, streamflow reduction increased significantly. As anticipated streamflow reduction decreases in July as the evaporative demand decreases and then increases in August as the evaporative demand increases. In September as evaporative demand increases to over 3mm again, streamflow reduction decreases. Figure 4.9 suggests there is a complex relationship between evaporative demand and streamflow reduction. Correlation analyses of streamflow reduction and evaporative demand were performed for various time frames including daily values, 5 day averages, 10 days running mean and groupings of months (Appendix 8). The highest correlation coefficient for all analyses was positive 0.15 for daily values in July, August and September (Appendix 8). The low correlation coefficients for all analyses indicate no significant relationship against expectations. The possible reasons for the absence of a relationship will be discussed further in Chapter 5.

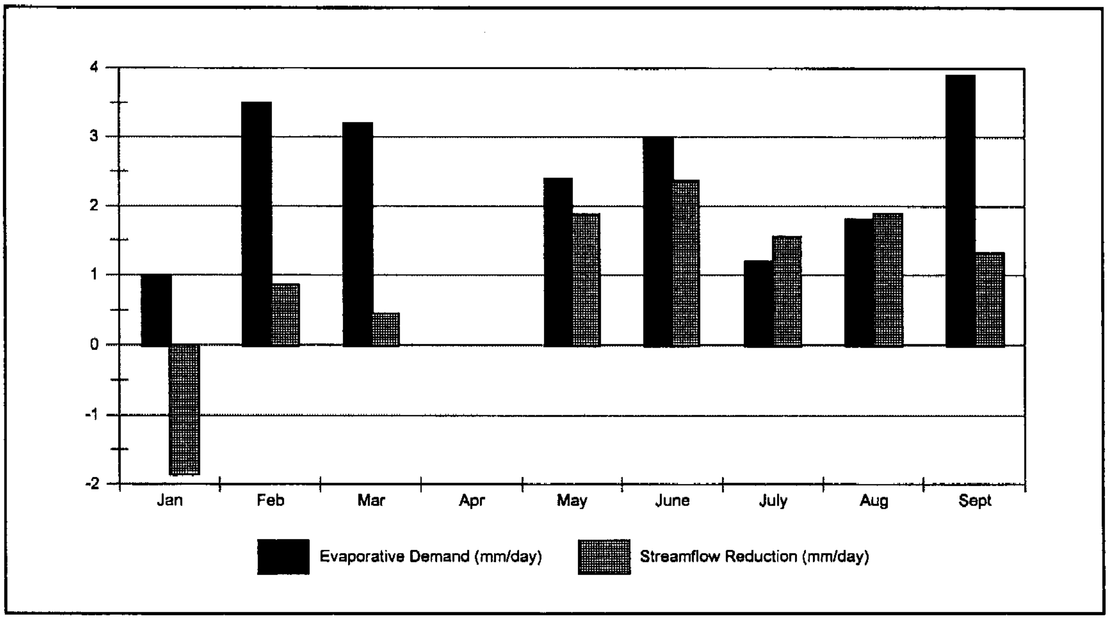


Figure 4.9: Comparison of monthly mean evaporative demand and streamflow reduction

4.4 SOIL MOISTURE

The percentage moisture content, calculated from the difference between wet and dried surface soil samples before and after clearing, is presented in Table 4.4. The average percentage moisture content of the daily surface soil samples is graphically presented in Figure 4.10. At the start of the monitoring period, in early January, both sites show similar soil moisture content (Figure 4.10). Subsequently, before and after clearing of the trees, site 2 showed a higher soil moisture content than site 1 (Figure 4.10). The only example of the cleared section showing a higher soil moisture content was on the 23rd of September after the monitoring period (Figure 4.10), due to one sample (Table 4.4 - 23rd Sept, Sample 3) with excess moisture causing the higher average.

Figure 4.11 illustrates the average percentage moisture content of surface soil samples before and after clearing. The cleared section (site 1) differed by less than half a percentage while site 2 in the uncleared section used as a control also has negligible difference of just under one percent (Figure 4.11).

Table 4.4: Percentage moisture content of surface soil samples.

Before Clearing								
	Site 1 - Cleared Section				Site 2 - Uncleared Section			
Jan	Sample 1	Sample 2	Sample 3	Average	Sample 1	Sample 2	Sample 3	Average
9	5.8	3.1	5.4	4.8	3.9	6.3	4.3	4.8
12	3.5	3.9	4.7	4.1	4.2	5.1	4.1	4.5
15	10.3	8.6	10.6	9.9	17.4	16.8	10.7	15.0
18	8.0	8.6	9.3	8.7	14.9	10.7	12.8	12.8
21	4.4	4.9	5.1	4.8	9.7	12.3	11.5	11.1
24	5.3	7.1	4.6	5.6	9.1	10.6	9.8	9.8
			Average	6.29			Average	9.68
After Clearing								
	Site 1 - Cleared Section				Site 2 - Uncleared Section			
Feb	Sample 1	Sample 2	Sample 3	Average	Sample 1	Sample 2	Sample 3	Average
6	4.2	5.0	4.8	4.7	9.7	8.7	8.1	8.8
7	5.1	5.2	4.4	4.9	10.4	9.1	9.0	9.5
8	5.9	5.7	5.8	5.8	10.6	8.8	8.1	9.2
March								
4	7.0	6.3	5.3	6.2	8.9	7.4	9.4	8.6
5	5.8	7.7	6.2	6.6	7.9	8.1	8.5	8.2
April								
2	6.7	5.7	5.2	5.9	9.2	10.7	8.4	9.4
Sept								
23	8.6	8.5	12.3	9.8	8.7	5.6	8.7	7.7
24	8.1	7.4	8.6	8.0	10.1	7.2	8.7	8.7
			Average	6.48			Average	8.75

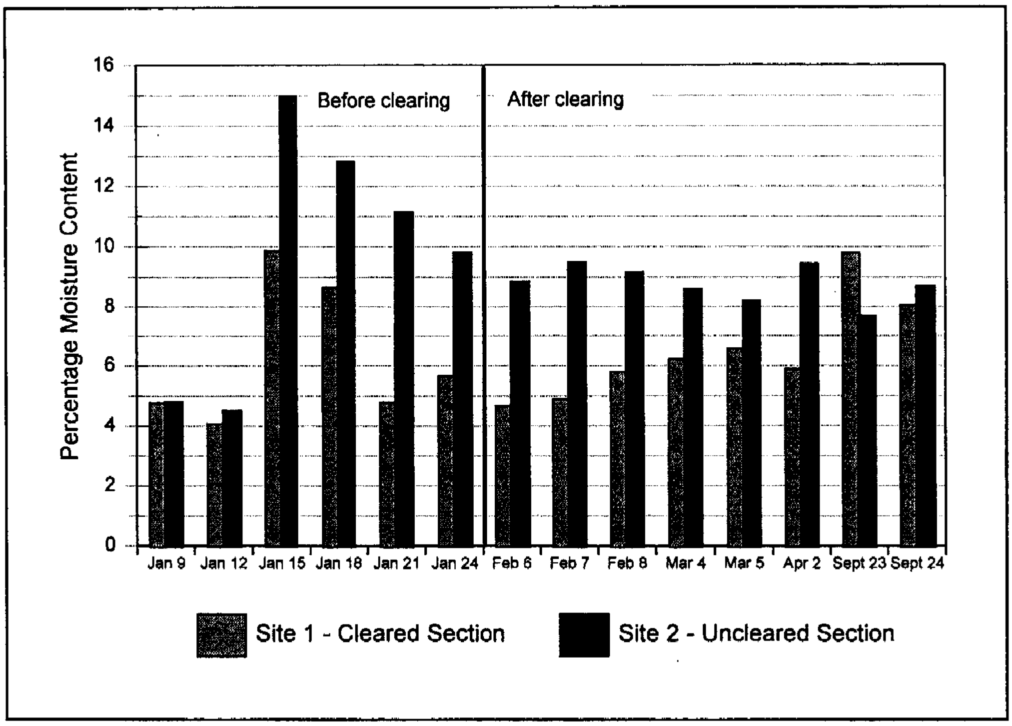


Figure 4.10: Percentage moisture content of individual surface soil samples.

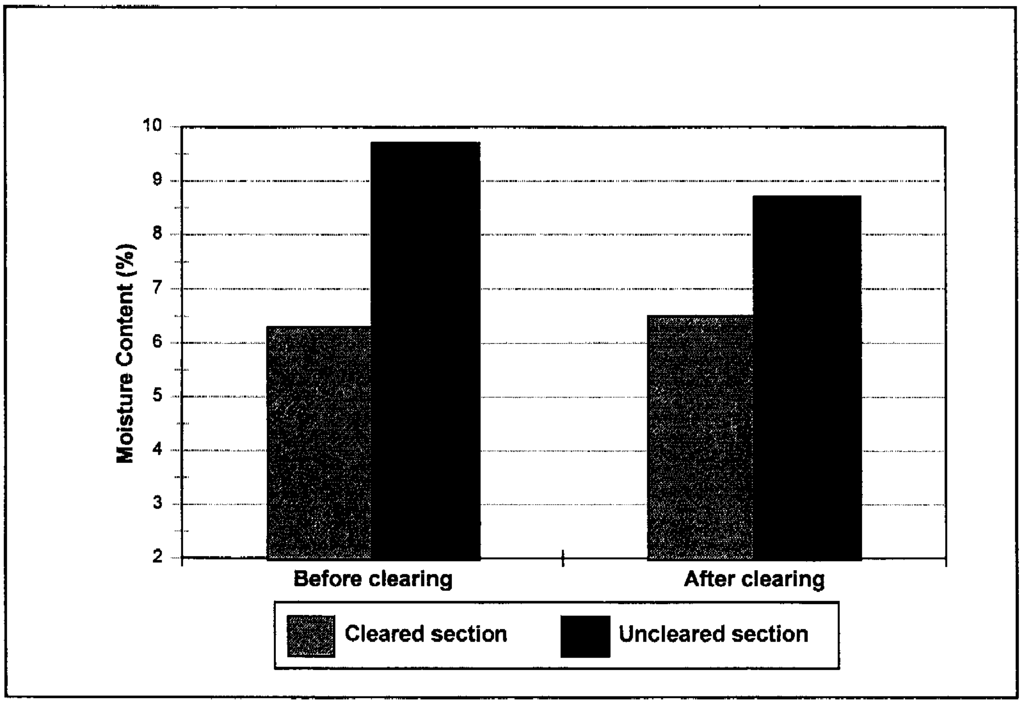


Figure 4.11: Average surface soil moisture content before and after clearing

4.5 EFFECTS OF CLEARING TREES

4.5.1 Water quality

Average conductivity readings (Table 4.5) calculated for the three weirs before and after clearing are presented in Figure 4.12. All values measured represent low conductivities and there is almost no difference in readings before and after clearing of the trees at any of the three weirs. Weir 3 has the highest average conductivity readings of 32.02mS/m and 31.83mS/m before and after clearing respectively, whereas weir 2 has the lowest conductivity values of 25.9mS/m before clearing and 26.15mS/m after clearing.

4.5.2 Channel Survey

The location of the representative channel survey sites can be seen in Figure 3.1. The cross-section survey results for sites A, B and C for the cleared section are shown in Figure 4.13 whereas sites D, E and F in the uncleared section are shown in Figure 4.14. It should be noted that the alluvium and bedrock depths are estimates, extrapolated from surface observations, and water levels were taken at the time of survey in early January. The extent of the primary channels is shown on the diagrams and it can be seen that no significant differences occur in channel shape between the surveyed sites in the two sections, although it should be noted that there is more bedrock in the section between weir 2 and weir 3. There was no significant event during the experiment to justify further surveys to monitor the difference in channel morphology before and after clearing. In all cross-sections surveyed the channel shape was wide and relatively deep, with some scoured banks forming steep channel banks (Sites A, C, D and E).

Table 4.5: Conductivity readings (mS/m)

BEFORE CLEARING

	Weir 1	Weir 2	Weir 3
January			
9	25.4	21.6	26.6
10	26.4	22.6	27.2
11	26.7	22.8	28.1
12	26.5	22.3	27.6
13	25.6	20.2	28.1
14	26.2	21.4	28.3
15	28.9	26.2	35.1
16	27.3	26.1	33
17	28.5	25.3	31.7
18	28.9	28	34.6
22	26.1	30.4	32.5
23	26.3	30.3	35.3
24	26.1	30.1	35.2
25	26.4	30.7	36.5
26	27.4	30.5	40.5
Average	26.85	25.9	32.02

AFTER CLEARING

	Weir 1	Weir 2	Weir 3
February			
6	26.2	27.2	32.6
7	25.6	24.7	31.2
8	26.8	27.2	33.5
9	26.3	25.9	32.1
10	25.8	26.7	31.9
March			
4	27.2	26.1	29.8
5	26.6	25.5	30.7
April			
2	25.4	24.8	31.3
September			
23	29.4	26.3	33.8
24	28.2	27.1	31.4
Average	26.75	26.15	31.83

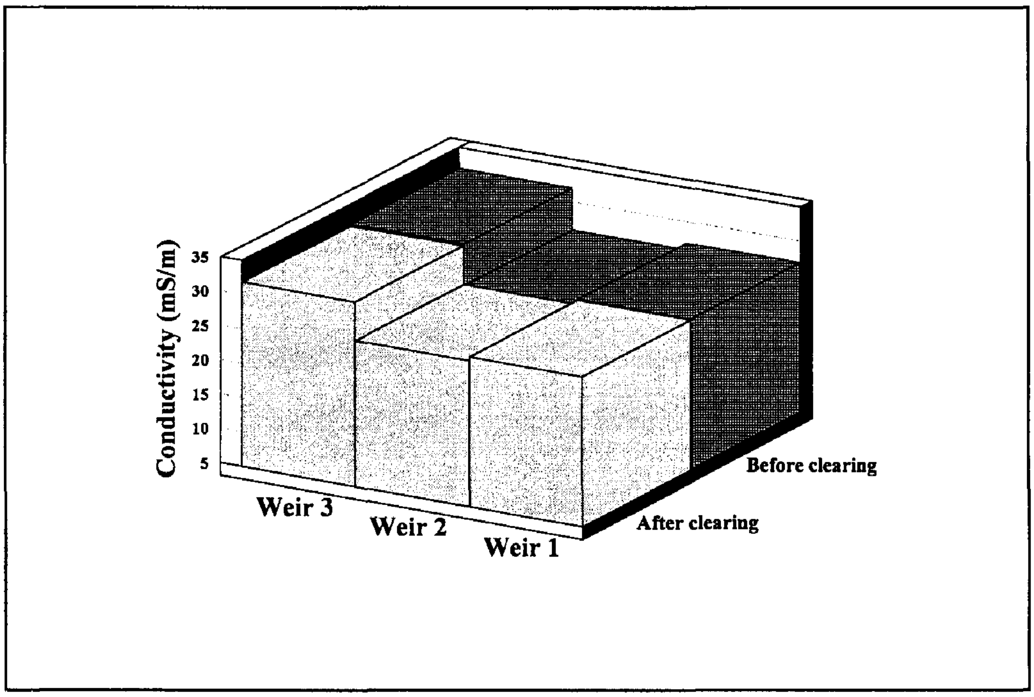


Figure 4.12: Average conductivity readings before and after clearing.

