EVALUATING THE ENVIRONMENTAL USE OF WATER – SELECTED CASE STUDIES IN THE EASTERN AND SOUTHERN CAPE

REPORT TO THE WATER RESEARCH COMMISSION

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EXECUTIVE SUMMARY

1.1 BACKGROUND TO AND MOTIVATION FOR THE PROJECT

South Africa is a drought-prone, water-poor region (Burgers, Marais & Bekker 1995:101). It has a mean annual rainfall of only 502mm and a mean annual runoff of only 42mm (420m^3/ha/a) and for these reasons it seems very probable that water shortages will limit economic development in South Africa during the Twenty-first century (Briers & Powell 1993:1). Consequently, it is imperative that its water supplies be managed efficiently.

The bulk of these supplies are generated in its mountain catchments. They cover approximately 10% of its surface area but yield in excess of 50% of the total annual water runoff. One of the things that undermine this yield is the invasion of them by alien woody spp., most notably, *Acacias*, *Pinus* and *Hakea* spp. These trees have a much higher standing biomass than the indigenous vegetation they replace and consequently use much more water and decrease streamflows. These decreases have negative economic consequences: increasing water prices for urban and agricultural use and reducing recreational services yielded by rivers, particularly in estuaries. Invasions by alien tree spp. also give rise to other negative effects: drastic changes of natural community structures, a reduction in spp. diversity, crowding out of agricultural activities based on indigenous vegetation, increased fire intensities and, in some cases, increased damage during floods. Evidence of the negative effects of alien tree invasion in mountain catchments has been accumulating steadily during the last 25 years. Over 20 years ago Bosch and

Hewlett (1982) found in a study of 94 catchments that alien invaded areas yielded 3 000 m^3 per annum less water per hectare than indigenous covered areas, where alien invasion was in excess of 75%. Official recognition that this problem was serious took place in 1996, when the Working for Water (WfW) Programme was born.

The WfW Programme is a management strategy which entails the removal of water-consuming alien vegetation and restoring of low water-consuming indigenous vegetation. The economic case for it in selected mountain catchments in the Western Cape was made by van Wilgen, Le Maitre & Cowling (1998) and Marais (1998). Our study, by way of contrast, explores the economic case for it in selected mountain catchments in the Eastern and Southern Cape.

1.2 RESEARCH OBJECTIVE

More specifically, our study explores the economic rationale underlying the WfW Programme on six selected project sites in the Eastern and Southern Cape. The six project sites are those of the Tsitsikamma, Kouga, Port Elizabeth Driftsands, Albany, Kat River, and Pott River. These sites harbour a great diversity of plant spp., most notably, fynbos spp. and grasses, but they also have been invaded by alien trees such as *Pinus*, *Hakea* and *Acacia* spp.

The relevance and importance of these catchments should be seen against the background of a growing scarcity of water in the Eastern Cape. The availability of water resources is one of the key problems facing the province.

Longevity projections for all the Eastern Cape's water supply schemes were made by the DWAF in a document entitled "Eastern Cape Water Resources Situation Assessment" prepared by Ninham Shand in 1997. In terms of their analysis the Amatola and Western Region Districts face the most severe crises. The annual runoff per square kilometre is significantly lower in these districts than those of the Drakensberg, Wild Coast and Kei Districts (DWAF 1999). The Stormsberg District, although it has a low runoff (DWAF 1999), is not facing a water crisis because supplies from the Orange River Scheme and boreholes are sufficient to meet the limited current urban and agricultural demand (DWAF 1999).

The Tsitsikamma catchment provides freshwater inflows into the Keurbooms Estuary, inter alia. A reduction in these flows could lead to estuary mouth closure and hence a substantial reduction of environmental services provided by the estuary. A second objective of this report was to value the freshwater inflow benefit to this estuary in order to provide policy makers with insights into the scale of economic tradeoffs resulting from reduced freshwater supplies to this estuary.

1.3 METHODOLOGICAL APPROACH TO THE STUDY

This study is a cost-benefit analysis of catchment management, as carried out by the WfW Programme, on the selected sites mentioned above. It entails the identification and estimation of the social costs and social benefits of the water resource conservation projects on these sites and the comparison thereof with those expected costs and benefits without the projects in question. Selected non-water benefits were also estimated and incorporated in the analysis. Costs and benefits were classified into primary and secondary ones. Primary costs are all financial in nature and included those for equipment, herbicides, protective clothing, wages and salaries, transport, contracts and running expenses. The only secondary cost identified was a reduction in the availability of alien tree spp. as a source of firewood.

The primary benefit of the programme is the increased water yield due to the clearing of alien vegetation. Secondary benefits include, training of workers and social upliftment, conservation of biodiversity, improvements in water quality, downstream industry development, flood control and the prevention of soil erosion, fire hazard reduction and soil erosion, increased livestock holding capacity and improved river system services. Of these only increased livestock holding capacity was included in the analysis.

A distinct cost benefit profile was generated for each site. From these profiles net benefits were calculated and discounted to present values for the purposes of establishing a standard of comparison. A social discount rate of 10,1% was employed to derive present values. This rate was derived as the weighted average annual (years 1996 - 2000) opportunity cost rate on government and foreign funding of the WfW Programme in South Africa. Three investment criteria, namely the internal rate of return (IRR), the net present value (NPV) and the benefit cost ratio (BCR) were generated.

The contingent valuation method was used to value the water benefit of the Keurbooms Estuary. This method entailed asking respondents how much they were willing to pay to prevent the loss of environmental services provided by the estuary due to reduced freshwater inflows.

1.4 SUMMARY OF RESULTS OF THE STUDY

The cost benefit analysis results are shown in the table below.

Summary of cost benefit analysis results

Project	CBA criteria		
	NPV (R)	**IRR (%)**	**BCR**
Tsitsikamma (agricultural water value)	-31 757 404	5,00	0,54
(esturine water value)	-55 492 203	1,20	0,20
Kouga	-33 854 196	7,25	0,75
Port Elizabeth Driftsands	-14 674 240	0	0
Albany	-15 232 753	1,13	0,21
Kat River	-1 031 609	3,60	0,43
Pott River	-1 446 624	-3,14	0,03

For all the WfW project sites assessed in this study (at a social discount rate of 10,1%) the NPVs are less than zero, the BCRs are less than one and the IRRs are less than the social discount rate. In the case of the Tsitsikamma project, when the water benefit was valued at willingness to pay for estuarine freshwater, the NPV is less than zero, the BCR less than one and the IRR less than the social discount rate. A composite project, defined as the sum of all of the above six projects, also yielded unfavourable results. For the composite project the NPV is -R97 996 826 and the BCR is 0,59.

The contingent valuation method was used to value the services yielded to recreation users through freshwater inflows into the Keurbooms Estuary.

Through this valuation it was concluded that the freshwater inflow had a value of R0,046/m^3/a.

1.5 CONCLUSIONS DRAWN FROM THE STUDY

The study concludes that the catchment management carried out under the WfW Programme on the Tsitsikamma, Kouga, Port Elizabeth Driftsands, Albany, Kat River and Pott River sites is inefficient in terms of what benefits could be valued. This conclusion is subject to three qualifications. The first is that more work remains to be done on the evaluation of the non-water benefits. Known non-water benefits, like fire damage reduction and preservation of biodiversity were not included in the calculations. The second qualification is that at lower discount rates, for instance 5%, the Kouga project is efficient. Our analysis was criticised for using too high a discount rate. The third qualification is that if 30% cost savings could be achieved (and project managers believe it could), and a discount rate of 5% was employed, that both the projects at the Tsitsikamma and Kouga sites would be efficient. These two projects are being run in catchments which serve areas where high consumptive demand exist.

Based on the results of this report it is recommended that the managers of the WfW Programme focus their future activities in areas where a high demand for water for consumptive use exists. This will ensure a high value for the water benefit and improve the economic rationale for the Programme.