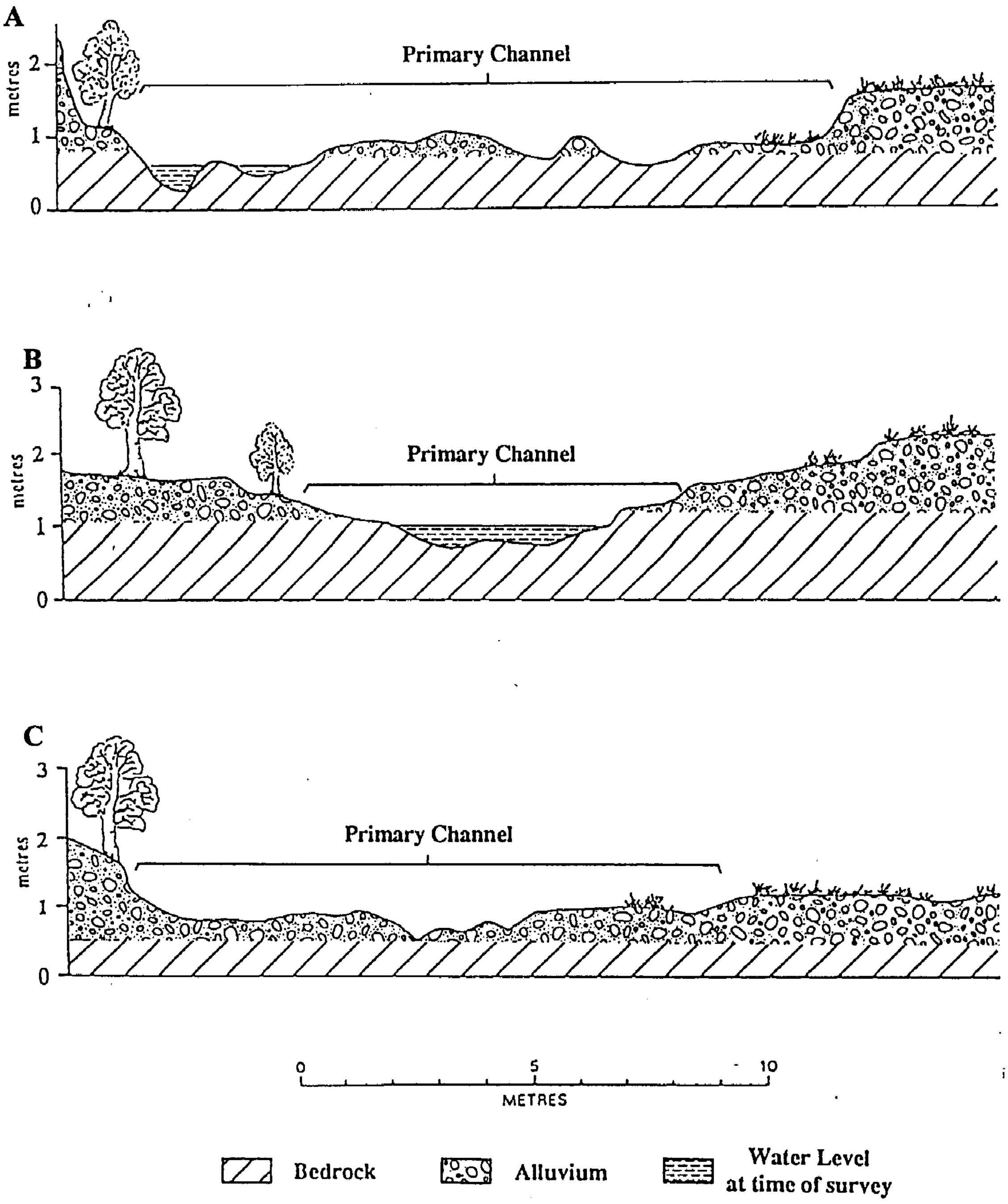


Figure 4.13: Representative cross-section survey sites for cleared section. Position of trees relative to channel as indicated. Contact between soil and bedrock are estimates.

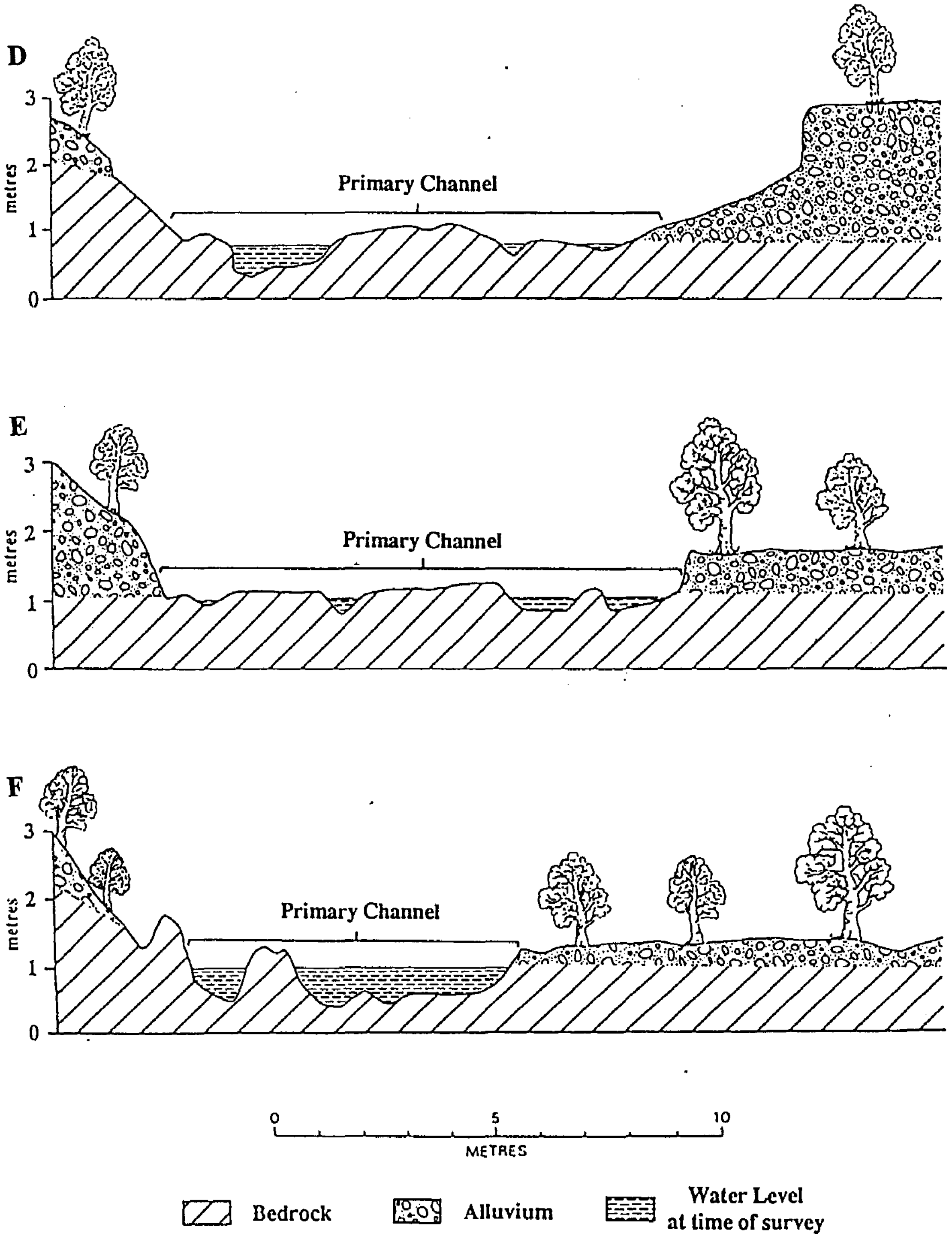


Figure 4.14: Representative cross-section survey sites for uncleared section. Position of trees relative to channel as indicated. Contact between soil and bedrock are estimates.

4.5.3 Rehabilitation and Restoration

The clear felling operation was carried out jointly by the Department of Agriculture 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 the 9th of September (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 *Acacia mearnsii.*

In late June *Acacia 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.

CHAPTER 5

ANALYSIS AND DISCUSSION

> **"It is easier to observe the movement of the stars, despite the incredible distance that separates one from another, than it is to understand the movement of water, even though this takes place beneath our very eyes."**
>
> *Galileo Galilei 1564 - 1642*

5.1 INTRODUCTION

Results of the study were described in Chapter 4. The purpose of this chapter is to synthesize the results, primarily to determine the effect on streamflow of clearing *Acacia mearnsii* from the riparian zone. Possible processes affecting the magnitude and variability of results will be discussed and related to each other. While not the focal point of the present study, additional effects of *Acacia mearnsii* in the riparian zone were identified and examined. These additional effects are important factors in the ecological health of a riparian zone and will be discussed as a secondary focus of the chapter.

In order to understand the changes in streamflow after the removal of vegetation, researchers have used modelling techniques with the aid of computer programmes to incorporate the various factors which have an influence on the variability and magnitude of streamflow (Section 2.2). At the forestry stations in the Western Cape, Cathedral Peak and Mpumalanga there have been considerable amounts of research on a catchment scale, on the effect of changes in vegetation on streamflow (Section 2.2). Researchers have been able to combine these results and find relationships between reductions in cover and streamflow reduction and between above ground biomass and streamflow reduction (Section 2.2) (Bosch and Hewlett, 1982; Le Maitre *et al.*, 1996). In the Eastern Cape however, forestry practices on a catchment scale are less of an issue than the invasion of riparian zones by *Acacia mearnsii* (Section 2.1). Researchers repeatedly state that there is a lack of information available on the water use and general characteristics of

Acacia mearnsii (Dye and Poulter, 1995a, 1995b; Dye, 1995, Le Maitre *et al.*, 1995, Smith *et al.*, 1992). Bosch and Hewlett (1982) stated that results from catchment experiments should be used with caution when catchment conditions vary, but could still be used as a general guideline for management decisions (Section 2.2.1).

Past research reveals many factors which could ultimately affect the magnitude and variability of streamflow responses to changes in vegetation density (Section 2.2). In order to understand the relationships between these factors, computer modelling has been successfully used on a catchment scale (Section 2.2) but not locally within riparian zones. The present research was designed as an experimental study and, while it was considered, the use of computer modelling would require results to be manipulated to such a degree that the end result could be misleading and take the focus away from the actual results obtained in the field. Alternatively it was decided to present and compare the results with related research and discuss the variables affecting the outcome of the results. For this purpose a conceptual model was devised which includes all the factors affecting the final measured streamflow (Figure 5.1).

The conceptual model (Figure 5.1) will be used as a reference point in the analysis and discussion of results. The focus of the chapter is to understand the effect on streamflow of *Acacia mearnsii* in the riparian zone(Section 5.2). Results from the present research will be compared to the reviewed literature (Chapter 2) and conceptual model (Section 5.3). The secondary aim of the research, to study the additional impacts of *Acacia mearnsii* in the riparian zone, will be discussed in the last section (Section 5.4).

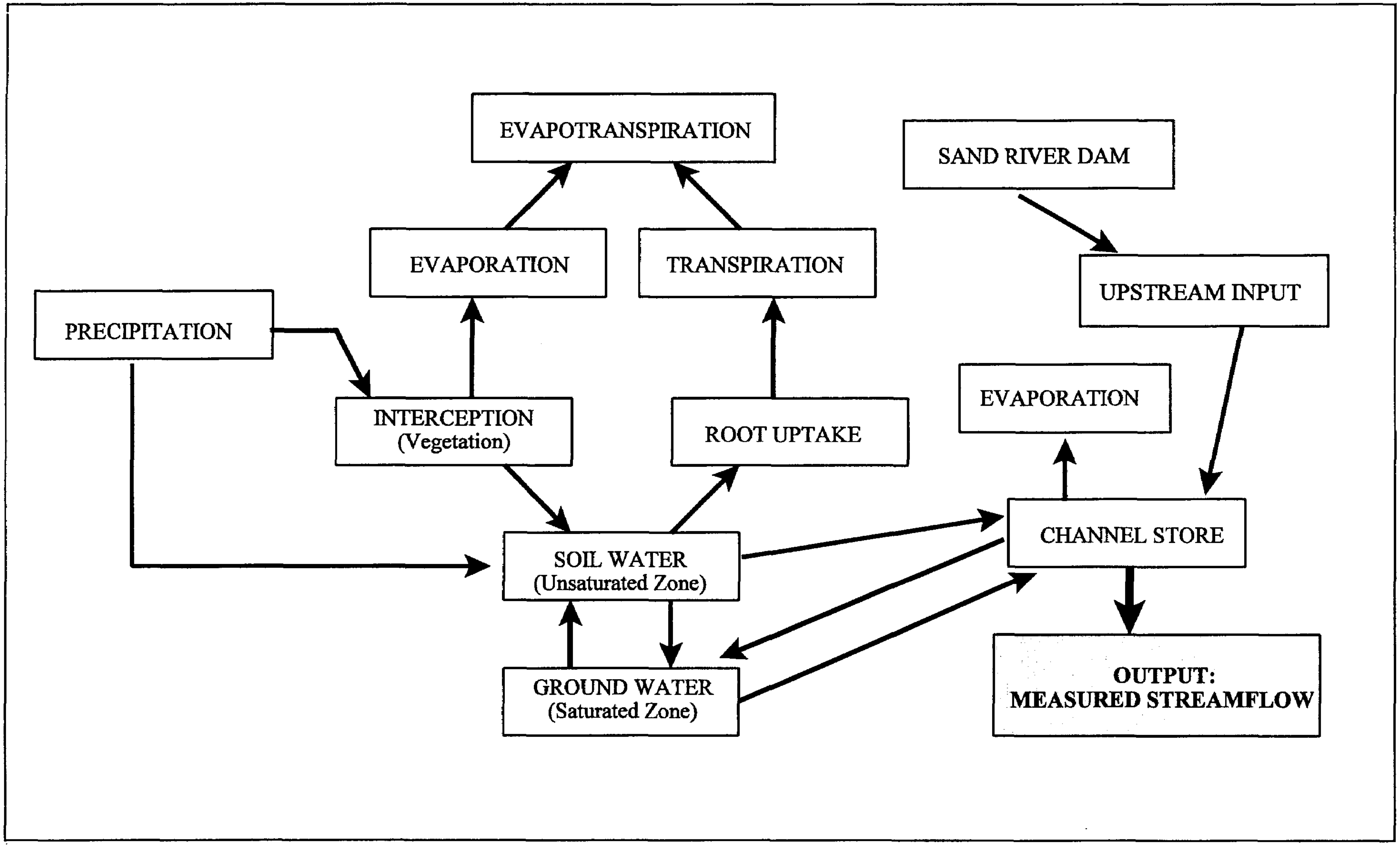


Figure 5.1: Conceptual model of the processes affecting measured streamflow

5.2 EFFECT OF *Acacia mearnsii* ON STREAMFLOW

5.2.1 Analysis of Streamflow

The use of three weirs allowed for the comparison of water released or consumed (Figure 4.3) in the cleared section as apposed to the uncleared section (Figure 3.1). In January, before clearing took place, it can be seen that both sections of the river were being augmented by flows from the banks (Figure 4.3). This was expected due to the high rainfall in the months preceding the monitoring period (Figures 4.4 and 4.5). Water was added to the system between weir 1 and weir 2 at a rate of 38m^3/d and between weir 2 and weir 3 at a rate of 93m^3/d. It is suspected the greater recharge rate between weir 2 and 3 was due to ground water moving into the channel at a faster rate as apposed to an increased amount of water available in the uncleared section. This could be as a result of bedrock closer to the surface in the riparian zone causing a shallower soil depth. Shallower soils would allow for less storage of water in the riparian zone and decreased resistance to movement of water through the soil towards the channel. There was no evidence to either prove or disprove this theory. It was also suspected, there could have been minor tributaries in the lower section contributing to flood peaks. However, field observations confirmed there was no surface flows entering the system in the lower section between weirs 2 and 3.

Over January, flow levels continued to decline in line with normal recession curves, which continued after clearing (Figure 4.2). By mid February minimal flow was entering the top of the system (weir 1), but it is clear from Figure 4.3 that flow was augmented in the cleared section. The total discharge between weir 1 and weir 2 amounted to 503m^3 while between weir 2 and 3 a mere 53m^3 was added to the system over February. The difference in recharge between the two sections could either be explained by the removal of the alien vegetation and/or the shallower soils as mentioned above. The shallower soils would account for less storage of water and therefore no sustained flow when there is no precipitation but as mentioned in the previous paragraph there is no evidence to clarify this.

In March, water continued to be added to the system between weir 1 and 2 (86m^3) whereas the difference between weir 3 and 2 showed uptake of water (-162m^3) (Figure 4.3). Flows continued to decline for the duration of March until negligible and/or no flow was sustained (Figure 4.2). It was decided to use the Sand River Dam as an upstream input (Figure 5.1) to allow for the possible measurement of streamflow uptake by *Acacia mearnsii*. As there was no natural flow it could now be presumed there was insignificant or no water being added to the system from the soil or ground water storage (Figure 5.1) in the riparian zone. Water added to the system would be primarily from water added to the channel store (Figure 5.1) from the upstream input with supplementary rainfall which as it turned out was insubstantial (Figures 4.4, 4.5 and 4.7).

On the 4th of April water was released from the Sand River Dam to augment and sustain flow through the system (Figure 4.2). There was a substantial increase in flows for the first week due to the initial release of water from the dam (Figure 4.2) until equilibrium was reached towards the end of the month. It was decided to remove these streamflow figures for April, out of the overall analysis, to allow for the system to settle. It is however interesting to note the large amount of water consumption in both sections for the first week of the dam release (Figure 4.3). It is assumed, due to the dry conditions (Figure 4.7) preceding the dam release, water recharged the ground water from the channel store (Figure 5.1). By the end of April the cleared section of the river was demonstrating the movement of water into the channel store (Figure 4.3 and 5.1) whereas the uncleared section was exhibiting movement of water out of the channel (Figure 4.3 and 5.1).

For the duration of the driest months of the monitoring period (May and June) water was released from the dam (Upstream input - Figure 5.1)until the 17th of July when it was presumed there had been sufficient rainfall to sustain flows throughout the system (Figures 4.2 and 4.7). From May until the end of the monitoring period on the 9th of September the cleared section continued to augment flows through bank releases (Soil and ground water movement into the channel store - Figure 5.1) while the uncleared section registered a net uptake of water (Movement of water out of the channel store - Figure 5.1) (Figure 4.3).

It was noticed and previously mentioned (Section 4.2) that abnormal flood peaks were occurring at weir 1 due to runoff from the nearby road. Figures for the actual streamflow measured (inclusive of all flood peaks and low flows) for the duration of the project were presented and used to calculate streamflow reduction for the duration of the monitoring period (Table 4.3a). However, it was expected that the abnormal flood peaks and low flows would cause the results to be unreliable. In an attempt to present realistic results of the effect of *Acacia mearnsii* on streamflow, relevant days were taken out of the analysis for all three weirs and presented accordingly for each respective month (Table 4.3b). The decreased amount of days (Table 4.3b) caused noticeable changes to the difference between weir 2 and 1(cleared section) but not significantly to the difference between weir 3 and 2 (uncleared section). This was accounted for by the removal of the flood peaks at weir 1 (Figure 4.2) which did not appear to have an effect on the remaining weirs 2 and 3 (Table 4.3b).