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GLOSSARY OF SELECTED ECONOMIC TERMS

Marginal cost (MC):	The approximate cost of one additional unit of output.
Average cost (AC):	Total cost divided by the number of units produced.
Market price:	A price established as a result of the interaction of demand and supply in the market place.
Proxy:	A best indirect estimate of value (not determined in the market place).
Reference value:	The cost per unit of bringing additional water to urban areas.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

South Africa is an arid country (Burgers, Marais, & Bekker 1995). The mean annual rainfall is 502 mm and the mean annual runoff is 42 mm. As a result of possible water shortages future development in South Africa may be increasingly limited (Briers & Powell 1993). For this reason the management of South Africa's water resources is a critical development issue in the country. Mountain catchment areas, which comprise 10% of the land surface area yet yield over 50% of the country's water, are resources that require sensitive management. Many catchment areas are invaded by alien plants and trees. These constitute a threat to the healthy functioning of river and estuary systems.

Alien-tree infestations in riparian zones lead to decreased streamflows. These trees have a much higher standing biomass than the indigenous vegetation they replace and consequently use much more water. Studies into the effect of afforestation show that river flows are often drastically reduced, sometimes by as much as 100% (the streams dry up completely). Invasion of the riparian zone can account for up to 40% of the total reduction in runoff (Smith & Scott 1992).

Alien infestations, coupled with ever-increasing human demand for freshwater, also pose a serious threat to the functioning and structure of estuary systems – the future conservation status of many estuaries around the South African coastline is heavily dependent on adequate freshwater inflows. An example of an estuary that is currently under threat due to alien tree invasion and human abstraction of fresh water is the Keurbooms Estuary, situated near the town of Plettenberg Bay in the Southern Cape. Insufficient freshwater supplies flowing into this estuary will lead to mouth closure with the subsequent loss of environmental services provided by it. The same can be said for several other estuaries reliant on rivers draining the Tsitsikamma Mountains, e.g. the Kromme River estuary.

The removal of high water-consuming alien vegetation and restoring of low water-consuming indigenous vegetation is a water resource management strategy which is receiving much attention in South Africa. The Working for Water (WfW) Programme, as this management strategy is known, is the biggest conservation project in terms of manpower use currently being undertaken in South Africa. Over 250 projects have been implemented in South Africa since its inception in October 1995 (Budget speech 1999). During 1998 about 40 000 jobs were created in it. Currently 23 998 people are employed by the programme (DWAF 2001).

The economic case for the WfW Programme in selected mountain catchments in the Western Cape has been presented by Van Wilgen et al. (1998). They have shown, through modelling exercises in the Western Cape, that this type of management strategy has the potential to prevent large water supply decreases and is efficient. Marais (1998) also provided an economic evaluation of invasive alien plant control programmes in the mountain catchment areas of the Western Cape Province which showed the desirability of such programmes.

The purpose of this study is twofold. First, to explore the economic rationale underlying the programme for selected project sites in the Eastern and Southern Cape. Second, to value the water benefit to an estuary in order to provide policy makers with insights into the scale of economic trade offs resulting from reduced fresh water supplies to estuaries. The approach taken (to achieve the first goal) is to identify and quantify (where possible) the social benefits and social costs that arise with the implementation of the WfW Programme on selected sites in the Eastern and Southern Cape (the project case), and compare them with those predicted to exist without the programme (the base case). The difference between the two cases is the incremental net benefit due to the programme on each site. The second objective is achieved by applying the contingent valuation method to value the benefit to the users of a Southern Cape estuary, the Keurbooms, of freshwater inflows.

1.2 OBJECTIVES OF THE STUDY

The objectives of this study are to:

- Provide a description of the nature, extent and distribution of alien plants and trees on the selected sites in the Eastern and Southern Cape.
- Estimate the water use by alien plants and trees.
- Determine the environmental services provided by the Keurbooms Estuary.
- Classify the social costs and social benefits related to the WfW Programme on selected sites in the Eastern and Southern Cape.
- Value the benefits.
- Value the freshwater inflow into the Keurbooms Estuary.

- Carry out cost benefit analyses on six sites of the WfW Programme in the Eastern and Southern Cape.
- Provide conclusions and recommendations based on the results of the abovementioned analyses.

1.3 HISTORY AND OBJECTIVES (PRIMARY AND SECONDARY) OF THE WORKING FOR WATER PROGRAMME IN SOUTH AFRICA

1.3.1 HISTORY OF THE WORKING FOR WATER PROGRAMME IN SOUTH AFRICA

Alien plant clearing programmes were first initiated in South Africa in the early 1970s (Van Wilgen et al. 1998). These programmes were small in scale but yielded positive results - ecosystem services were preserved and cost-benefit analysis showed the clearing to be efficient and jobs were created (Van Wilgen et al. 1998). These results were brought to the attention of the Minister of Water Affairs and Forestry, Kader Asmal. He was impressed and the WfW Programme was born.

The WfW Programme was formally initiated in September 1995, with a grant of R25 million from the Government's Reconstruction and Development Programme. The funding to clear invading alien plants was motivated by Kader Asmal on account of three principal benefits: the enhanced runoff of water, the benefits for biological diversity and ecological functioning, and the social benefits of a labour intensive clearing programme. Over 250 projects have been implemented in South Africa since the Programme's inception in October 1995.

(a) The period 1 October 1995 to 31 March 1996

From the inception of the WfW Programme on 1 October 1995 up to 31 March 1996 an area in excess of 33 000 hectares was cleared of alien plants and trees. Indications were that this action increased the runoff to rivers by up to 3 500 m^3/ha/a in areas which were previously densely infested. A total of 6 686 direct job opportunities were created for South Africans. Indirect job opportunities were also created via assistance services provided to the WfW Programme. More than half (55%) of the people who were employed were women (DWAF 1996).

(b) The period 1 April 1996 to 31 March 1997

From 1 April 1996 to 31 March 1997 approximately 71 000 hectares were cleared from alien plants and trees. Follow-up operations were carried out on 12 000 hectares. The number of new jobs created during this period amounted to 8 386 of which 4 483 (53%) were women (DWAF 1997).

(c) The period 1 April 1997 to 31 March 1998

From 1 April 1997 to 31 March 1998 an area in excess of 220 000 hectares was cleared from alien invasives. Follow-up operations were carried out on 55 731 hectares. The number of new jobs created during this period amounted to 42 059, of which 55% were for women (DWAF 1998).

(d) The period 1 April 1998 to 31 March 1999

From 1 April 1998 to 31 March 1999 an area of 107 565 invaded hectares was cleared and 128 648 hectares of follow-up work was done. About 23 662 jobs were created during this period, of which 54% were for women, 16% were for youths (16 - 25 years) and 1% were for disabled people (DWAF 1999a).

1.3.2 THE GOALS OF THE WORKING FOR WATER PROGRAMME

The goal of the National WfW Programme is “to bring invading alien plants under control in South Africa within 20 years, in a way that both contributes to the potential use of natural resources and maximises the reconstruction and development benefits that are possible from such a labour intensive environmental programme” (DWAF 1999a).

The primary and secondary objectives that flow from this goal are as follows:

(a) Primary objectives

- To enhance water security through regaining control over invasive alien plants in South Africa.
- To restore agricultural capacity and security.
- To improve the ecological integrity of our natural systems through the removal of these plants.
- To maximise the social benefits that are possible as a community based public works programme
- To develop the economic benefits (land, water, wood and trained people) from clearing these plants.
- To demonstrate that partnerships can work across line-functions with a wide spectrum of interests (DWAF 1999a).

(b) Secondary objectives

- To promote the quest for equity, efficiency and sustainability in the supply and use of water.
- To derive the physical benefits of the removal of invading plants.
- To promote the appropriate use of land that is cleared of invading alien plants.
- To protect and restore biological diversity by reducing the competition by invading alien plants.
- To assist in the government's drive to eliminate poverty.
- To invest in the most marginalised sectors in South African society.
- To support the Masakhane Campaign actively and effectively.
- To develop secondary industries and resource beneficiation for long term of economic growth.
- To empower non-governmental organisations, tertiary institutions and other deserving partners.
- To empower democratic structures in the implementation of the programme.
- To promote regional and international practices that further the WfW Programme (DWAF 1999a).

(c) The proposed 20 year clearing strategy

The WfW Programme is aiming to implement a 20 year strategy whereby 750 000 hectares, covered by alien invasives, will be cleared annually at a cost of approximately R600 million per annum. It is anticipated that this strategy will provide the following benefits:

- the creation of more than 50 000 direct job opportunities;
- the prevention of a loss of more than 4 000 million m^3 of water from the hydrological cycle annually;
- intensive (for crops and grazing) and extensive (for wild flowers) use of more than one million hectares of land after 20 years;
- the use of more than one million tonnes of wood per annum (from alien trees removed for furniture, charcoal); and
- more successful fire management and control (DWAF 1998).

1.4 INVASIVE ALIEN PLANTS IN THE EASTERN AND SOUTHERN CAPE PROVINCE

1.4.1 ALIEN INVADERS IN THE EASTERN AND SOUTHERN CAPE

A number of spp. are currently considered as alien plant invaders in the Eastern Cape. Table 1.1 provides a list of the invader plant spp. recorded for the purposes of the WfW Programme.

Table 1.1: Most important invaders spp. in the Eastern and Southern Cape Province based on condensed invaded area

Species	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Acacia mearnsii	344 535	49 022	14,23
Acacia mixed spp.	36 640	20 378	55,62
Acacia dealbata	65 730	18 876	28,72
Acacia saligna	202 952	12 809	6,31
Eucalyptus spp.	163 121	9 515	5,83
Acacia cyclops	212 790	8 579	4,03
Pinus pinaster	295 346	7 283	2,47
Acacia longifolia	73 212	7 155	9,77
Solanum mauritianum	43 379	4 262	9,83
Schinus molle	82 799	2 061	2,49
Hakea sericea	14 760	1 927	13,06
Opuntia ficus-indica	47 374	1 885	3,98
Pinus spp.	14 112	1 317	9,33
Lantana camara	2 297[1]	1 156	50,32
Acacia melanoxylon	22 151	963	4,35

Source: Versveld, Le Maitre & Chapman (1998).

[1] Possible under-estimation – large coastal areas of the former Transkei are covered with this spp. It is difficult to identify these trees from aerial photographs (Buckle, pers. comm. 2001).

Due to the fact that only a few spp. are dominant in the WfW Programme sites in the Eastern and Southern Cape only these spp. will be discussed in detail. They are discussed below, grouped by genus.

(a) *Pinus* spp.

Pinus pinaster originates from Europe and Asia (the Mediterranean basin) whereas *Pinus radiata* originates from North America (California). The reasons for their introduction include timber, poles, firewood, ornamental, and shade. These trees cover 3 million hectares of South Africa. They are widespread in mountain catchments, forest fringes, grasslands and fynbos. *Pinus* spp. are well-adapted to fire, have a low seed load and their juvenile term is short (Marais 1998). Their seeds are dispersed over long distances by the wind.

(b) *Acacia* spp.

All *Acacia* spp. originate from Australia. *Acacia mearnsii* (Black Wattle) which is valued for its timber and tannin was introduced into South Africa during the second half of the 1800s (Richarson et al. 1992). Other uses of Black Wattle include shelter, shade, firewood and pulp, building material, droppers and poles. It covers 2,5 million hectares of South Africa. Its coverage is densest in riparian zones. It is not, however, found in arid areas (Briers & Powel 1993). An endemic fungus which causes woodrot after clearfelling has been identified as a method of biological control of Black Wattle (Marais 1998). Resprouting does occur after clearfelling, but dies back after 3 to 4 months due to the woodrot if the fungus is applied manually to the cut stump surface. Mechanical clearing, however, is still deemed necessary in the overall control operations. Another biological control agent (seed eating snout beetle) has been introduced on black wattle to attack the green pods on the trees in order to reduce future seed spread.

Acacia saligna (Port Jackson) was introduced into South Africa during the first half of the 1800s. The reasons for its introduction include dune reclamation, shelter, tanbark, fodder and firewood (Richardson, Macdonald, Holmes & Cowling 1992). As with Black Wattle, Port Jackson occurs mostly in riparian zones (Richardson et al. 1992). There is also very effective biological control available for Port Jackson (rust fungus) that eventually kills the trees. The biological control is so effective that very little clearing work on this spp. will be necessary in future.

Acacia cyclops (Rooikrans) was introduced into South Africa during the late 1800s. The reasons for its introduction include dune reclamation, shelter and firewood. Rooikrans occurs mostly along the coast of South Africa and therefore only constitutes a problem in mountain ranges situated in coastal areas. A seed eating snout beetle has also proved effective in reducing its seed load.

Acacia longifolia (Longleafed Wattle) was introduced into South Africa during the early 1800s for horticultural purposes but was also utilised for dune stabilisation (Marais 1998). Seed production is minimum due to a gaul forming wasp that attacks the flower. This attack has effectively controlled its spread over the last ten years.

Acacia melanoxylon (Blackwood) was introduced into South Africa in 1848. The reasons for its introduction include horticultural purposes and timber. It occurs mostly in the riparian zones of a number of rivers, especially in the Southern Cape near the indigenous forests (Marais 1998). It is also a big problem in the Afro Mantane forest of the Eastern Cape in areas like Tsitsikamma coast, Katberg, Hogsback, Pirrie Forest and Kubusi Forest.

(c) *Hakea* spp.

Hakea sericea (silky *Hakea*) is thought to have been introduced to South Africa in 1833 (Fugler 1983). *Hakea* spp. originate from Australia. The reasons for the introduction of *Hakea* into South Africa include shelter, dune reclamation, hedging and firewood (Fugler 1983). It occurs in 0,7 million hectares of mountain and lowland fynbos. It is a problem in the Eastern Cape in the Tsitsikamma mountains, Suuranyo, Kouga mountains and in the Governers Kop area outside Grahamstown.

(d) *Eucalyptus* spp.

Eucalyptus spp. originate from Australia and were introduced into South Africa during the 1800s (Wells, Balsinhas, Joffe, Engelbrecht, Harding & Stirton 1986). They are successful invaders of the riparian zones. The spp. were most likely introduced for use in furniture, firewood, and poles (Marais 1998).

(e) *Populus* spp.

Populus canescens (Grey Poplar) is the only *Populus* spp. at this stage that could pose an invasive threat (Marais 1998). *Populus* spp. originate from

Europe and was introduced into South Africa before 1903 for its value as matchwood and furniture. They mostly invade riparian zones and the ecotones of forest patches.

1.4.2 CHARACTERISTICS OF ALIEN INVADERS

Alien plants meet most of the criteria listed below, which enable them to become aggressive invaders.

(i) Successful alien invader plants originate from areas with similar climate, and similar soils, and are well adapted to grow in their new environment.

(ii) These plants come from areas with similar ecology, for example, areas prone to fire, and are thus well adapted to fire.

(iii) These plants possess the ability to produce a large number of viable seed, and the ability to grow fast and quickly reach a mature age.

(iv) They have seeds that can be easily spread by wind, birds or water.

(v) In some cases these plants have no natural enemies (for example, *Pinus* spp.) (Richardson 1989).

1.5 SITE SELECTION AND STUDY AREAS

1.5.1 WORKING FOR WATER PROGRAMME SITES IN THE EASTERN AND SOUTHERN CAPE

In 1999 there were 21 sites in the Eastern Cape where the clearing of alien invaders was taking place. One more site was added to the list for the purposes of this study, namely the Tsitsikamma site. The latter site did not fall under the control of the Eastern Cape branch of the WfW Programme, but was included on the grounds that this catchment constitutes an important future water supply source for the Eastern Cape. This site is situated in the Southern Cape. A future bulk water supply option for the Algoa Bay region, specifically, is to capture water runoff on the seaward side of the Tsitsikamma Mountain and pipe it to the Kouga/Krom water supply system.[2] It is estimated that this can be done at a cost of 57 cents/m^3 of water (1996 price levels) and that this scheme could produce up to 10 million m^3 of water per annum.

The sites of existing WfW Programmes in the Eastern Cape, including the Tsitsikamma site, are listed in Table 1.2 below.