Streamflow reduction after clearing was the highest in June with a net uptake of 23.7m^3/day/ha and lowest in March at 4.5m^3/day/ha (Table 4.3b). The average streamflow reduction for the duration of the monitoring period after clearing is 15.1m^3/day/ha or 551mm (Table 4.3b). Reliability of results and possible explanations for periods of higher or lower streamflow reduction will be examined in following sections (Section 5.2.1 - 3). The average streamflow reduction of 551mm caused by *Acacia mearnsii* in the riparian zone will be compared to related research (Chapter 2) in Section 5.3.

5.2.2 Evaporation and Rainfall (Weather)

In order to study the effect of weather conditions on streamflow, evaporation and rainfall data for the area was analysed. It almost seems obvious that streamflow will respond to precipitation but the water might not always reach the channel. Precipitation can be intercepted by vegetation or infiltrate into the soil and ground water stores (Figure 5.1). It is seen in a comparison of Figure 4.2 and Figure 4.7 that daily flow at all weirs responded to rainfall events with a peak relatively soon after the event. Weir 1 however, has an abnormally high peak immediately after an event which is explained by the road above the weir (Figure 3.1). Runoff from the road reaches the section of river behind weir 1 soon after a rainfall event and creates a sudden increase in streamflow but then also decreases quickly once the rainfall event has past. In comparison weir 2 and 3 also show increases in streamflow after a rainfall event but the peaks are lower and last longer. This is due to the soils in the riparian zone accumulating water which is then released over the following days (Figures 4.2 and 5.1). In addition the peaks at weirs 2 and 3 after a rainfall event are as a result of the attenuation of the upstream peak and peak from the road run-off as it moves down the system.

Evaporation and/or evapotranspiration could indirectly affect streamflow (Figure 5.1) as observed by daily fluctuations in streamflow in response to the evaporative demand of the air (Dye and Poulter, 1995b). These authors noted a decrease in streamflow during the daylight hours, and an increase 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 2.6). Daily fluctuations were also noted in the present study, but instead of streamflow decreasing over midday when the evaporative demand of the air is high, streamflow is seen to increase (Figures 4.8a - 4.8c). This is believed to be as a result of *Acacia mearnsii* exhibiting control of water loss as the evaporative demand of the air increases, as observed by Poulter *et al.* (1994) (Figure 2.1). The results observed by Dye and Poulter (1995b) were for *Pinus patula* and *Acacia mearnsii* trees unlike the present study with a homogenous stand of *A. mearnsii* trees which could explain the different results. Although the scale is considerably smaller than the adjacent graphs, Figure 4.8b shows the influence of evaporation and thus evapotranspiration on streamflow. Weir 3 (below uncleared section) shows the biggest increase over midday on the 21st of February, when the potential evaporation was the highest of the three days.

In a comparison of daily evaporative demand (evaporation minus rainfall) and daily streamflow reduction (Table 4.3b) it was anticipated a relationship would be found (Figure 4.9). In January when there was ample rainfall and resultant availability of water in the riparian zone, water was added to the channel (Figure 4.9). In February and March evaporative demand exceeds 3mm/day and as the evaporative demand decreases slightly from February to March so does the streamflow reduction (Figure 4.9). In May and June as the evaporative demand increases from 2.4 mm/day to 3mm/day, streamflow reduction increases. In July and August evaporative demand drops to below 2mm/day. As evaporative demand increases slightly from July to August, as expected streamflow reduction also increases. In September, however, evaporative demand increases substantially to over 3mm/day but instead of streamflow reduction increasing, it decreases from the previous month (Figure 4.9). It appears that when the evaporative demand exceeds 3mm/day (hottest months) streamflow reduction is moderately affected but below an evaporative demand of 3mm/day as the evaporative demand increases so does streamflow reduction.

Correlation analyses were performed over different time scales to confirm a relationship but no significant relationship could be found (Appendix 8). It has been discussed and shown (Figure 4.8a-c) above that evaporative demand has a direct influence on streamflow within the time frame of one day (Figure 4.8a - 4.8c) but the strongest correlation found over longer periods proved insignificant (Appendix 8). In considering possible solutions for the lack of a relationship the conceptual model (Figure 5.1) establishes the relationship between the processes involved. Weather conditions (precipitation and evaporation/evapotranspiration) primarily interact with the soil water which in turn interacts with the ground water and channel store (Figure 5.1). In January the weather conditions did not play a role in streamflow reduction as water was added to the system. February and March there was evidence of streamflow reduction due to the presence of *A. mearnsii* but this was insignificant due to the preceding wet conditions. However, once conditions became dry and soil water reserves depleted, streamflow reduction increased (Figure 4.9 May/June). In April it was decided to release water from the Sand River Dam as a consequence of the dry conditions (Figure 4.2). Although the dam release proved vital in the experiment to continue observing the effect of *A. mearnsii* on streamflow reduction, it is believed this caused interference on the outcome of any possible correlation between weather conditions and streamflow reduction for the duration of the monitoring period. The interference is explained by the upstream release of water or upstream input (Figure 5.1) not forming part of, or interacting with the weather conditions influencing possible streamflow reduction.

5.2.3 Study Site and Vegetation Survey

The vegetation survey gives an estimate of the biomass removed from the southern side of the river between weir 1 and 2 at 160t/ha (16 000g/m^2) (Table 4.1 and 4.2). The uncleared section of *Acacia mearnsii* was also calculated to have a biomass of 160t/ha even though the densities in the different DBH size classes differed (Table 4.1 and 4.2). This confirmed the suitability of the site to make a comparison between the two sections of riparian zone.

There is a lack of data on the general characteristics of *Acacia mearnsii*, such as biomass (Chapter 2). Figure 4.1 shows the relationship between above ground wet biomass and diameter at breast height (DBH). For the purposes of the present research the comparison does not influence the outcome of the results but it is interesting to note the obvious relationship between the two variables.

Le Maitre *et al.* (1996) used results from a number of experiments to derive a relationship between above ground biomass and streamflow reduction (Figure 2.3). The authors state that biomass can be used as a function of transpiration and interception. Interception can have two effects in the riparian zone (Figure 5.1). Firstly, precipitation is intercepted by the *Acacia mearnsii* canopy, thus obstructing the water from reaching the soil allowing evaporation directly back into the atmosphere (Section 2.2) (Figure 5.1). Fynbos has considerably lower biomass and will intercept less water, allowing more precipitation to reach the soil (Cowling, 1992). Secondly, with substantial rainfall events the canopy can become saturated, at which point the excess water falls through the vegetation to the soil (Figure 5.1). Transpiration (Figure 5.1) is the loss of water through the leaves of the plant during the process of photosynthesis (Section 2.2). Water for the process of transpiration is taken up from the soil through the plants roots (Figure 5.1).

A comparison of the relationship between streamflow reduction and above ground biomass (Figure 2.3) (Le Maitre *et al.*, 1996) and the results of the present study do not compare. For the amount of biomass removed (160t/ha or 16 000g/m^2) in the present study a streamflow reduction of approximately 375mm would be expected from Figure 2.3 but in fact the actual streamflow reduction is 551mm. This suggests that streamflow reduction as a result of alien vegetation in catchments is less of a concern than when alien vegetation invades the riparian zone. Le Maitre *et al.* (1996) used results from catchment experiments in the Western Cape where the indigenous vegetation and climate are similar, but there could be additional reasons for the difference. Firstly the exotic vegetation studied in the western Cape is mostly Pine and Eucalypt plantations which are different species of trees and will therefore have different water use characteristics, such as transpiration rates. Secondly, as stated above, the results are derived from catchment experiments which, according to Scott and Lesch (1995), use less water than riparian vegetation.

Although Le Maitre *et al.* (1996) mention that biomass can be used as a function of transpiration, the technique of measuring sap flow rates and thus transpiration using the Heat Pulse Velocity (HPV), has been verified for *Acacia mearnsii* (Smith *et al.*, 1992). Smith *et al.* (1992) measured the sap flow rate for an *A. mearnsii* tree of 9.2cm DBH at 30*l*/day while Poulter *et al.* (1994) used two sample trees of 14.7cm and 17.2 cm to find an average transpiration rate of 20 *l*/day.

HPV is a suitable measure of transpiration (Smith *et al.*, 1992), an average of the above examples show a tree of approximately 14cm DBH will use 20*l* of water per day. When multiplying this value by the number of trees sampled in the corresponding size class (Table 4.1) of the present study, the amount of water used by the trees would exceed the mean annual precipitation of 611mm for the area. This suggests i) water is concentrated in the riparian zone and therefore more water than the mean annual precipitation is available and/or ii) only those trees relatively close to the channel use an increased amount of water.

5.2.4 Geology and Soils

The movement of water between ground and soil water play a role in the analysis of streamflow (Figure 5.1). Unfortunately it was not possible to measure soil moisture during the present study and this is seen as a limitation to the observed results. According to Toerien and Hill (1989) the area is made up of undifferentiated sandstones and shales. The sandstones are impermeable to water but fractures are common. These fractures can allow for the movement of water either into the alluvium or if the ground water storage is low the fractures can be responsible for draining the soil water. It is thought that a possible additional water source for the study site is from ground water reserves being replenished by the Sand River Dam upstream.

Newson (1994) recommends using water tracing dyes or spores to detect where water is coming from in the riparian zone to have a clear understanding of the sources of water, especially in the case of rocks characterised by fissures. If fractures in the bedrock were present, the most important effect of these fracture zones would be the loss of water from the channel to deep groundwater zones, especially during drought periods. This could explain the excessive streamflow reduction levels during April after the release of water from the Sand River Dam.

The sandy loamy soils in the area are characteristically permeable (Rust, 1988). While attempting to set up access tubing to monitor soil water levels it was noticed that the soils are porous with large cobbles and stones, allowing for relatively easy movement of water through the riparian zone. Water in the riparian zone will move between the soil water, ground water and channel store (Figure 5.1) and be available for plants to use. Surface soil moisture samples were taken in each of the sections (Table 4.4) and there were no significant changes in surface soil moisture before and after the clearing of the trees took place (Figure 4.10 and 4.11).

Although surface soil moisture is a small part of the system, differences might have been expected due to changes in interception, i.e. less water reaching the soil surface after precipitation events or direct evaporation from the soil surface. However, there were no fluctuations before and after clearing to indicate any marked influence the trees have on interception or evaporation from the soil surface (Figure 4.10 and 11). The fact there is little difference could be a result in itself as it could be reasoned that the trees do not necessarily use surface water but rather rely on deep root systems to tap ground water reserves.

In the months preceding the monitoring period and during January there was more rainfall than the mean rainfall for each month and this was seen to be a wet period (Figure 4.4 and 4.5). This period showed no streamflow reduction (Figure 4.9) and water was added to the system from the riparian zone. The rest of the monitoring period from February through to September there was less rainfall than the mean rainfall for these months (Figure 4.4 and 4.5) and was seen to be a dry period. Streamflow reduction or loss of water from the channel was highest during this dry period. Although there were no tests to verify levels of soil and/or ground water, if the assumption is made that soil/ground water is recharged by rainfall, the greatest streamflow reduction was in the months with the lowest available soil moisture.

5.3 RELATED RESEARCH

5.3.1 Catchment related research

Bosch and Hewlett (1982) derived approximate values for the changes in water yield as a result of vegetation changes within a catchment (Section 2.2.1) (Figure 2.2). The authors regard precipitation as the most significant variable influencing water yield responses and explain that results in extreme low or high rainfall regions showed the greatest increases or decreases in water yield in response to vegetation changes. The present research agrees with Bosch and Hewlett (1982) as streamflow was augmented after the wet period in the first months of monitoring. As the weather conditions became drier, streamflow reduction as a result of *Acacia mearnsii* became more significant.

Bosch and Hewlett (1982) explain that due to the variability of catchment and climatic conditions their results should be used with caution but maintain they can be used as a guideline for general management decisions. Ninham Shand Inc. (1993) were commissioned to determine the effect of *Acacia mearnsii* on water yield in the Kouga and Krom River catchments in the Eastern Cape. Using the results from the Bosch and Hewlett (1982) review, reduced streamflow as a result of *A. mearnsii* was estimated at 300mm (Section 2.2.2). Further investigation showed the majority of *A. mearnsii* was located in riparian zones covering an area of 3170 ha. It was concluded the removal of *A. mearnsii* should be considered as the first option to increase water supply to the dams in the area which could amount to an increase of 9.5 million m^3 per annum. Although the same conclusion would have been reached, results from the present research would have had more significance as the streamflow reduction would be representative of the water use of *A. mearnsii* in riparian zones as apposed to vegetation in catchments. The average streamflow reduction in the present study is 551mm and would account for an additional increase of 8 million m^3 per annum of water (almost double) in comparison to the figure calculated by Ninham Shand Inc. (1993).

A comparison of the present results with results from catchment experiments by Van Wyk (1987)

(Table 2.1) show differences in streamflow reduction. The highest recorded streamflow reduction of 313mm was recorded in a catchment 98% afforested with *Pinus patula* in comparison to 551mm in the present study. Catchment conditions are similar in the south Western Cape Province where the catchment experiments were carried out and the present research site (Section 2.2.1). It is suspected the difference in streamflow reduction is explained by the difference in locality of vegetation and consequently vegetation in the catchment is suspected to use less water than trees growing in the riparian zone.

5.3.2 Riparian zone related research

In the only other experiment similar to the present study, Dye and Poulter (1995b) used two portable weirs to monitor the effect on streamflow of clearing a mixed stand of *Pinus patula* and *Acacia mearnsii* (Section 2.2.2). The authors found that clearing of the exotic trees between the two weirs, 500m apart, accounted for an increase in streamflow equivalent to 438mm. The study was carried out from the 1st to 19th of September until data was lost due to piping being stolen and blockages in the v-notch caused by debris from the clear felling (Dye and Poulter, 1995b).

As the above experiment was of a short term nature, the 9 days of monitoring during September in the present study when conditions were similar were used as a comparison. In the present study a mean net uptake of 482mm of water was recorded between the 1st and 9th of September. The cleared areas in both experiments were 2.5ha in size and consisted entirely of alien vegetation. It is interesting to note how similar the values are even though the respective study sites were in different climatic zones. The experimental site in Mpumalanga has a mean annual precipitation of 1030mm whereas the Sand River study site is lower at 611mm.

The technique of using two weirs and clearing vegetation between them to measure the effect on streamflow was first used by Nanni (1972) (Section 2.2.2). Dye and Poulter (1995b) agreed with the conclusions made by Nanni (1972) that portable weirs were cost effective and the ability to move the weirs to different locations is an advantage. It was mentioned that during dry periods and light rainfall events, accurate measurement of streamflow would be possible and in the event of heavy rain the financial loss would be small. Dye and Poulter (1995b) also mentioned that portable weirs are useful for short term experiments when risk of theft or vandalism is a factor. In the present study the use of three permanent weirs allowed the measurement of streamflow response to the removal of *Acacia mearnsii* for a longer term study. The weirs were successful in recording low flows and light rainfall events and even though loggers were removed as a precaution due to a minor flood there was no damage to the structures. Data loggers were locked in secure boxes alongside the river and there were no incidents of theft or vandalism.

An experiment comparing the water use of alien trees within catchments and the riparian zone show that trees in the riparian zone are liberal users of water when compared to vegetation in the surrounding catchment (Section 2.2.2) (Scott and Lesch, 1995). The research was carried out in Mpumalanga and the southern Cape. The results from the southern Cape experiment were found to be more reliable than those of the Mpumalanga experiment, because the same age, density and species were compared. The southern Cape climatic and catchment conditions are similar to the present and provide a useful comparison even though *Pinus patula* was used in the research and not *Acacia mearnsii.* It was concluded that riparian trees use roughly three times the amount of water than those found on non-riparian slopes (Section 2.2.2).

In the Northern Province a comparison between the effects of riparian zone clearing and clear felling within the catchment of indigenous vegetation was carried out (Scott and Lesch, 1996) (Section 2.2.2). Although the authors explain there was a drought during the monitoring period, which could have affected the outcome of results, it was concluded that the clearing of indigenous vegetation was not a practical means of augmenting streamflow in the region. The above research, although not widespread, supports that alien vegetation in the riparian zone accounts for more water use than vegetation within the surrounding catchment (Section 2.2.2).

In southern California a pilot study was carried out showing streamflow increases after removing woodland-riparian vegetation (Section 2.2.2) (Rowe, 1963). The catchment characteristics are similar to the present study in that mean annual rainfall and soil types are similar and while the vegetation removed from the riparian zone was indigenous to the area, it consisted mainly of woody trees (Section 2.2.2). The area of riparian vegetation cleared was considerably larger and the time frame for the study was longer than the present study. However, the highest recorded increase of streamflow of 369mm is notably lower than the average 551mm in the present study. The highest streamflow reduction over the period of a single month was 866mm in June (Table 4.3b) when there were dry conditions (Figure 4.7). Streamflow reduction caused by alien vegetation in the present study is more significant than the southern California study. While there are no further examples found for comparative purposes it appears as if the removal of indigenous woody riparian vegetation does not have the same effect as the removal of woody alien vegetation from a riparian zone.