Table 1.2: WfW Programmes in the Eastern and Southern Cape

PROJECTS	ESTIMATED PERCENTAGE OF INVADING ALIEN PLANT COVER	INDIGENOUS GROUND COVER	TYPES OF ALIEN VEGETATION PRESENT
Kat River	1,1-5,0	Grasslands	Variety of *Acacia* spp. and *Eucalyptus* spp. and *Pinus* spp.
Buffalo River	10,1-20,0	Forest & Riparian forest	Black Wattle and Seringa
Dwesa / Cwebe	0,1.-1,0	Forest	Bugweed, Guava, *Lantana* and Ink berry
Engcobo	0% / No data	Grasslands	Black and Silver Wattle spp.
Hogsback	1,1-5,0	Indigenous Forest	Variety of *Acacia* spp. and *Pinus* spp.
Jozannas Hoek	0% / No data	Grasslands	None
Kabeljous and Seekoei Rivers	1,1-5,0	Fynbos, Wetland	Black Wattle and Pines
Kei Mouth	0,1-1,0	Grasveld & Bush	Ink berry, Black Wattle, Pines and *Lantana*

2 Currently this is not the preferred option due to high cost of pumping the water. The preferred option by DWAF is to build a second reservoir dam in the Kouga River.

PROJECTS	ESTIMATED PERCENTAGE OF INVADING ALIEN PLANT COVER	INDIGENOUS GROUND COVER	TYPES OF ALIEN VEGETATION PRESENT
Kokstad	1,1-5,0	Grasslands	Black and Silver Wattle
Kouga	5,1-10,0	Fynbos	Black Wattle, Pines and *Hakea*
Matatiele	1,1-5,0	Grassland	Black and Silver Wattle
Mbidlana	0,1-1,0	Grassland	Black and Silver Wattle
Mt Ayliff	1,1-5,0	Grassland	Black and Silver Wattle
Port Elizabeth (Driftsands)	5,1-10,0	Coastal fynbos	*A. cyclops, A. mearnsii, A. longifolia, A. saligna, Eucalyptus* spp.
Pott River	0,1-1,0	Grasslands	Black and Silver Wattle, Crack Willow
Swartkops	1,1-5	Mountain fynbos	Black Wattle, Pines and *Eucalyptus* spp.
Xuka Drift	1,1-5	Grasslands	Black and Silver Wattle
Albany	5,1-10	Grassy fynbos & Valley	Variety of *Acacia*, *Hakea*, *Eucalyptus* spp., *Pinus pinaster*
Albany Coast	5,1-10	Coastal Bushveld	*A. cyclops* and Beefwood
Amatola	10,1-20	Grassland	Variety of *Acacia* spp.
Keiskammahoek	1,1-5	Grassland & Forest	Variety of *Acacia* spp. and Pines
Tsitsikamma	10,1-20	Fynbos (Wet)	Black Wattle, Pines and *Hakea*

1.5.2 SITE SELECTION

Site selection was made by the Department of Economics and Economic History in conjunction with Japie Buckle, former project leader of the WfW Programme in the Eastern Cape (now the technical adviser for this region), and the Water Research Commission. It was made with a view to obtaining a sample of sites that represented the diversity of areas in the Eastern and

Southern Cape, in which WfW projects are being run, with special reference to topography, indigenous and alien vegetation present.

Six sites were selected, namely Tsitsikamma, Kouga, Port Elizabeth Driftsands, Albany, Kat River and Pott River (see Figure 1.1). The areas being cleared at these sites are indicated in more detail in Figures 1.2 to 1.6.

(i) Tsitsikamma area

This area also falls within a catchment area, namely the southern slopes of the Tsitsikamma mountains. The estimated percentage of alien cover present is between 10,1 and 20,0%. Wet mountain fynbos is the indigenous ground cover found in this area, but like the Kouga (much drier) site, it is invaded by Black Wattle and Pines spp. This area also forms part of the catchment area of the Keurbooms River. The Keurbooms Estuary in the Plettenberg Bay area is heavily used for recreation and is ranked sixteenth in conservation importance of all estuaries in South Africa (Turpie 2000). The specific features of this estuary are discussed at the end of this chapter.

(ii) Kouga area

The Kouga site falls within a large catchment area including the northern slopes of the Tsitsikamma mountains and the Southern slopes of the Kouga mountains. It drains into the Kouga and Kromme Rivers. The area has scattered infestations ranging in density between 5,1 and 10,0%. The indigenous ground cover is Mesic mountain fynbos, but the area is invaded with Black Wattle, Pine spp, Poplar spp. and *Hakea*.

(iii) Port Elizabeth Driftsands

This area is situated in and around the town of Port Elizabeth and on coastal dunes. The estimated percentage of invading alien plant cover present is 5,1-10,0%. The indigenous ground cover in this area is coastal fynbos. The area is invaded with the following alien spp., *Acacia cyclops*, *Acacia longifolius*, *Acacia saligna*, and *Euacalyptus* spp.

The Port Elizabeth Drifsands area is different to the other sites chosen for this study due to the fact that it is not a catchment area or watershed. The alien spp. have only an effect on the water supply in terms of the water table situated in this area. By cutting back alien vegetation water supply is increased to the underlying aquifer – possibly as a future water resource for the Port Elizabeth metropole. There are no rivers that drain this Driftsands area. All the rainwater that infiltrates the dunes goes either to the aquifer or comes out at a lower point, next to the coastline as fountains (freshwater).

(iv) Albany

The Albany area is situated in the Valley Bushveld area in the upper catchment of the Kowie and Kariega Rivers. The alien plant cover in this area, expressed as an estimated percentage, is 5,1-10,0%. The indigenous ground cover is fynbos (on the Table mountain sandstone ridges), grassland and Valley Bushveld. The types of alien vegetation present are *Acacia* spp., *Hakea* spp. and *Eucalyptus* spp.

(v) Kat River

The Kat River site forms part of the Amatola escarpment. It is a mountain catchment area for the Kat River. The Hogsback and Buffalo River sites which also form part of the Amatola Escarpment are very similar to the Kat River site. The estimated percentage of invading alien plant cover is 1,1 - 5,0%. The indigenous vegetation present are forests with grassland. A variety of Wattle spp. and Pine spp. are found on this site.

(vi) Pott River

The Pott River site is situated in the high lying grass areas of the foothills of the Eastern Cape Drakensberg. This is classified as a mountain catchment area (Buckle pers. comm. 1999). The estimated percentage of invading alien plant cover is 0,1-1,0%. The indigenous cover is mainly grassveld. The following types of alien vegetation are present: Black and Silver Wattle, Crack Willow, and *Populus* spp.

Figure 1.1 Location of the six WfW Programme projects used in this study. Red areas are those that had been cleared in the Programme by end 2001