5.3.3 Context of Research Findings

The concept of alien plant invasions reducing streamflow around South Africa has resulted in a nation wide drive to eradicate exotic plants from our catchments. There has been research focussing on the water use of vegetation, but with the need for further funding to complete projects around the country, additional research will be required to sustain the desired goals. Researchers have perceived this demand for further research and attempted to fill gaps in the knowledge base and develop a framework for decision makers to use.

Versveld *et al.* (1998) published a report in an attempt to create a framework for all present and future research. The authors state their calculations are not conclusive and suggest further research will refine their estimates. The average water use of alien plants in South Africa was calculated at 5.4m^3/ha/day, while the Eastern Cape was 10 m^3/ha/day (Versveld *et al.*, 1998). Although no specific figure for the water use of *Acacia mearnsii* trees was given in the report, the figure of 12m^3/ha/day was calculated (Versveld *et al.*, 1998; Table 4.6, pp 75) and used in Table 5.1 for comparative purposes. Using alien plant distribution information from the Versveld *et al* (1998) report, updated water use figures have been calculated using water use figures from the present study (15.1m^3/ha/day) in comparison to water use figures in the report (Table 5.1).

Table 5.1: Comparison of water use estimates between the Versveld *et al.* (1998) report and results from the present study.

Alien Plants			
	Area (ha)	Water use (millions of m^3 / yr)	Adjusted water use (millions of m^3 / yr)
South Africa	**1.7 million**	**3 303 (5.4 m^3/ha/day)**	
10 % Riparian invasion	170 000	937 (15.1 m^3/ha/day)	3953
Catchment balance	1.53 million	3016 (5.4 m^3/ha/day)	
Eastern Cape	**151 258**	**558 (10 m^3/ha/day)**	
20% Riparian invasion	30 252	167 (15.1 m^3/ha/day)	609
Catchment balance	121006	442 (10 m^3/ha/day)	
Swartkops Catchment	**11 358**	**41 (10 m^3/ha/day)**	
20% Riparian invasion	2272	13 (15.1 m^3/ha/day)	46
Catchment balance	9086	33 (10 m^3/ha/day)	
Acacia mearnsii			
South Africa	**131 341**	**576 (12 m^3/ha/day)**	
50% Riparian invasion	65671	362 (15.1 m^3/ha/day)	650
Catchment balance	65671	288 (12 m^3/ha/day)	
Eastern Cape	**49 022**	**215 (12 m^3/ha/day)**	
50% Riparian invasion	24511	135 (15.1 m^3/ha/day)	242
Catchment balance	24511	107 (12 m^3/ha/day)	

☞ If 10% of the 1.7 million hectares of alien plants in South Africa occur in riparian zones this would amount to an additional 650 million m^3 of water per year to that calculated by Versveld *et al.* (1998). This amounts to 20% of municipal and domestic water use throughout South Africa for a year or $^1/_3$ of the volume of the Vaal Dam .

☞ If 20% of the 151 258 hectares of alien plants in the Eastern Cape occur in riparian zones this would amount to an additional 50 million m^3 of water.

☞ If 20% of the 11 358 hectares of alien plants in the Zwartkops catchment occur in the riparian zone this would amount to an additional 5 million m^3 of water.

- If 50% of the 131 341 hectares of *Acacia mearnsii* trees in South Africa occur in riparian zones this would amount to an additional 75 million m^3 of water.
- If 50% of the 49 022 hectares of *Acacia mearnsii* trees in the Eastern Cape occur in riparian zones this would amount to an additional 27 million m^3 of water.

The above figures are a few examples clearly showing the extent of water use of alien invaders and *Acacia mearnsii* in riparian zones. While it is recognised that the percentages of riparian zone invasions are purely speculative the figures still give a clear indication of the importance of riparian zone clearing and the need to keep them clear.

5.4 ADDITIONAL IMPACTS OF CLEARING *Acacia mearnsii*

Researchers have commented on and are concerned about the impact *Acacia mearnsii* has on the riparian zone (Section 2.3). The loss of habitat due to invasion of *A. mearnsii* in the riparian zone is the main concern, leading to ecosystem health deteriorating and consequently leading to a lack of diversity of both fauna and flora (Macdonald and Richardson, 1986; Cambray and de Moor, 1995; Belcher, 1996). The resultant lack of species richness due to the invasion of *Acacia mearnsii* was clear in the present study site. While mapping and surveying the site, the lack of diversity was noticed by the scarcity of additional flora species in any form (Trees, shrubs or grasses). To understand some of the effects *A. mearnsii* has in the riparian zone, literature on the subject was reviewed (Section 2.3) and where possible, tests were carried out to make comparisons to the present study.

5.4.1 Channel Survey

Vegetation has often been played down as a significant variable in channel instability leading to increased bank erosion and the resultant loss of habitat (Section 2.3.1). Fluvial geomorphologists are recognising the importance of riparian vegetation in controlling channel processes and form, but the response is complex (Section 2.3.1). Alien trees in the riparian zone increase the shear strength of the river bank allowing a steeper cross-section to be maintained (Rowntree, 1991) (Figure 2.10). In flood situations, the high biomass pushing down on the banks causes large blocks to fall away, whereas indigenous vegetation with a lower biomass bind the upper soil surface and protects the banks against erosion (Beyers, 1994; Rowntree, 1991).

Channel cross-sections have been surveyed in different catchments and along individual rivers to understand and compare the processes involved in the Eastern Cape (Beyers, 1994; Rowntree, 1991; Rowntree, 1990). In the hope that a major flood event occurred during the monitoring period and for comparative purposes, representative channel cross-sections were surveyed in the cleared (Figure 4.13) and uncleared sections (Figure 4.14) of the study site (Figure 3.1). There has been no significant flood event since the start of the experiment to justify surveying the sites again for comparative purposes, but it was possible to make comparisons to previous research. Beyers (1994) found *Acacia mearnsii* to cause a wider and deeper channel approximately ten times the cross-sectional area of a channel with indigenous vegetation in the riparian zone (Figure 2.8). Rowntree (1990) remarked that *A. mearnsii* was responsible for a decreased width to depth ratio and caused a larger cross-sectional area when compared to a grassy reach of the same river (Figure 2.9). The results from the present study show a wide and relatively deep channel cross section (Figures 4.13 and 4.14) as opposed to the shallow cross sections of uninvaded rivers (Section 2.3.1) and therefore compare with past research. It would be illogical to try and restore channels to their previous pristine state but it is worthwhile to rehabilitate vegetation in the riparian zones to avoid further loss of habitat.

5.4.2 Water Quality

As part of a survey to compile an inventory of the fish and aquatic macro invertebrates found in selected invaded and pristine rivers in the Eastern Cape water quality was tested (Section 2.3.2) (Cambray and de Moor, 1995). The average conductivity readings for invaded rivers were found to be considerably higher (175 - 404 uS.cm^{-1}) than those measured in pristine rivers (54 - 119 uS.cm^{-1}). Conductivity readings were taken at the three weirs (Table 4.5) where the highest average reading was 320.2 uS.cm^{-1} measured at weir 3 before clearing while the lowest average reading of 259 uS.cm^{-1} was measured at weir 2 before clearing. However, the conductivity readings for all three weirs over the duration of the monitoring period did not vary much between weirs before and after clearing (Figure 4.12). The conductivity measurements all fall into the category of invaded rivers when comparison is made with results presented by Cambray and de Moor (1995). It is possible differences would only become apparent after a significant time once the soil chemistry has changed in response to clearing of the trees.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

An experimental study to establish the effect of *Acacia mearnsii* on streamflow was motivated by the need for further research in the Eastern Cape and the following concerns:

- The lack of research on the consequences of alien vegetation and the need for further research to motivate additional clearing and sustain the current clearing programmes (DWAF, 1998).

- There is a lack of information on the effects of wattles on streamflow (Scott *et al.*, 1998).

- There is a need for further research on the effects of clearing alien vegetation from catchments in the Eastern Cape and, more specifically, the effect on streamflow of clearing *Acacia mearnsii* from riparian zones (Section 1.2).

- Past research has focussed 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 *Acacia 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, Le Maitre *et al.*, 1995; Scott *et al.*, 1998)

The following chapter will relate and contextualise the present findings with reference to the aims and objectives of the research. Research limitations and contribution of the study to the subject will also be highlighted.

6.2 SUMMARY OF MAJOR FINDINGS

A suitable site was located in the Zwartkops River catchment in the Eastern Cape. A section of the Sand River with similar channel morphology and vegetation density was used to investigate the effects of *Acacia mearnsii* on streamflow. Reviewed literature established that research on the effect of alien invading plants on streamflow in riparian zones are based on short periods of observation, on different kinds of streams and in different parts of the country. Conclusions state that experiments should be repeated over a wider geographical and vegetation range in order to improve estimates of water use by riparian vegetation (Bosch and Marais, 1995; Dye and Poulter, 1995b; Scott and Lesch, 1995, 1996). Temporary weirs have been used successfully for short term experiments to compare streamflow before and after clearing riparian zone vegetation (Dye and Poulter, 1995b).

However, for an extended study encompassing different seasons, three permanent weirs were constructed to compare streamflow changes between a cleared and uncleared section of the river. The layout and design of the experiment proved to be effective as there were no blockages at the weirs, data collection was accurate, vandalism and/or theft of equipment was averted and the weirs were able to withstand a minor flood event.

Following the removal of the riparian trees (*Acacia mearnsii*) a successful comparison was made between a cleared and uncleared section of the river. Previous studies had to carefully synchronize monitoring during periods without rain, however in the present study this was not essential due to the configuration of three consecutive weirs to allow the comparison of streamflow over a longer time frame and spanning different weather conditions. Minor adjustments to the results were necessary to remove flood peaks due to abnormal runoff entering the system above weir 1 from the nearby road. This was seen to make the results more reliable as complete days were removed from all three data sets from the weirs. A period of monitoring was unusually dry for the region and it was necessary to augment flows from the upstream dam. This allowed for surface streamflow to be maintained and uptake of water due to the presence of *Acacia mearnsii*, to be measured.

Modelling on a large scale to show the implications of vegetation change provides valuable information for catchment managers (Section 2.2.1). Catchment experiments show increases in water flow when alien vegetation is removed, but in the case of *Acacia mearnsii,* where invasions are worst in the riparian zone, research is necessary at a smaller scale within riparian zones. The present research indicates an average streamflow reduction, as a consequence of *Acacia mearnsii* in the riparian zone, of 15.1m^3/ha/day or 551mm per year. This was found to be notably different to water use estimates for alien plants within catchments but comparable to previous estimates of streamflow reduction caused by alien vegetation in riparian zones.

Research on the effect of vegetation on streamflow has shown that results are influenced by certain general trends of which weather conditions are the most significant (Chapter 2). In January when there was ample rainfall and resultant availability of water in the riparian zone, water was added to the channel. When conditions became dry, the evaporative demand exceeds 3mm/day and as the evaporative demand decreases so does the streamflow reduction. It appeared that when the evaporative demand exceeded 3mm/day (hottest months), streamflow reduction was diminished but below an evaporative demand of 3mm/day as the evaporative demand increases so does streamflow reduction. Over midday, on selected days, streamflow reduction increased when evaporative demand increased which corresponds to Poulter *et al.*, (1994) who found *Acacia mearnsii* to exhibit control of water use when weather conditions become dry. This suggests if the evaporative demand of the air was less, the trees would have used more water and consequently an even bigger effect on streamflow reduction. Correlations between streamflow reduction and evaporative demand were carried out, and while a relationship was expected, no significant long term relationship was established. A possible explanation was the water released from the dam which made water available to the trees in the riparian zone, that would not have been there as a result of the dry conditions. While continued availability of water implies that trees should transpire at potential rate, it was shown in Figure 5.1 that the two components (weather conditions and upstream inputs) do not interact, creating an additional variable in the relationship between streamflow reduction and evaporative demand.

Relationships have been found between the biomass of vegetation in a catchment and streamflow reduction. In models using biomass as a function of streamflow reduction *Acacia mearnsii* has not been used because of lack of data (Scott *et al.*, 1998). When the trees were felled, they were weighed and a relationship was found between the diameter at breast height and biomass. A total wet above ground biomass of 16 000g.m^{-2} was removed from the riparian zone between weirs 1 and 2. Due to the relatively small sample these results are not conclusive, but contribute to previously unknown aspects of *Acacia mearnsii.* A comparison of the relationship between streamflow reduction and above ground biomass (Le Maitre *et al.*, 1996) and the results of the present study do not compare. This suggests that streamflow reduction as a result of alien vegetation in catchments is less of a concern than when alien vegetation invades the riparian zone.

While the main focus of the study was to determine the effect of *Acacia mearnsii* on streamflow, additional information is also necessary to understand the effects of invasions on riparian zones. As part of the study water quality and channel morphology were investigated at the study site. Conductivity readings at the weirs were recorded as an indicator of water quality. When compared to reviewed literature, the readings corresponded to invaded rivers as expected.

The channel morphology of invaded rivers is expected to be relatively wide and deep in relation to the amount of water during base flows. A comparison of representative cross-sections within the study site showed no differences to those reviewed in the literature. There was no significant flood event for the duration of the research period to review these cross sections and assess any changes.

6.3 CONTRIBUTION TO THE SUBJECT / AIDING WATER MANAGERS

Results from the present experimental study contribute to the understanding of streamflow reduction caused by alien invasions in the riparian zone, and specifically the effect on streamflow of *Acacia mearnsii* invasions in the riparian zones of the Eastern Cape. The study confirms previous research, estimates and short term studies that show streamflow reduction caused by alien plant invasions in the riparian zone use significantly more water than the alien plant invasions in a catchment. This is an important consideration for decision makers when deciding on new areas to clear, or the need to concentrate efforts in a particular region where riparian zone invasions are increasing. While it is recognised that it would be pointless removing alien trees only from the riparian zones around the country or the Eastern Cape, it should be considered as a priority to clear and concentrate follow-up operations on riparian zones if funding becomes an issue.

For the first time actual experimental data originating from the Eastern Cape can be used in models and analysis of streamflow responses to the removal of vegetation. The biomass data collected and the clear relationship between a diameter at breast height and above ground biomass can be used as an alternative way to estimate the biomass of a stand of *Acacia mearnsii* instead of time consuming and often difficult weighing procedures. This was an attempt to answer a question posed in literature, as one of the frequently used models focusses on the biomass of alien invading species (Le Maitre *et al.*, 1996). Although the present water use results did not compare with the model, scientists and decision makers alike will be able to use the biomass relationships to estimate the weight of *A. mearnsii* trees in catchments for application to models such as that of Le Maitre *et al.*, (1996).

The use of three weirs allowed for an extended period of research. The technique has not been used previously and proved to be effective in the comparison of a cleared and uncleared section of river. Previous methods used temporary weirs for short term studies but had difficulties with blockages, theft and vandalism. These issues were not experienced in the present study and the extra money spent in the construction of the weirs was worthwhile. If temporary weirs had been used, they would have been washed away with the minor flood at the start of the experiment.

Acacia mearnsii invasions in the riparian zone have been confirmed to use more water than alien invaders in catchments. The present study has resulted in valuable new data for streamflow reduction as a result of a specific species which can be used to refine present estimates of water use within catchments and can be included in future modelling exercises. The Working for Water programme currently operating around South Africa is a worthwhile programme. It is anticipated the results from the present study will emphasize the advantages of clearing riparian zone invasions and the need to keep them clear. In addition, the proven increased water use of trees in the riparian zone might lead to further funding of the programme

Catchment managers and specifically the Zwartkops Water Resources Management Plan task group on the control of alien plant invasions will be able to use the streamflow reduction figures to educate land owners. Researchers have often stated the need for the involvement of all land owners for the continued success of the clearing programmes. The basic research design and water use data, without the use of mathematical equations and modelling, can be used to educate communities about the advantages of clearing riparian zones and keeping them clear of alien plant invasions.

6.4 RESEARCH LIMITATIONS

It would be ideal to set up an experiment of this nature and control all environmental factors but this is impossible. The study provides useful information for catchment managers but some research limitations are recognised and should be noted when extrapolating results. The results are based on a limited area and a short period of time. The lack of an assessment of water use by indigenous vegetation and the secondary effects of clearing over a longer period of time and in different areas was seen as a limitation of the study. The study is representative of the Eastern Cape Fynbos region and for the dry weather conditions experienced during the monitoring period. It would be preferable to continue monitoring to assess the effect of *Acacia mearnsii* over a longer period incorporating wet and dry weather conditions. The results represent the worst case scenario with dry conditions but it is unknown what effect the trees will have during a wet season.