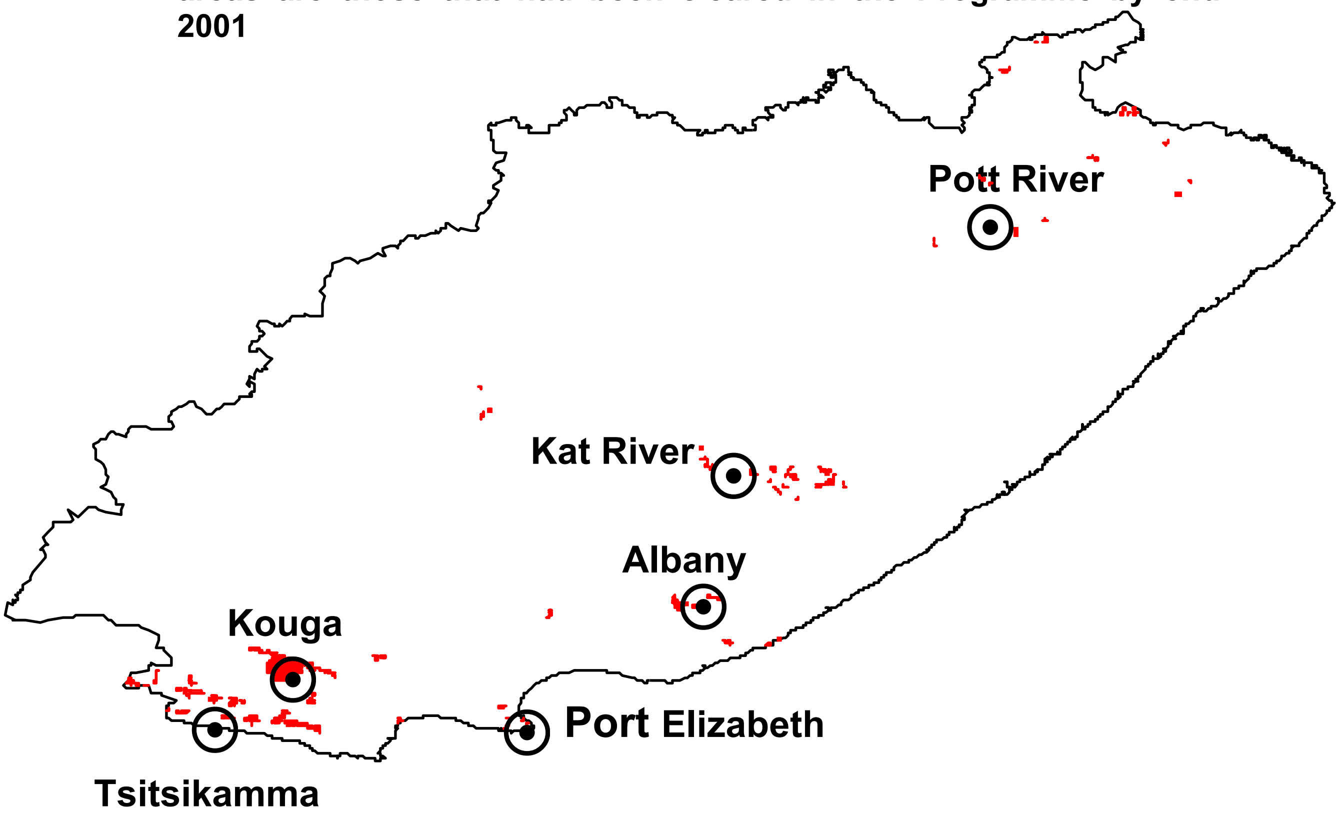


Figure 1.2 **The Tsitsikamma WfW Programme site. Red areas are those that had been cleared in the Programme by end 2001. The Department of Water Affairs provided the data shown here. The data is of variable reliability and has not been verified nor checked for accuracy**

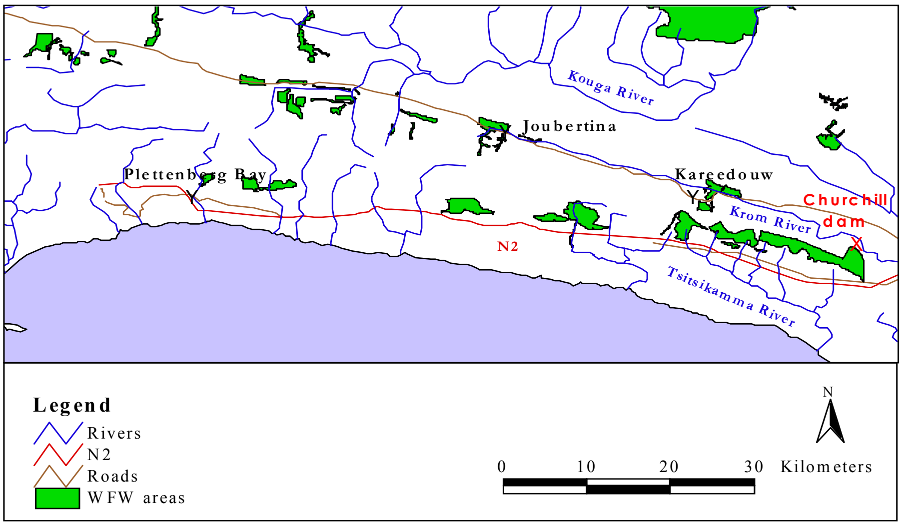


Figure 1.3 **The Kouga WfW Programme site. Red areas are those that had been cleared in the Programme by end 2001. The Department of Water Affairs provided the data shown here. The data is of variable reliability and has not been verified nor checked for accuracy**

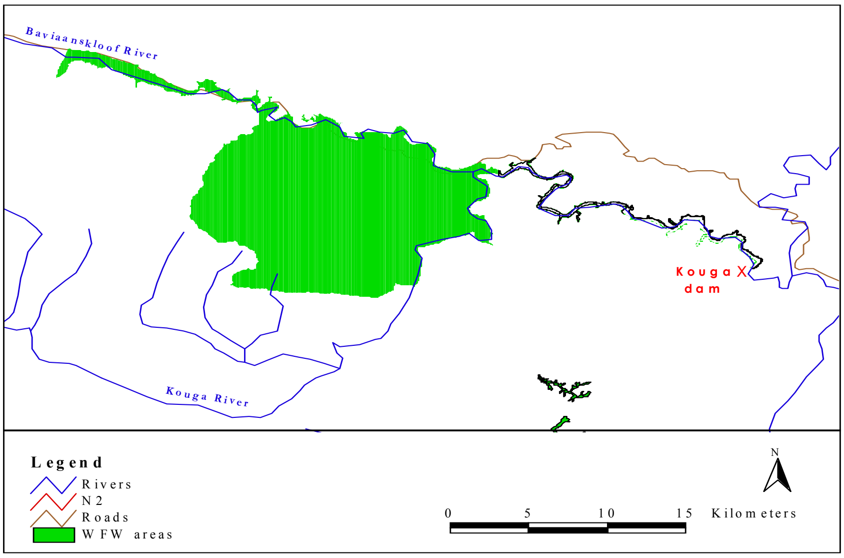


Figure 1.4 The Port Elizabeth Driftsands WfW Programme site. Red areas are those that had been cleared in the Programme by end 2001. The Department of Water Affairs provided the data shown here. The data is of variable reliability and has not been verified nor checked for accuracy

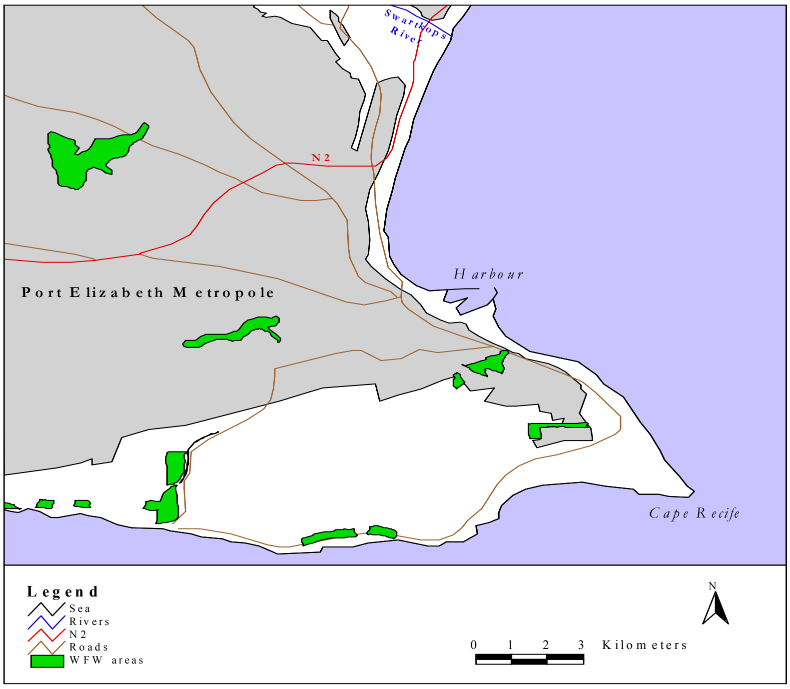


Figure 1.5 The Albany WfW Programme site. Red areas are those that had been cleared in the Programme by end 2001. The Department of Water Affairs provided the data shown here. The data is of variable reliability and has not been verified nor checked for accuracy

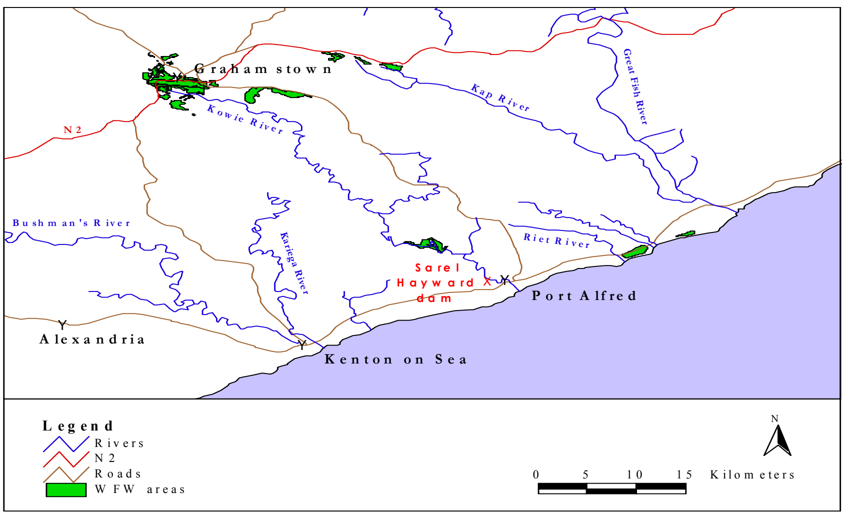


Figure 1.6 The Kat River WfW Programme site. Red areas are those that had been cleared in the Programme by end 2001. The Department of Water Affairs provided the data shown here. The data is of variable reliability and has not been verified nor checked for accuracy

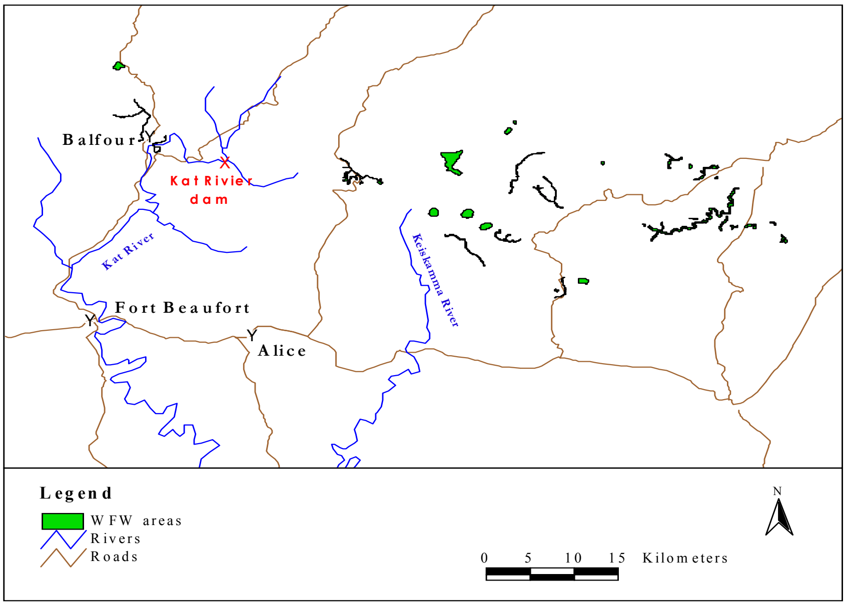
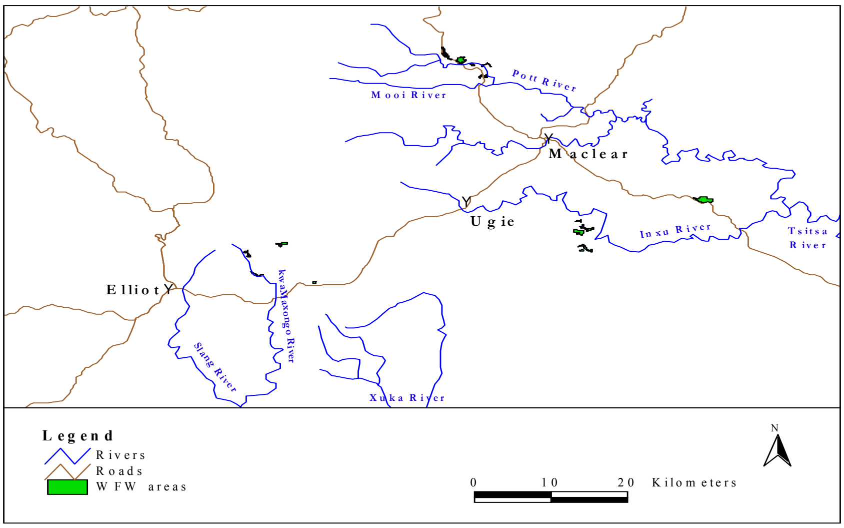


Figure 1.7 The Pott River WfW Programme site. Red areas are those that had been cleared in the Programme by end 2001. The Department of Water Affairs provided the data shown here. The data is of variable reliability and has not been verified nor checked for accuracy



1.5.3 TOPOGRAPHY AND GEOLOGY IN THE SELECTED PROJECT AREAS

The topography and geology of the WfW Programme project sites in the Eastern and Southern Cape have an effect on the quality of ecosystem services provided in these areas. In the mountain catchments (except the Port Elizabeth Driftsands area) chosen for this study the geology is dominated by sandstones and quartsites of the Table Mountain Group formations. Shale belts are commonly found in these landscapes (Marais 1998). They are narrow, less rocky strips sandwiched between the sandstones and possess a higher nutrient content than the rest of the landscape.

(i) Tsitsikamma area

Two subsections are identifiable within this area; a mountainous area and a coastal plain. The coastal plain in the Tsitsikamma area is wide in places. Further inland, the Uitenhage Group outcrop lies on either side of Plettenberg Bay and comprises of gently rolling hills. The hills increase in size towards the rugged Cape Fold Mountains, which run parallel to the coastline. The elevations range from sea level to 1 618 m. The major soil types found in this area include those derived from sandstone and shale. The soil in the upper reaches of the catchment is predominantly acidic, poor in nutrients and shallow. By contrast the soil type found in the lower reaches of the catchment and the plateau is less acidic, higher in nutrient content and deeper (Spies pers. comm. 1999).

(ii) Kouga area

The topography in this area is composed of a series of parallel mountain ranges rising step-wise to an altitude of about 1 500 m. A valley, namely the

Langkloof valley, lies between these mountain ranges. These mountains form part of the Cape Fold system, and the parent rock is Table Mountain Group sandstone. The soils in this area are derived from quartzitic sandstone and shale and are shallow and poorly developed (Buckle pers. comm. 1999).

(iii) Port Elizabeth Driftsands area

This area comprises of a coastal dune system and two river valleys, namely the Baakens and the Papenkuils. In the dune system the predominant soil type is sandy soil. Alluvial clays are found in the valleys (Marsh pers. comm. 1999).

(iv) Albany site

The topography in the Albany area can be described as mountainous (of the Cape Fold variety) with exposed rocky outcrops. Rolling hills are found closer to the coast. The following soil types are found in this area: Mispah, Westleigh, Longland, Kroonstad and Katspruit. Soils derived from quartzitic sandstone and shale are also found, but are generally sandy, shallow and poor in organic matter.

(v) Kat River area

The topography of the Kat River catchment can be described as mountainous (of the Cape Fold variety). The soils in this area are derived from weathered sandstone, shale and dolorite.

(vi) Pott River area

The topography of the Pott River catchment can be described as mountainous (of the Cape Fold variety). The soils in this area are derived from weathered sandstone, shale and dolorite.

1.5.4 CLIMATE AND RAINFALL CONDITIONS IN THE SELECTED PROJECT AREAS

Precipitation varies significantly across the different project sites. This can be attributed partly to the topography. The coastal mountains form "rain barriers" which lead to relatively high precipitation along coastal areas and reduced rainfall figures inland.

Table 1.3 shows the mean annual precipitation for the project sites discussed in this report.

Table 1.3: Mean annual precipitation for selected project sites

Project site	S Lat	E Long	MAP (mm)
Tsitsikamma	34°01'S	23°54'E	960
Kouga	33°43'S	24°35'E	547
PE Driftsands	33°55'S	25°35'E	500
Albany	33°18'S	26°31'E	650
Kat River	32°31'S	26°40'E	950
Pott River	31°11'S	28°14'E	939

Rainfall seasonality varies among the different project sites. In the Tsitsikamma area 41,25% (calculated over a 5 year period) of the mean annual precipitation falls between April and September. In the Kouga area the western regions receive much less rainfall than the eastern regions. Between 10 and 20 thunderstorms occur annually. This catchment is positioned in an area that experiences year round rainfall, but the most rain tends to fall in autumn. The time period December to February is the driest time of the year.