Soil moisture, sap flow rates, leaf areas, plant stress, soil and bedrock profiles were all recognised as factors which could help support and/or interpret the results. Analysis of soil moisture would have been advantageous to interpret the availability of water in the riparian zone, and the distance from the channel trees had direct access to the saturated zone. Soil and bedrock profiles would have further supported the similarity between the two sections of river used in the comparison and assisted in reasons for increased recharge rates after the initial wet period at the start of the experiment. Soil depth measurements could have explained the depth at which trees were drawing water from the saturation zone or if there was water available in the upper soil horizons for the trees to use. Unfortunately it was not possible to measure soil depths or soil moisture and this was seen as a limitation of the study (Section 3.6).

Sap flow rates, leaf area indices and plant stress measurements would have helped in the interpretation of the comparison between streamflow reduction and weather conditions. The physiological adaptions of the trees would have assisted in the interpretation of the ability of *Acacia mearnsii* to limit its water use when conditions become hot and dry. Sap flow rates would have been useful in a comparison between actual streamflow reduction and water use of the trees.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Research has been done on the effect of alien vegetation on streamflow reduction but this was the first experiment to investigate at the effect of *Acacia mearnsii* specifically in the riparian zone. *Acacia mearnsii* is recognised as the worst invader in the country (Versveld *et al.*, 1998) and future research should be orientated towards a complete understanding of its water use characteristics. It appears as if *A. mearnsii* has the ability to control water use when conditions become hot and dry. This will have implications on streamflow reduction and water use in the riparian zone. Further research needs to focus on sap flow rates for *A. mearnsii* in different geographical regions with different climates.

The use of hydrogen isotope analysis should be considered in future research to investigate the source of water used by alien trees in the riparian zone. The root structure of *Acacia mearnsii* would also assist in knowledge on the depths of water the trees can use.

The vacant niche for a higher steady state biomass in the Fynbos Biome could pose a problem in the future success of eradicated alien woody species. Research into understanding the success of alien woody invasions in the Fynbos Biome needs to be resolved for the long term success of clearing and rehabilitation programmes.

The Versveld *et al.* (1998) report on alien invading plants and water resources in South Africa is a thorough report on the distribution and water use of alien plants in South Africa. Further research should focus on the extent of alien invasions in riparian zones around the country and should be included in the report. Water use figures for individual alien species in riparian zones should be investigated and the additional increase of water should be made available to decision makers and sponsors of the clearing programmes.

6.6 CONCLUSIONS

The effect of *Acacia mearnsii* in the riparian zone caused a reduction in streamflow. This conclusion was achieved by identifying a suitable site for an experiment and a comparison was made between a cleared and uncleared section of a river. The biomass of the trees removed was calculated and a relationship between diameter at breast height and above ground wet biomass of the trees was established. Streamflow reduction and the weather conditions for the duration of the monitoring period were compared. No significant relationship between streamflow reduction and weather conditions could be established but there was evidence that weather effects the magnitude of flow responses. The highest streamflow reduction occurs during the hottest and driest months when streamflow is crucial. Due to time and financial constraints soil moisture could not be examined but as an alternative, soil surface moisture was monitored before and after clearing with no variation found.

Additional impacts of *Acacia mearnsii* within the riparian zone were examined. Literature explains that alien vegetation results in an unhealthy riparian ecosystem. Water quality was analysed before and after clearing, and while there was no difference found, the results corresponded to previous research on invaded riparian zones. The water quality of river systems with *A. mearnsii* in the riparian zone is adversely affected. It was clear from previous research that *A. mearnsii* in the riparian zone adversely affected the channel morphology. Representative cross sections were surveyed in the study to assess the impact which compared to previous findings. On completion of clearing the site, various grass types were planted which successfully germinated after sufficient rain and follow up clearing of seedlings was carried out to eradicate any possible future regrowth.

In conclusion, it has been established that *Acacia mearnsii* in the riparian zone is responsible for significant streamflow reduction. It is envisaged that water managers will benefit from these updated water use figures in motivations for funding, deciding on new clearing sites and the resultant ongoing success of the 'Working for Water' programmes around the country.

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APPENDIX 1

Historical Rainfall Data and Daily Rainfall (January - September 1996)

Measured at the 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	49.8
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	520.2	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	58.9	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	531.9	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	98.1
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	**680.8**	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	**535.7**	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	69.5	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**	**43.58**
* 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 2

Vegetation Sampling

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		

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		

APPENDIX 3

Weir Construction Report

NOTES

Design capacity = 0.247 m^3/s

Weir limit = 0.200m

Low notch to be manufactured of 5mm mild steel.

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

Concrete strength = 20 MPa

Concrete mix ratio = 1 : 3 : 5

Where possible the walls have to be anchored with Dowels

Dowels = 400mm R12, 200mm sunk.

Steel reinforcement of the walls = REF 245

Concrete mixer to be used.

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

The low notch will be manufactured by an outside institution.

All construction waste to be removed at completion of project.

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

All neccesary materials will be supplied by this office.

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

All construction works to be done under supervision.

The weir sites will be shown to the Superintendent

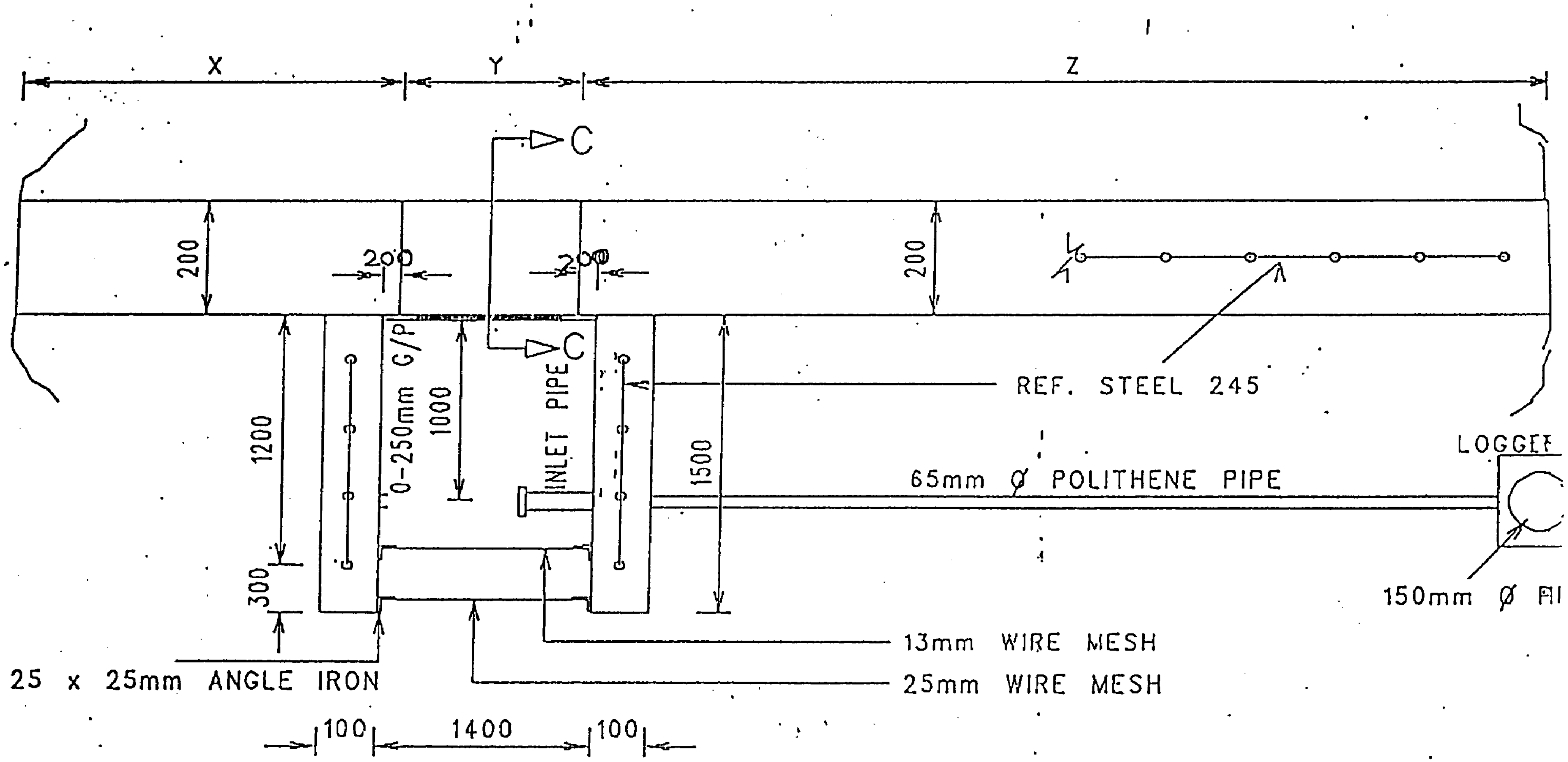
Permission to enter private property to be acquired before construction commenses.

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

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.

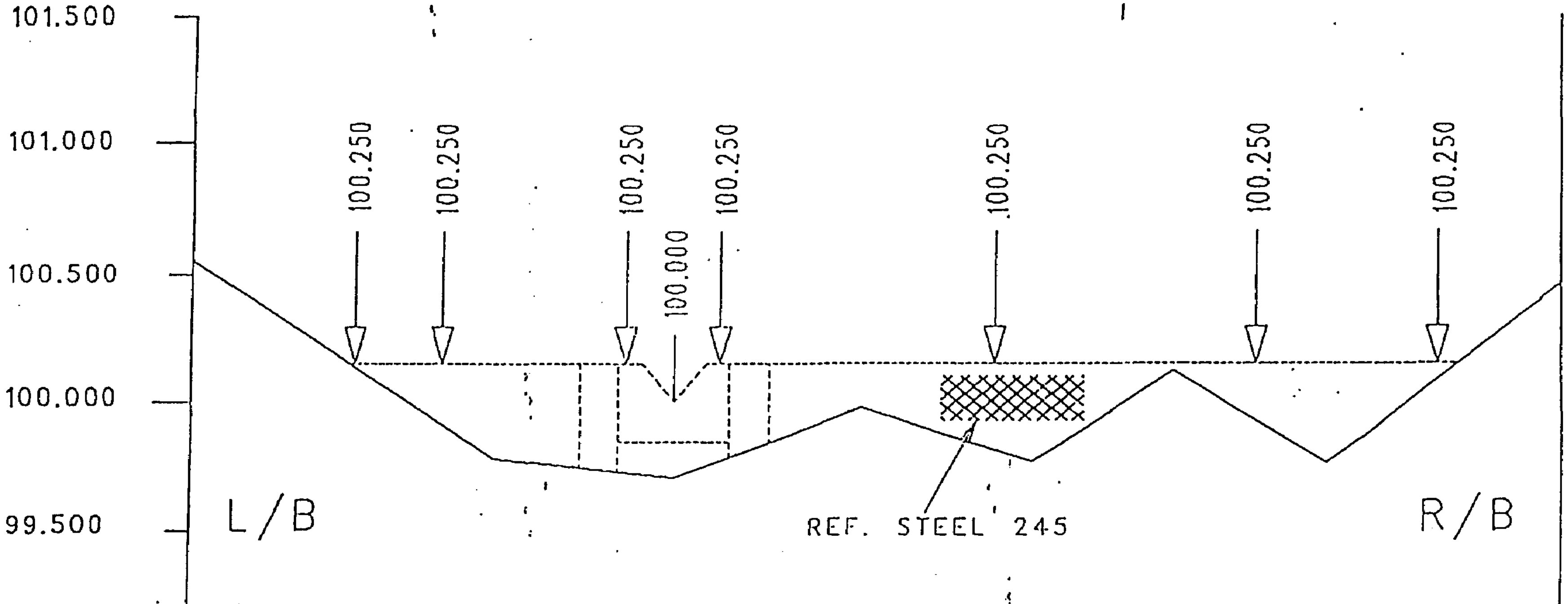
PRELIMINARY COSTING LIST

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	99.952	99.770	100.117	99.759	100.450

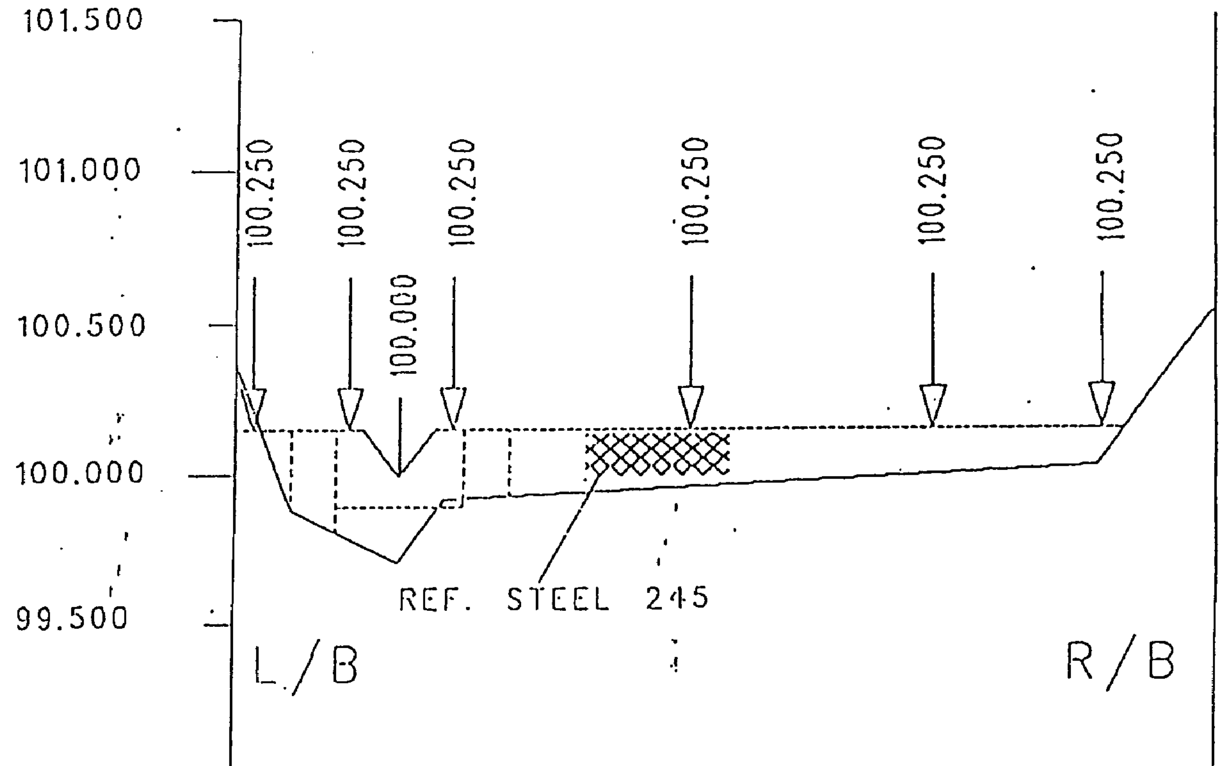
SECTION 1

CHAINAGE = 0:000m

SCALE: HOR 1:100
VERT 1:25

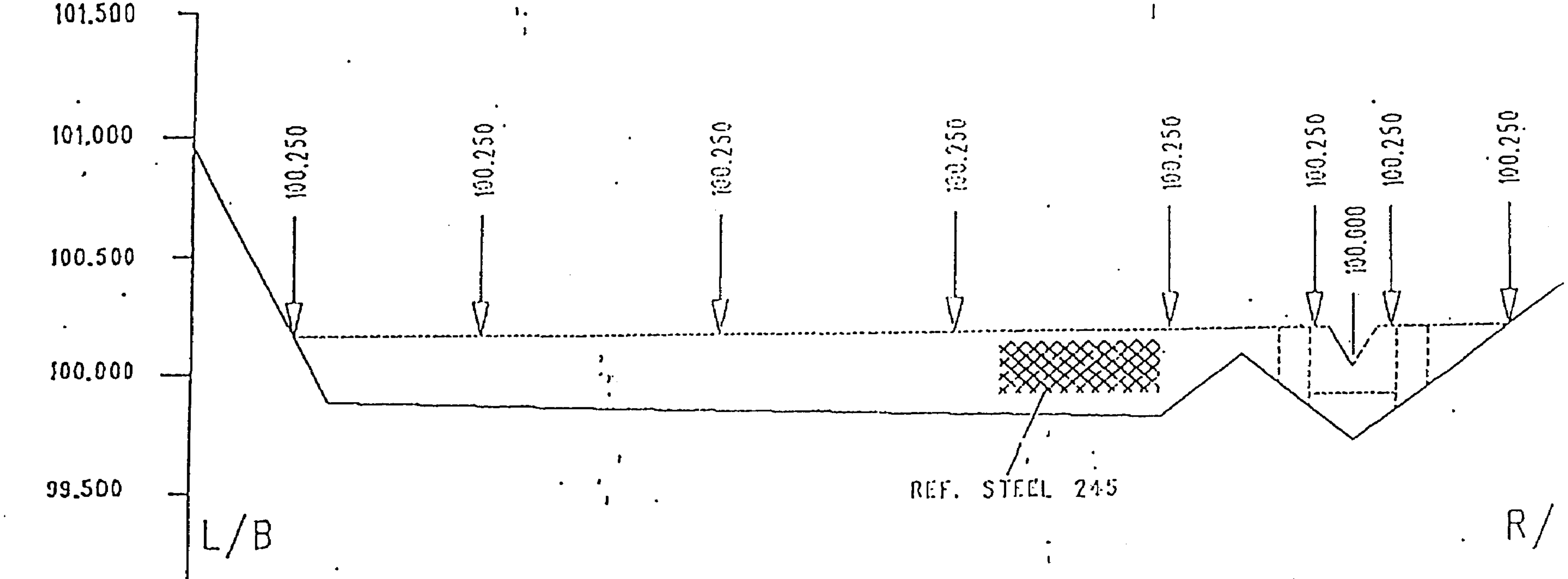
SECTION 2

SCALE: HOR 1:100
VERT 1:25



CHAINAGE AFSTAND (m)	0.000	0.600	1.800		2.300	9.300	10.600
REDUCED LEVEL (m)	100.348	99.869	99.700		99.925	100.071	100.547