In the Port Elizabeth Driftsands area 40 to 45% of the precipitation falls between April and September. Less than 30% of the annual rainfall falls between April and September in the case of the Albany area. The most rainfall occurs during February/March and October/November. June/July are the driest months in this area.

In the Kat River catchment 37% (350,6 mm) of the annual precipitation falls during winter. In the Pott River catchment between 5 and 10% of the annual precipitation falls between April and September.

1.5.5 INDIGENOUS VEGETATION FOUND IN THE SELECTED PROJECT AREAS

The indigenous vegetation varies across the different project sites. In the Tsitsikamma area wet mountain fynbos comprises 90% of the indigenous vegetation and indigenous forest 10%. In the Kouga area shrubland and mesic low fynbos and grassy fynbos (75,53%) are found in the upper reaches of the catchment, whereas patches of Thicket and Bushland (14,84%) and natural forest (0,04%) occur in the lower reaches of the catchment.

Grassy fynbos (70%) and dune thicket (30%) comprises the indigenous vegetation in the Port Elizabeth Driftsands area. The Albany area contains a mixture of indigenous vegetation: grassland (90%), grassy fynbos (5%), indigenous forest (2%) and valley bushveld (3%). The indigenous vegetation in the Kat River catchment comprises of tree fuchsia (65%), false olive (25%)

and other (10%). The natural vegetation found in the Pott River catchment comprises of “ouhout” (*Leucosidea sericea*) in mainly grassland.

1.5.6 LAND USES IN THE SELECTED PROJECT AREAS

The Tsitsikamma project area is mostly comprised of state-owned land on which nature conservation and catchment management are the main objectives. This entails the maintenance of both indigenous plant and animal communities and the protection of the landscape from erosion. A small proportion of the land in this project area is privately owned. The Tsitsikamma mountain catchment is largely unsuited to intensive agriculture. Agriculture, in the form of dairy farming on the coastal plateau and commercial afforestation carried out by the South African Forestry Company (SAFCOL), are the main land uses on the privately owned land.

The major part of the Kouga project area is comprised of privately owned farms. The land on these farms is mainly utilised for growing apple orchards, but beef cattle and sheep farming are also practiced. On the state-owned land near-pristine natural vegetation can be found. The primary objective on this land is the conservation of natural plant and animal communities.

The land falling within the Port Elizabeth Driftsands project area is owned and managed by the Nelson Mandela metropolitan authority. The project area is situated in the urban areas of the city of Port Elizabeth.

The Kat River project area is mostly comprised of state-owned forestry plantations, but privately owned farm land is also found. The main agricultural activity on the private farm land is cattle farming.

The Albany project area is comprised of privately owned land, where cattle farming is the main agricultural activity, and land owned and managed by the Grahamstown Municipality.

All the land that falls within the Pott River project area is privately owned. The main land uses are livestock farming and commercial forestry.

1.5.7 THE PRESENCE OF FIRE ON THE SELECTED PROJECT AREAS

(i) Fire frequency

According to Marais (1998) fires occur on average every 12 to 15 years in fynbos areas, whereas the average fire cycle in grassland and savanna areas is 1 to 4 years. Table 1.4 below shows the average fire cycle and the year when the last fire occurred for each of the six WfW projects chosen for this study.

Table 1.4: Average fire cycles and the year when the last fire occurred for six project sites

Project site	Indigenous ground cover	Average fire cycle (years)	Last fire
Tsitsikamma	Fynbos	12	1998
Kouga	Fynbos	12	1999
PE Driftsands	Coastal fynbos	12	1997
Albany	Grassy fynbos and valley bushveld	4	1999
Kat River	Grassland	4	1999
Pott River	Grassland	4	1999

(ii) Fire as an element of the invasion process

According to Richardson et al. (1992) most alien invader spp. are well adapted to fire. Richardson and Brown (1986) recorded the invasion by *Pinus radiata* of a fynbos catchment situated in the Jonkershoek Valley. According to this study an area adjacent to afforested land was invaded by *Pinus radiata* between 1938 and 1981. It was found that an increase in the presence of invasive plants is associated with fire. Fire stimulates the release of large quantities of seed from serotitious cones. It also leads to favourable microsites for germination and the establishment of seedlings.

Similar results to those in the 1986 study were achieved by Richardson (1989) which confirmed the close link that exists between invasion by alien plants and trees and the occurrence of fire. During this study a stand of *Pinus halipensis* at Miller's Point near Muizenburg was surveyed. Only two of the trees that make up the stand (657 trees in total) were older than the date of the previous fire in the area during 1972. In excess of 50% of the trees in the area were established within the first year following the fire, and less than 1% after 4 years. An average of 465 seedlings established per 50m^2 plot within 8 months after a fire in 1986.

1.5.8 MAJOR PROBLEMS RESULTING FROM ALIEN INVADERS IN THE SELECTED PROJECT AREAS

The major problems as listed by the respective project managers resulting from alien invaders in the six WfW Programme project sites are shown in Table 1.5 below.

Table 1.5: Problems associated with alien plant invasions

Project area	Problem			
	Loss of water yield	Erosion	Loss of biodiversity	Fire hazard
Tsitsikamma	✓	✓	✓	✓
Kouga	✓	✓	✓	✓
PE Driftsands	✓		✓	✓
Albany	✓	✓	✓	✓
Kat River	✓		✓	
Pott River	✓	✓	✓	✓

Increased soil erosion occurs as a result of increased fire damage. Loss of biodiversity occurs when alien vegetation pushes out indigenous spp. The higher biomass of aliens leads to more intense fires.

1.6 THE CONTROL OPERATIONS

The control of plant invaders entails their removal in places where they have established themselves and in those areas where infestation is at its initial stages. The areas are divided into management units, ranging in size from approximately 50 - 2 000 hectares. Objectives are set for each such unit, and records kept for all management operations. The spread of alien vegetation is controlled through concentrated efforts of initial clearing of management units and repeated follow-up procedures. Initial clearing entails the removal of alien vegetation whereas follow-up operations entail the removal of the re-growth of alien vegetation in a previously cleared area. Follow-up operations in areas that have already been cleared normally take priority in field operations because if re-growth is allowed to occur the initial investment is wasted. Two initial follow-ups are normally carried out after initial clearing, each in consecutive years. Maintenance management is conducted for 2 to 5 years thereafter. The eradication methods include manual, mechanical, chemical and biocontrol techniques. Control programmes differ depending on the spp.

present, the density of the stands and the accessibility of the management units.

1.6.1 MANUAL, MECHANICAL AND CHEMICAL CONTROL

Manual and mechanical clearing are carried out mainly using chain saws, slashers and brush cutters. Slashing invasive plants with slashers is mainly carried out in areas where the individual trees are less than 15cm diameter at breast height (DBH) (Marais 1998). Mature trees (more than 10cm DBH) are felled using a chainsaw for Pines and *Acacia* spp., and brushcutters for dense stands of *Hakea*, as well as young Pine trees and *Acacia* spp. According to Marais (1998) young plants were cut down on an experimental basis in the Stettynskloof area in the Limietberg mountain catchment in young *Hakea* (less than 5cm DBH) at densities between 25-50% using long handle pruning scissors. Chemical control of invader plants is limited by factors of cost and practicality (Seydack & Bekker 1995). Herbicides are used with stump treatment on *Acacia* spp. (and on young Black Wattle up to <6 – 8 years).[3] Follow-up operations involve the use of mattocks and spraying equipment (mainly boom and knapsack sprayers). The first follow up treatment is carried out after the first fire in a specific area or after a controlled burn (Marais 1998).

Pine spp. are felled with chainsaws and debranched, and allowed to dry out (and shed seed) for approximately one year. During late summer the area in question is burnt. Follow-up operations involve the pulling out or cutting down of seedlings using pruning scissors. Follow-up clearing of seedling growth is

[3] If the bark is still green, Black Wattle will coppice if you do not treat the stump with herbicide (Timbrel).

carried out in the second year, and every second or third year for about six years.