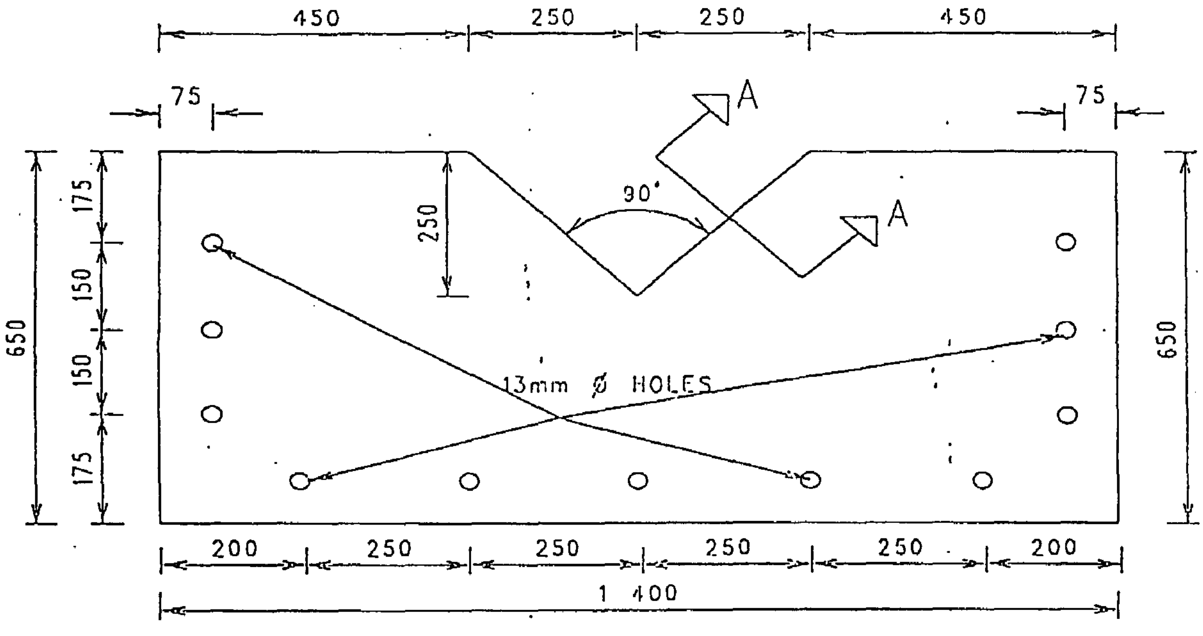
CHAINAGE = 500m



CHAINAGE (m)	0.000	2.300		15.500	17.200	13.000	
REDUCED LEVEL (m)	100.997	99.837		99.817	100.074	99.700	

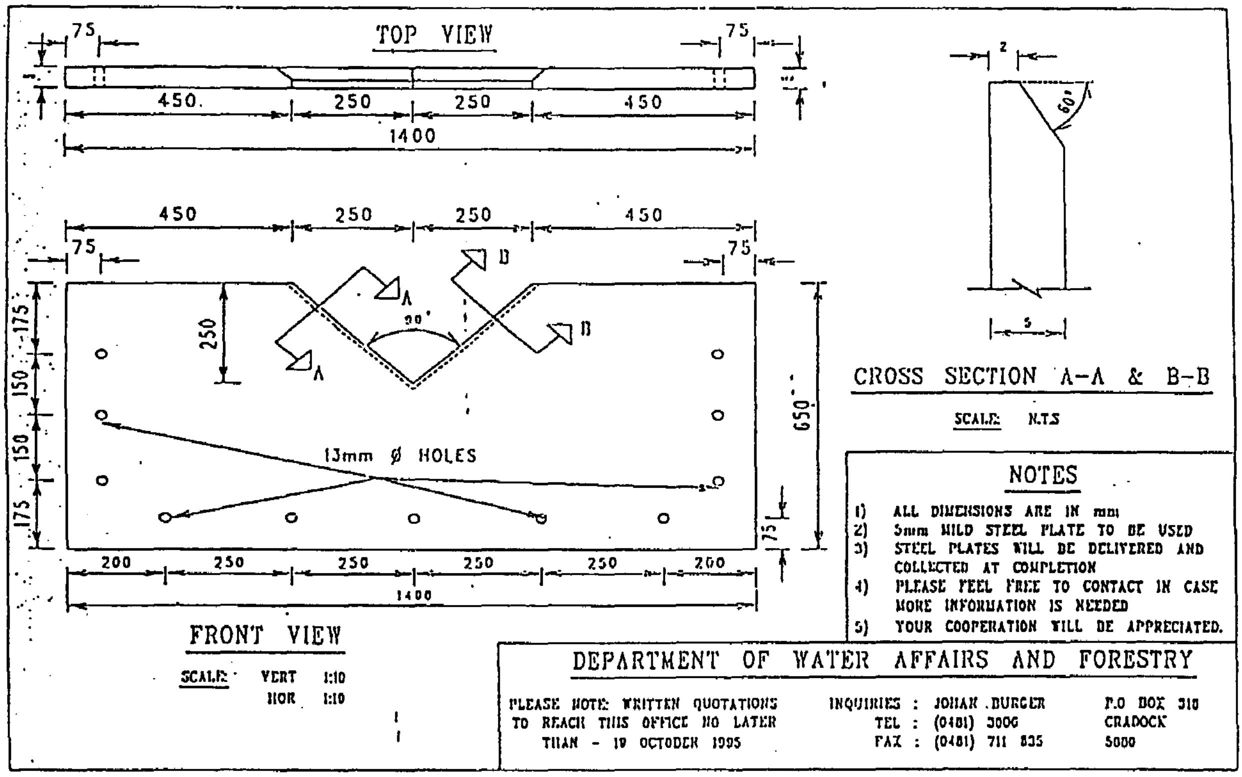
SECTION '3 CHAINAGE = 1000m

SCALE: HOR 1:100
VERT 1:25



LOW NOTCH

SCALE: HOR 1:10
VERT 1:10



FRONT VIEW

SCALE: VERT 1:10
HOR 1:10

CROSS SECTION A-A & B-B

SCALE: N.T.S

NOTES

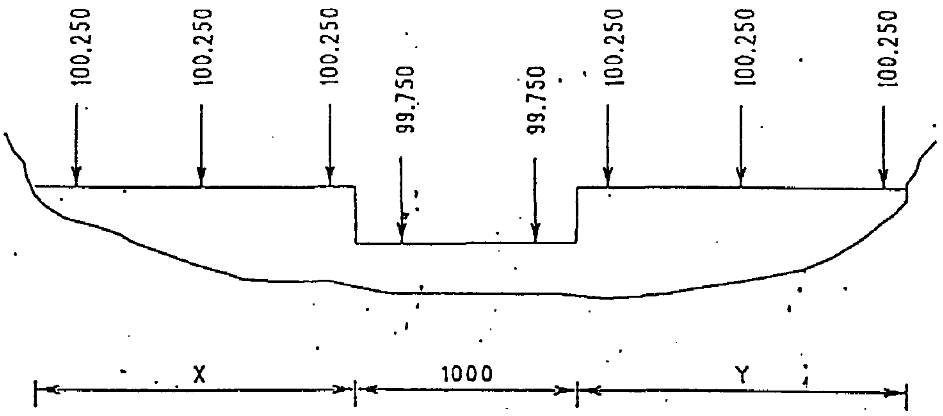
1) ALL DIMENSIONS ARE IN mm
2) 5mm MILD STEEL PLATE TO BE USED
3) STEEL PLATES WILL BE DELIVERED AND COLLECTED AT COMPLETION
4) PLEASE FEEL FREE TO CONTACT IN CASE MORE INFORMATION IS NEEDED
5) YOUR COOPERATION WILL BE APPRECIATED.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

PLEASE NOTE: WRITTEN QUOTATIONS TO REACH THIS OFFICE NO LATER THAN - 19 OCTOBER 1995

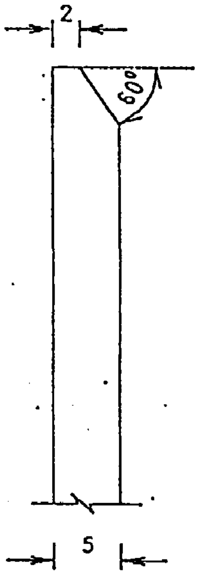
INQUIRIES : JOHAN BURGER
TEL : (0481) 3006
FAX : (0481) 711 835

P.O BOX 310
CRADOCK
5880

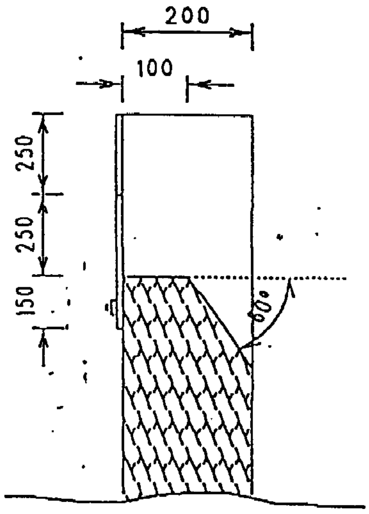


WEIR CONSTRUCTION
SECTIONS 1, 2 & 3

SCALE: N.T.S

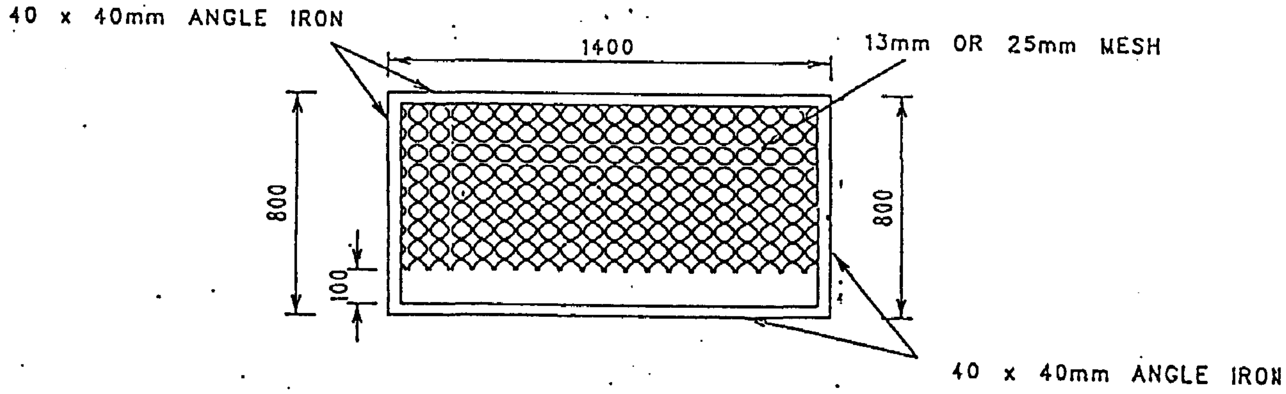


CROSS SECTION A-A



SECTION C-C

SCALE: N.T.S



OBSTRUCTION IN FRONT OF THE LOW NOTCHES

TOESTEMMING OM EIENDOM TE BETREE

Hiermee gee ek, die ondergetekende,

NAAM: L. WEAKMORE

ADRES: "FIRGROVE"
ROCKLANDS.

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

L. ENGELBRECHT

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

APPENDIX 4

Examples of Raw Streamflow Data Received

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 5

Examples 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
	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 6

Complete Data Set of Daily Flows and Calculated Uptake and Release of Water Between Weirs.

	Wier 1	Weir 2	Weir 3	Wier 1 (X)	Weir 2 (y)	Weir 3 (z)	(y - x)	(z - y)
	ℓ/s	ℓ/s	ℓ/s	m^3/day	m^3/day	m^3/day	m^3/day	m^3/day
January								
10	0.68	2.30	5.96	59.14	198.58	514.95	139.44	316.37
11	0.58	1.86	3.90	50.28	160.37	337.11	110.09	176.75
12	0.56	1.40	2.80	48.30	121.04	242.14	72.74	121.10
13	0.49	1.08	2.07	41.94	93.24	179.01	51.30	85.76
14	0.42	0.95	1.72	36.63	82.20	148.92	45.57	66.72
15	0.42	0.88	2.18	36.43	75.74	188.44	39.31	112.70
16	0.22	0.69	1.48	18.70	59.20	128.09	40.51	68.89
17	0.18	0.58	1.09	15.65	49.81	94.59	34.17	44.78
18	0.38	0.53	1.26	32.68	45.42	108.69	12.74	63.27
19	0.88	0.48	1.86	75.75	41.10	160.67	-34.65	119.57
20	0.24	0.50	1.53	20.50	43.23	131.90	22.73	88.67
21	0.28	0.59	1.65	23.81	50.95	142.27	27.14	91.33
22	0.14	0.54	1.14	12.01	46.76	98.58	34.75	51.82
23	0.12	0.49	0.93	10.41	42.60	80.14	32.19	37.54
24	0.09	0.41	0.87	7.95	35.71	74.89	27.76	39.18
25	0.11	0.35	0.84	9.53	29.96	72.52	20.43	42.56
26	0.73	0.31	1.00	63.14	26.92	86.06	-36.21	59.13
February								
7	0.52	1.25	1.82	44.76	107.68	157.55	62.92	49.86
8	0.49	1.04	1.36	42.45	89.58	117.55	47.13	27.98
9	0.40	0.92	0.98	34.56	79.32	84.76	44.76	5.44
10	0.43	0.82	0.85	37.19	70.98	73.68	33.79	2.71
11	0.39	0.69	0.89	33.58	59.72	76.77	26.14	17.05
12	0.22	0.63	0.80	18.73	54.61	69.34	35.88	14.73
13	0.14	0.54	0.51	11.67	46.70	44.14	35.03	-2.55
14	0.12	0.43	0.36	10.77	37.47	31.36	26.71	-6.11
15	0.06	0.35	0.32	4.91	30.34	27.72	25.42	-2.62
16	0.04	0.31	0.28	3.35	27.21	23.79	23.86	-3.42
17	0.03	0.29	0.25	2.95	25.24	21.37	22.29	-3.87
18	0.03	0.25	0.19	3.01	21.19	16.78	18.19	-4.41
19	0.05	0.21	0.19	4.07	18.15	16.34	14.08	-1.81
20	0.03	0.18	0.14	2.33	15.67	11.79	13.34	-3.89
21	0.03	0.17	0.11	2.78	14.42	9.74	11.64	-4.67
22	0.02	0.14	0.07	2.15	12.06	6.28	9.91	-5.78
23	0.02	0.12	0.05	1.99	10.06	4.55	8.07	-5.51
24	0.03	0.11	0.05	2.23	9.24	3.96	7.01	-5.28
25	0.03	0.11	0.05	2.81	9.21	4.53	6.40	-4.68
26	0.10	0.14	0.10	8.80	12.23	8.41	3.43	-3.82
27	0.02	0.09	0.10	1.31	7.58	8.59	6.28	1.01
28	0.00	0.11	0.08	0.39	9.70	6.59	9.31	-3.11
29	0.01	0.12	0.07	0.55	10.38	5.68	9.83	-4.70
March								
1	0.01	0.13	0.06	0.89	10.94	4.99	10.05	-5.95
2	0.01	0.10	0.04	1.20	8.50	3.44	7.30	-5.06
3	1.26	0.18	0.18	108.77	15.20	15.18	-93.57	-0.02
4	0.04	0.17	0.15	3.80	15.06	13.06	11.26	-2.00
5	0.02	0.29	0.07	1.99	24.78	6.32	22.79	-18.46
6	0.01	0.30	0.05	1.18	26.14	4.51	24.96	-21.62

	Wier 1 Δs	Weir 2 Δs	Weir 3 Δs	Wier 1 (X) m^3/day	Weir 2 (y) m^3/day	Weir 3 (z) m^3/day	(y - x) m^3/day	(z - y) m^3/day
7	0.01	0.27	0.03	0.79	23.74	2.94	22.95	-20.80
8	0.01	0.22	0.02	0.99	19.10	1.73	18.11	-17.37
9	0.01	0.18	0.01	1.04	15.68	1.03	14.64	-14.65
10	0.01	0.13	0.01	0.78	11.17	0.92	10.39	-10.25
11	0.01	0.11	0.01	0.75	9.87	1.01	9.12	-8.86
12	0.01	0.10	0.00	0.99	8.82	0.34	7.83	-8.47
13	0.01	0.10	0.00	1.14	8.49	0.12	7.35	-8.37
14	0.01	0.08	0.00	1.00	6.54	0.01	5.54	-6.52
15	0.01	0.05	0.00	0.95	4.06	0.00	3.12	-4.06
16	0.01	0.04	0.00	0.93	3.09	0.00	2.16	-3.09
17	0.01	0.03	0.00	0.68	2.47	0.00	1.79	-2.47
18	0.01	0.03	0.00	0.66	2.20	0.00	1.55	-2.20
19	0.00	0.01	0.00	0.21	1.19	0.00	0.98	-1.19
20	0.00	0.01	0.00	0.29	0.46	0.00	0.17	-0.46
21	0.01	0.00	0.00	0.70	0.33	0.00	-0.37	-0.33
22	0.00	0.00	0.00	0.03	0.01	0.17	-0.02	0.16
23	0.00	0.00	0.00	0.01	0.00	0.00	-0.01	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.02	0.00	0.00	1.78	0.00	0.00	-1.78	0.00
30	0.00	0.00	0.00	0.34	0.00	0.00	-0.34	0.00
31	0.00	0.00	0.00	0.07	0.00	0.00	-0.07	0.00
April								
1	0.01	0.00	0.00	0.69	0.00	0.00	-0.69	0.00
2	0.01	0.00	0.00	0.60	0.00	0.00	-0.60	0.00
3	0.00	0.00	0.00	0.16	0.00	0.00	-0.16	0.00
4	15.61	4.61	0.00	1349.12	397.89	0.00	-951.23	-397.89
5	18.36	14.26	6.83	1586.31	1232.38	589.74	-353.93	-642.64
6	18.41	16.77	14.31	1590.51	1448.65	1236.45	-141.86	-212.20
7	18.65	17.81	15.61	1611.76	1538.87	1348.90	-72.89	-189.97
8	18.72	18.25	16.03	1617.50	1576.79	1384.70	-40.71	-192.09
9	10.56	14.83	14.40	912.08	1281.65	1244.17	369.58	-37.48
10	0.49	5.52	5.63	42.71	476.79	486.29	434.08	9.49
11	0.24	3.62	3.32	21.14	312.47	286.81	291.33	-25.66
12	0.15	2.52	2.10	13.02	217.62	181.80	204.60	-35.82
13	0.12	1.87	1.47	10.33	161.43	127.31	151.10	-34.12
14	0.09	1.27	1.00	8.07	109.40	86.52	101.33	-22.89
15	0.06	0.96	0.66	5.57	82.65	56.78	77.08	-25.86
16	0.05	0.80	0.32	4.41	68.80	27.66	64.39	-41.14
17	0.26	0.72	0.31	22.14	62.16	26.86	40.03	-35.30
18	2.05	0.62	0.23	176.86	53.72	19.57	-123.15	-34.15
19	0.31	0.67	0.15	26.46	57.64	12.53	31.18	-45.11
20	0.14	0.72	0.10	12.42	61.84	8.62	49.42	-53.22
21	0.11	0.67	0.11	9.19	58.24	9.53	49.05	-48.71
22	0.09	0.60	0.13	7.54	52.14	11.07	44.61	-41.08
23	0.07	0.53	0.12	6.18	45.73	10.69	39.55	-35.04
24	0.28	0.50	0.11	24.60	42.99	9.29	18.40	-33.70

	Wier 1	Weir 2	Weir 3	Wier 1 (X)	Weir 2 (y)	Weir 3 (z)	(y - x)	(z - y)
	ℓ/s	ℓ/s	ℓ/s	m^3/day	m^3/day	m^3/day	m^3/day	m^3/day
25	0.34	0.48	0.09	29.23	41.89	8.10	12.65	-33.79
26	0.33	0.46	0.07	28.58	39.96	5.74	11.38	-34.22
27	0.29	0.44	0.04	25.21	37.97	3.51	12.76	-34.46
28	0.20	0.45	0.03	17.58	38.89	2.48	21.31	-36.42
29	0.16	0.45	0.02	14.03	38.91	1.87	24.88	-37.04
30	0.12	0.43	0.02	10.24	37.07	1.65	26.83	-35.42
May								
1	0.09	0.41	0.02	8.18	35.24	1.74	27.05	-33.50
2	0.08	0.40	0.03	7.05	34.71	2.22	27.65	-32.49
3	0.08	0.39	0.05	7.34	34.10	4.23	26.76	-29.88
4	0.06	0.39	0.04	5.58	33.69	3.69	28.11	-30.01
5	0.06	0.37	0.04	4.86	32.36	3.05	27.51	-29.31
6	0.05	0.33	0.03	4.29	28.16	2.24	23.87	-25.92
7	0.04	0.28	0.02	3.24	24.12	1.41	20.88	-22.71
8	0.03	0.31	0.01	2.36	26.69	1.29	24.34	-25.40
9	0.03	0.33	0.02	2.66	28.34	1.36	25.68	-26.97
10	0.03	0.30	0.01	2.56	25.66	1.09	23.09	-24.57
11	0.02	0.29	0.01	1.67	25.32	0.79	23.65	-24.53
12	0.02	0.30	0.01	2.01	25.57	0.48	23.55	-25.09
13	0.01	0.22	0.00	1.15	19.33	0.19	18.19	-19.15
14	0.01	0.15	0.00	0.98	13.12	0.07	12.14	-13.05
15	0.01	0.13	0.00	0.58	11.64	0.01	11.06	-11.62
16	0.00	0.12	0.00	0.40	10.35	0.01	9.95	-10.34
17	0.00	0.16	0.00	0.36	13.76	0.04	13.39	-13.72
18	0.00	0.13	0.00	0.32	11.39	0.15	11.07	-11.25
19	0.00	0.19	0.01	0.27	16.07	0.47	15.81	-15.60
20	0.00	0.13	0.01	0.39	10.94	0.47	10.55	-10.47
21	0.00	0.10	0.04	0.37	8.43	3.15	8.05	-5.28
22	0.00	0.10	0.04	0.38	8.33	3.15	7.96	-5.18
23	3.03	0.10	0.05	262.01	9.02	4.55	-252.99	-4.47
24	0.09	0.30	0.05	8.00	25.98	4.45	17.99	-21.53
25	0.03	0.49	0.02	2.86	42.57	2.09	39.71	-40.48
26	0.02	0.54	0.03	1.43	46.80	2.86	45.36	-43.94
27	1.28	0.44	0.06	110.72	38.18	4.89	-72.54	-33.28
28	2.08	0.44	0.09	179.44	38.42	7.78	-141.02	-30.64
29	0.42	0.74	0.13	36.37	63.84	11.01	27.47	-52.82
30	0.44	0.76	0.17	37.66	66.04	15.05	28.38	-50.99
31	0.41	0.74	0.12	35.07	64.02	10.52	28.95	-53.49
June								
1	0.48	0.70	0.00	41.84	60.21	0.00	18.37	-60.21
2	0.47	0.68	0.00	40.84	58.54	0.00	17.70	-58.54
3	0.38	0.64	0.00	32.69	54.91	0.15	22.22	-54.76
4	0.29	0.60	0.02	25.05	51.57	1.60	26.52	-49.97
5	0.24	0.55	0.05	20.87	47.64	4.30	26.76	-43.34
6	0.22	0.50	0.05	19.04	43.08	4.42	24.04	-38.66
7	0.20	0.49	0.04	16.90	42.20	3.51	25.30	-38.69
8	0.16	0.45	0.03	13.65	38.70	2.65	25.05	-36.05
9	0.16	0.42	0.02	14.18	36.43	1.44	22.26	-34.99
10	0.17	0.39	0.01	14.68	33.27	0.92	18.59	-32.34

	Wier 1	Weir 2	Weir 3	Wier 1 (X)	Weir 2 (y)	Weir 3 (z)	(y - x)	(z - y)
	l/s	l/s	l/s	m^3/day	m^3/day	m^3/day	m^3/day	m^3/day
11	0.16	0.36	0.01	14.08	31.35	0.79	17.27	-30.56
12	0.17	0.35	0.01	14.34	30.46	1.30	16.13	-29.17
13	0.18	0.34	0.04	15.54	28.95	3.26	13.40	-25.69
14	0.14	0.31	0.04	12.48	26.92	3.22	14.44	-23.69
15	0.14	0.45	0.03	12.40	38.73	2.19	26.33	-36.53
16	0.35	0.70	0.02	30.48	60.25	1.65	29.77	-58.60
17	0.61	0.80	0.01	52.39	68.82	1.00	16.43	-67.83
18	0.40	0.31	0.01	34.33	27.09	0.62	-7.24	-26.47
19	0.02	0.21	0.01	1.94	17.97	0.44	16.03	-17.54
20	1.38	0.18	0.00	119.39	15.16	0.18	-104.23	-14.99
21	1.53	0.19	0.00	132.16	16.35	0.07	-115.80	-16.28
22	0.26	0.35	0.00	22.39	30.47	0.01	8.08	-30.46
23	0.25	0.47	0.00	21.32	40.36	0.00	19.04	-40.36
24	0.23	0.50	0.00	19.89	42.92	0.00	23.03	-42.92
25	0.23	0.51	0.00	19.72	43.79	0.00	24.07	-43.79
26	0.23	0.45	0.00	20.24	39.16	0.00	18.93	-39.16
27	0.23	0.41	0.00	19.53	35.49	0.01	15.96	-35.48
28	0.24	0.39	0.00	20.57	33.99	0.07	13.42	-33.92
29	0.21	0.38	0.00	18.05	32.88	0.22	14.82	-32.66
30	0.16	0.38	0.01	14.21	32.77	0.44	18.56	-32.32
July								
1	0.17	0.39	0.01	14.99	33.31	0.81	18.32	-32.50
2	0.16	0.36	0.01	13.58	31.26	0.98	17.68	-30.28
3	0.14	0.36	0.01	12.33	31.39	1.18	19.06	-30.21
4	0.19	0.34	0.01	16.59	29.63	1.09	13.03	-28.54
5	1.60	0.40	0.04	138.60	34.38	3.27	-104.22	-31.11
6	2.15	0.66	0.89	185.38	57.02	76.61	-128.37	19.59
7	0.44	1.10	0.70	37.75	94.86	60.42	57.11	-34.44
8	0.39	1.12	0.67	33.68	96.43	57.53	62.75	-38.90
9	0.37	0.87	0.64	32.39	75.26	55.22	42.87	-20.04
10	0.34	0.74	0.52	29.59	63.74	45.21	34.15	-18.52
11	0.33	0.66	0.43	28.37	57.02	37.41	28.65	-19.61
12	0.32	0.58	0.37	27.30	50.30	31.70	23.00	-18.61
13	0.32	0.52	0.31	27.49	44.68	26.53	17.19	-18.15
14	0.25	0.46	0.27	21.40	40.13	23.71	18.73	-16.42
15	0.24	0.43	0.22	20.38	37.11	18.98	16.73	-18.13
16	0.70	0.48	0.44	60.37	41.76	38.20	-18.61	-3.56
17	0.24	0.45	0.40	20.43	39.21	34.37	18.78	-4.84
18	0.12	0.47	0.27	10.45	40.56	23.45	30.10	-17.11
19	0.09	0.43	0.24	7.51	37.39	20.99	29.88	-16.40
20	0.07	0.39	0.21	6.27	33.61	18.49	27.34	-15.12
21	0.07	0.36	0.21	5.88	30.70	18.50	24.82	-12.20
22	0.06	0.32	0.20	5.21	27.39	17.70	22.17	-9.68
23	0.05	0.29	0.20	4.55	25.03	17.15	20.47	-7.88
24	0.04	0.25	0.17	3.42	21.18	14.73	17.76	-6.45
25	0.03	0.22	0.16	2.96	19.42	13.44	16.46	-5.98
26	0.03	0.20	0.14	2.87	17.62	12.49	14.75	-5.13
27	0.03	0.18	0.12	2.88	15.96	10.25	13.08	-5.71
28	0.04	0.19	0.11	3.15	16.20	9.48	13.06	-6.72
29	0.03	0.15	0.09	2.86	13.22	7.70	10.36	-5.52

	Wier 1	Weir 2	Weir 3	Wier 1 (X)	Weir 2 (y)	Weir 3 (z)	(y - x)	(z - y)
	Δs	Δs	Δs	m^3/day	m^3/day	m^3/day	m^3/day	m^3/day
30	0.03	0.12	0.07	2.61	10.61	6.07	8.00	-4.55
31	0.03	0.11	0.06	2.31	9.24	4.89	6.94	-4.36
August								
1	0.03	0.10	0.05	2.34	8.26	4.63	5.91	-3.63
2	0.03	0.12	0.05	2.85	9.99	4.60	7.14	-5.39
3	0.04	0.11	0.06	3.19	9.39	5.23	6.20	-4.16
4	0.04	0.12	0.09	3.76	10.46	7.55	6.70	-2.91
5	0.76	0.19	0.67	66.09	16.41	58.11	-49.69	41.70
6	2.00	0.74	0.52	172.98	63.53	45.11	-109.45	-18.42
7	0.10	0.89	0.39	8.88	77.09	33.47	68.21	-43.63
8	0.08	0.61	0.20	6.69	53.11	16.89	46.42	-36.23
9	0.06	0.58	0.15	5.25	50.14	12.64	44.88	-37.50
10	0.05	0.49	0.18	3.89	42.71	15.91	38.82	-26.80
11	0.05	0.41	0.18	4.63	35.70	15.78	31.08	-19.93
12	0.04	0.36	0.17	3.76	30.89	14.45	27.14	-16.44
13	0.04	0.30	0.16	3.83	25.86	13.45	22.03	-12.41
14	0.04	0.32	0.16	3.21	27.28	13.44	24.06	-13.83
15	0.03	0.28	0.13	2.92	24.56	11.41	21.65	-13.16
16	0.04	0.25	0.11	3.45	21.51	9.70	18.06	-11.82
17	0.34	0.43	0.21	29.60	36.87	18.14	7.27	-18.73
18	0.04	0.15	0.16	3.84	12.87	13.99	9.04	1.12
19	0.11	0.33	0.20	9.49	28.47	16.90	18.99	-11.57
20	0.05	0.35	0.17	4.23	30.17	15.08	25.94	-15.09
21	0.03	0.34	0.13	2.90	29.35	11.65	26.45	-17.71
22	0.03	0.36	0.11	2.32	31.32	9.08	29.00	-22.24
23	0.02	0.36	0.09	1.99	30.97	7.90	28.98	-23.07
24	0.02	0.35	0.09	1.53	30.62	7.89	29.09	-22.73
25	0.02	0.36	0.09	1.60	31.11	7.38	29.51	-23.73
26	0.01	0.37	0.08	1.26	31.57	7.02	30.31	-24.55
27	0.05	0.53	0.18	4.64	45.97	15.17	41.33	-30.80
28	0.04	0.46	0.19	3.37	39.97	16.24	36.60	-23.73
29	0.03	0.45	0.20	2.79	38.83	17.06	36.04	-21.77
30	0.03	0.43	0.20	2.24	36.86	17.35	34.62	-19.51
31	0.02	0.42	0.18	1.50	36.32	15.38	34.82	-20.94
September								
1	0.02	0.39	0.10	1.34	33.89	8.92	32.55	-24.97
2	0.01	0.35	0.06	0.67	30.64	5.41	29.97	-25.23
3	0.00	0.30	0.04	0.03	25.81	3.71	25.78	-22.10
4	0.00	0.24	0.02	0.00	21.09	2.13	21.09	-18.96
5	0.00	0.20	0.02	0.00	17.44	1.34	17.44	-16.11
6	0.00	0.17	0.01	0.00	14.59	1.08	14.59	-13.51
7	0.00	0.12	0.01	0.00	10.08	0.51	10.08	-9.57
8	0.00	0.07	0.00	0.00	6.28	0.26	6.28	-6.03
9	0.00	0.04	0.00	0.00	3.48	0.03	3.48	-3.46

APPENDIX 7

Open Water Potential 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

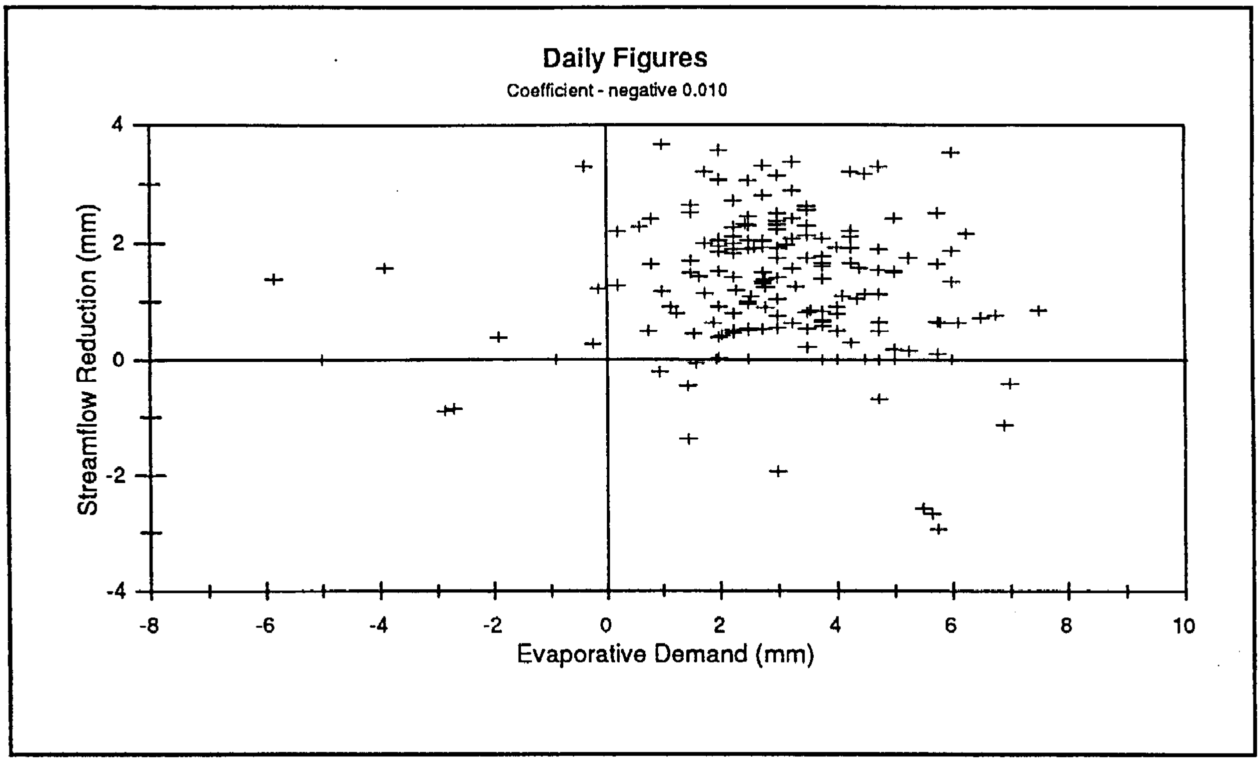
Potential Evaporation (mm) - Loerie Dam

	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

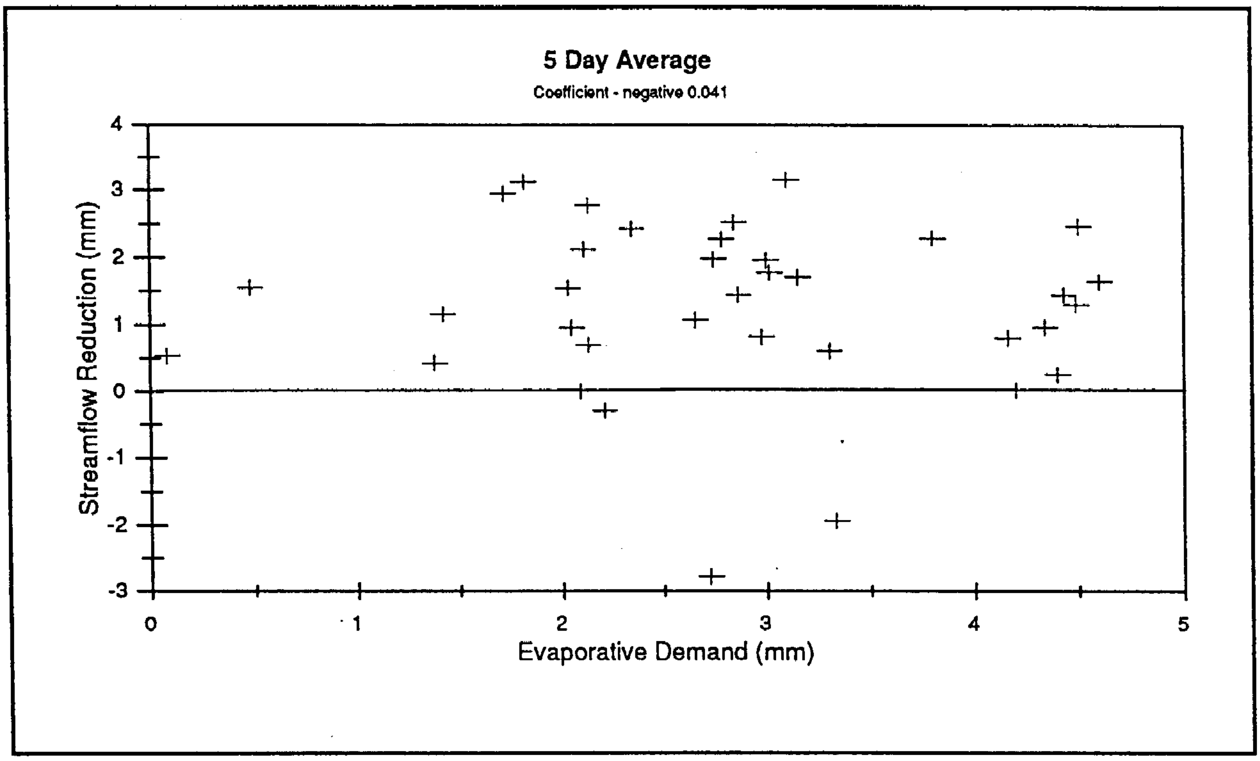
APPENDIX 8

Correlation Analysis of Evaporative Demand and Streamflow Reduction



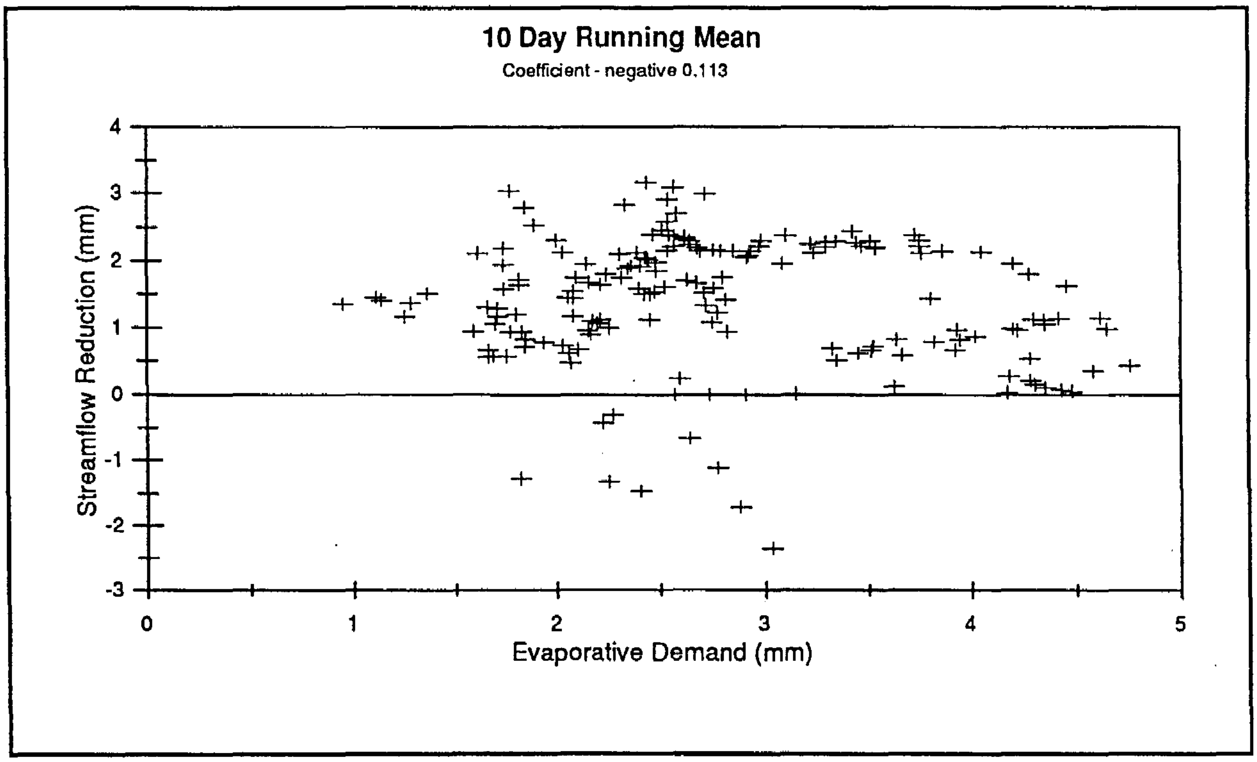
Daily Figures

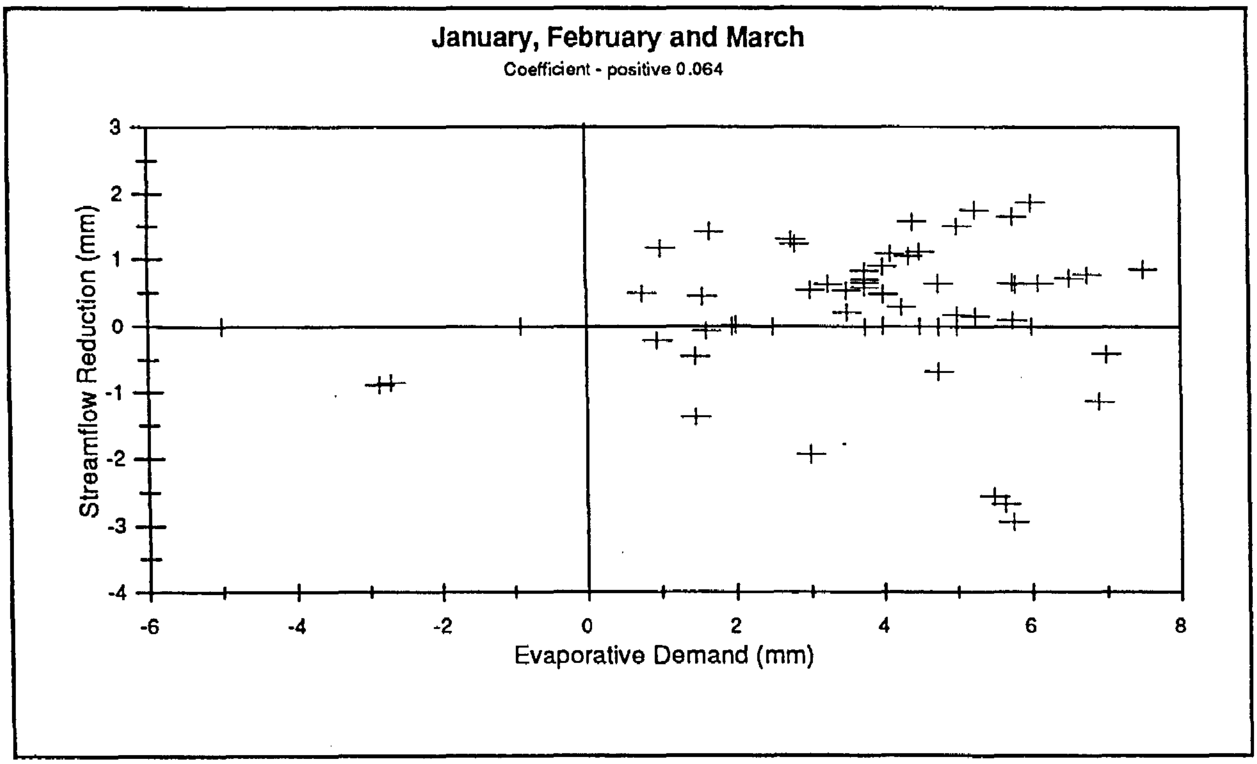
Coefficient - negative 0.010



5 Day Average

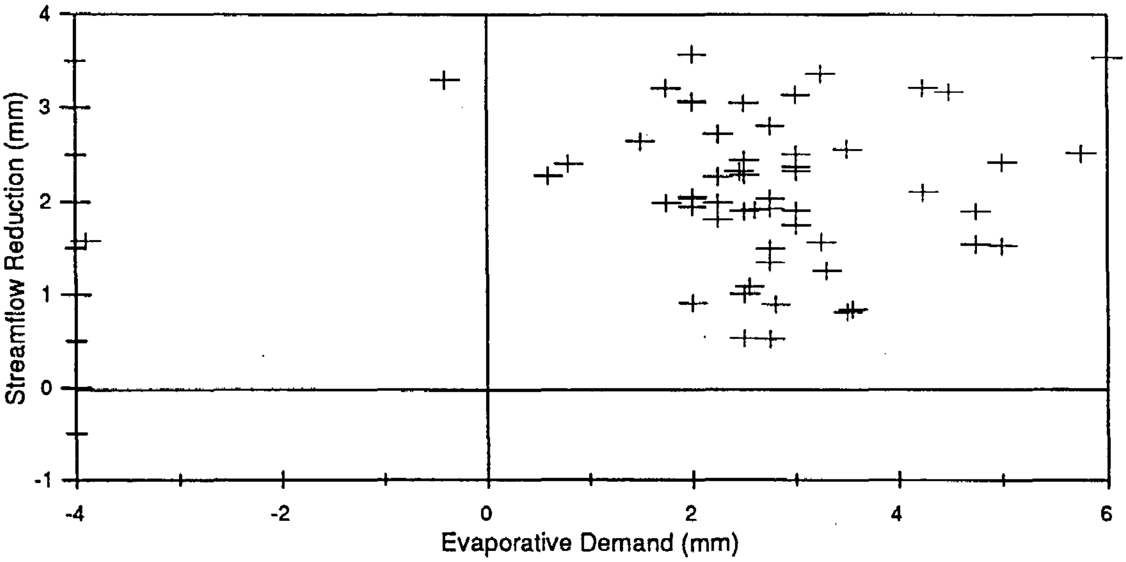
Coefficient - negative 0.041


10 Day Running Mean
Coefficient - negative 0.113
Streamflow Reduction (mm)
4
3
2
1
0
-1
-2
-3
0
1
2
3
4
5
Evaporative Demand (mm)


January, February and March
Coefficient - positive 0.064
Streamflow Reduction (mm)
3
2
1
0
-1
-2
-3
-4
-6
-4
-2
0
2
4
6
8
Evaporative Demand (mm)

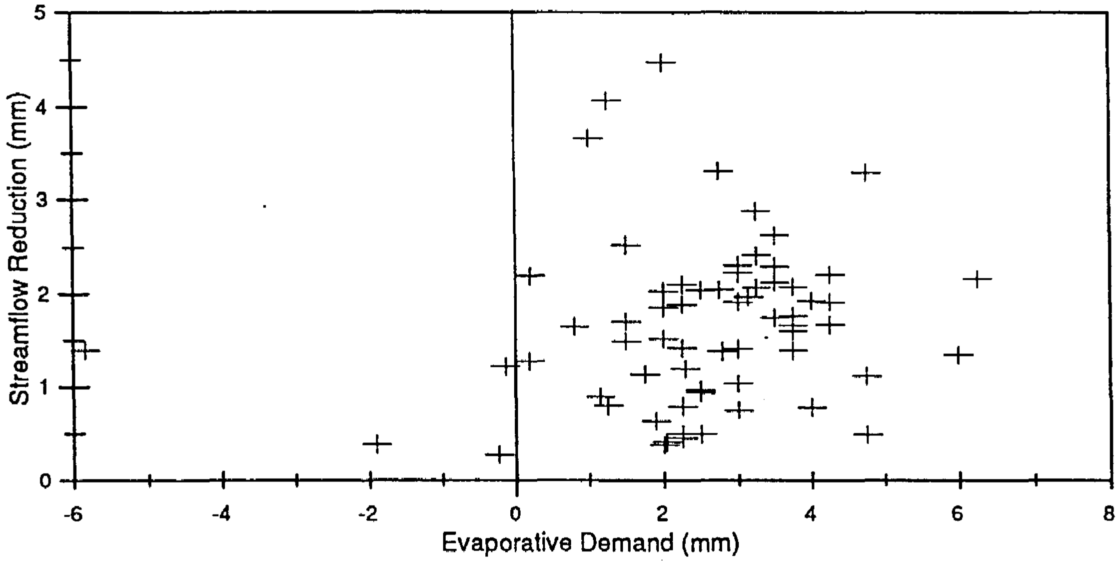
May and June

Coefficient - positive 0.029



July, August and September

Coefficient - positive 0.150



APPENDIX 9

Channel Cross-Section Surveys

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 10

Grass Types and Amounts of Seed Sown in Cleared Area

Grass seeds sown on Saturday 16 March 1996.

Eragrostis Curvula (6kg)
Variety - Ermelo
Code 5519
Germination % 70-79

Cynodon (6kg)
Variety - Kweek
Code 5510
Germination % 80-89

Panicum Maximum (C) (9kg)
Variety - Cutter
Code 5433
Germination % 20-29

Chloris Gayana (C) (9kg) (Rhodes Grass)
Variety - Katambora
Code 05059
Germination % 20-29

Digitaria Eriantha (C) (9kg) (Smuts)
Variety - Irene
Code 5517
Germination % 20-29

Cenchrus Ciliaris (C) (3kg) (Bloubuffel)
Variety - Molopo
Code 05395
Germination % 20-29