Hakeas are cut, allowed to dry out (and the fruits open) for 12 to 18 months (Fugler 1983). The fruit on dead plants open during this period and the winged seed are released. Seeds germinate around the fallen parent plants, but are destroyed due to the fact that the area in question is burned. Regeneration is controlled by hand-pulling the seedlings. The following herbicides, namely Roundup (± R20/ℓ) and Garlon (± R154/ℓ), have been applied to *Hakea* spp. (most notably *Hakea sericea*) but with little success (Fugler 1983). These herbicides are broad spectrum and expensive and therefore unsuitable (Fugler 1983).

Acacias are cut, stacked and later burnt. Seedling regeneration is treated either by hand-hoeing or herbicide spray, depending on the density of re-growth and the suitability of the terrain. Repeated (annual) follow-up clearing is essential for the control of seedlings. *Acacia* spp. regenerate from soil-stored seedbanks which require more intensive follow-up operations compared to *Hakea* and Pine spp. (Burgers, Marais & Bekker 1995).

A method that has been implemented the last two to three years is to kill the bigger *Acacia* trees (specially Black Wattle) standing by frilling them and treating the frilled area with herbicide. Trees smaller than DBH of 50mm are slashed, but all the trees greater than five centimeters are killed standing. The recovery of the area is much quicker doing it this way. Fire intensity has also been reduced because of less litter on the soil surface.

1.6.2 BIOLOGICAL CONTROL

According to Seydack and Bekker (1995), biological control of alien invasives will have to be used in the long-term if high and continuous control expenditures are to be avoided. The Plant Protection Research Institute has investigated and initiated biological control programmes in respect of many invader plant spp., notably *Hakea* and certain *Acacia* spp.

Success has been achieved in reducing the seed set of *Acacia longifolia* through the application of the bud-galling wasp *Trichilogaster Acacia longifoliae* (Marais 1998). The gall rust *Uromycladiun tepperiarum* largely reduced seed production of *Acacia saligna* and as a result vast areas of this spp. died (Van Wilgen, Bond & Richardson 1992).

Agents have also been introduced with considerable success on *Hakea sericea*. Two seed-attacking insects were released, namely the *Hakea* fruit weevil, *Erytenna consputa* and the *Hakea* seed moth, *Carposina autologa* (Fugler 1983). Attention has also been focused on insects that attack the vegetative parts of plants. A leaf-boring weevil, *Cydmaea binotata*, specific to *Hakea sericea* reduces growth and competitiveness of seedlings (Fugler 1983).

An endemic fungus, *Collectotrichum state of Glomerella cingulata* also attacks *Hakea sericea*. It is prevalent in many *Hakea sericea* stands and in areas in the southern and south-western Cape natural infection in excess of 90% and many dead plants have been observed (Fugler 1983).

According to Marais (1998) no agents have been released for alien spp. grown for commercial use such as *Pinus pinaster* and *Pinus radiata*. Biological control is regarded as the ultimate answer to the removal of alien invaders which produce a high seed load, especially the *Acacia* spp. which are found in riparian zones (Wilson 1985). Seed eating snout beetle (*Melanterius meculatus*) has recently been released on Black Wattle in the Western and Eastern Cape. Buckle (pers. comm. 2000) believes that active biological control could reduce the costs of follow-up and maintenance in the long-term by up to 50% – depending on the biocontrol agent that is used.

1.6.3 CLEARING METHODS USED ON THE SELECTED PROJECT AREAS

The clearing methods used in each project area are described below.

(i) Tsitsikamma area

Alien invasives are eradicated using a combination of slashers, brushcutters and chainsaws. Felled trees are cut up and stacked in windrows to minimise erosion. All felled trees are carried above the floodline. Trees are ringbarked if required. Pine trees are only felled - no cutting up or stump treatment takes place. Each management unit is followed-up for two years after initial clearing. Maintenance of each unit occurs for at least another 4 to 5 years after the follow-up operations have been carried out.

(ii) Kouga site

Mechanical control (i.e. slashing), using a combination of slashers, brushcutters and chainsaws is employed to remove alien invasives. Follow-up control operations, which entails the application of herbicides, are carried out two years after initial clearing. Maintenance of each management unit occurs for five years after follow-up control operations have been completed.

(iii) Port Elizabeth area

The clearing of alien invasives in this area is achieved by means of mechanical control, using a combination of brushcutters, chainsaws and slashers. Herbicides are also applied during initial clearing and follow-up operations (which take place two years after initial clearing). Maintenance of the management units occur six times in the first 10 years after follow-up operations have been carried out.

(iv) Albany area

Mechanical clearing with chainsaws and brushcutters is employed during initial clearing. The cleared grassland and grassy fynbos areas are burnt within two months of clearing taking place. Follow-up operations are carried out for two years after initial clearing. Herbicides are applied during follow-up control. Five years of maintenance of management units occurs after follow-up operations.

(v) Kat River area

Initial clearing in the Kat River area entails mechanical control using slashers, bowsaws, chainsaws and brushcutters. In the first year stump treatment of Black Wattle (with Timbrel) is also applied. Follow-up control is carried out two years after initial clearing (herbicides are applied). Maintenance of each management unit is required for 4 years after it has been cleared and followed-up for two years.

(vi) Pott River area

In the Pott River catchment initial clearing entails ringbarking and felling trees (mechanical clearing). The logs are carried a distance of 30 metres away from the water level. Follow-up operations are carried out two years after initial clearing. Approximately five years of maintenance of management units occurs after follow-up operations – the number of years required depending on the success and timing of the first follow-up operations. The number of years required for maintenance becomes less as grass is restored/planted because this reduces germination.

1.7 WATER RESOURCES IN THE EASTERN CAPE PROVINCE

The availability of water resources is one of the key problems facing the Eastern Cape Province. The aridity of the province and the high population growth has serious implications because in many parts a shortage of water is limiting economic development. Projections for all the Eastern Cape's water supply schemes were made by the DWAF in a document entitled "Eastern Cape Water Resources Situation Assessment" prepared by Ninham Shand in 1997. In Tables 1.6 to 1.11 the water supply situation analysis for the six different districts in the Eastern Cape is shown.[4]

Table 1.6: Water supply situation analysis - The Wild Coast District

SCHEME NAME	CONSUMERS	SITUATION
Flagstaff Local Scheme	5,300	Demand exceeds resources in 2005
Lusikisiki rural Scheme	50,000	Demand exceeds resources in 2005
Mt Ayliff Local Scheme	6,000	Not sufficient water presently
Mr Fletcher Local Scheme	11,500	Not sufficient water presently
Umzimkulu Local Scheme	Unknown	Not sufficient water presently
TOTAL	72,800	People

Source: DWAF (1999a).

[4] It should be noted that demand in this context exceeds supply at the current cost of supply.

Table 1.7: Water supply situation analysis - The Kei District

SCHEME NAME	CONSUMERS	SITUATION
Corana Regional Water Supply Scheme	47,000	No sufficient water presently
Engcobo Local Scheme	11,000	Not sufficient water presently
Libode Regional Water Supply Scheme	60,000	Demand exceeds resources in 2003
Mtangana Regional Water Supply Scheme	16,000	Not sufficient water presently
Qumbu Local Scheme	2,000	Demand exceeds resources in 1997
Tsolo Local Scheme	6,000	Demand exceeds resources in 2005
Umtata Water Supply Scheme	150,000	Demand exceeds resources in 2000
Total	292,000	People

Source: DWAF (1999a).

Table 1.8: Water supply situation analysis - The Drakensberg District

SCHEME NAME	CONSUMERS	SITUATION
Barkly East Local Scheme	16,000	Demand exceeds resources in 2000
Burgersdorp Local Scheme	20,000	Not sufficient water presently
Elliot Local Scheme	18,000	Not sufficient water presently
Herschel Rural Water Supply Scheme	170,000	Demand exceeds resources in 2012
Jamestown Local Scheme	4,500	Not sufficient water presently
Lady Grey Local Scheme	7,500	Not sufficient water presently
Maclear Local Scheme	8,600	Not sufficient water presently
Steynsburg Local Scheme	16,000	Not sufficient water presently
Ugie Local Scheme	12,000	Not sufficient water presently
TOTAL	272,600	People

Source: DWAF (1999a).

Table 1.9: Water supply situation analysis - the Stormsberg District

SCHEME NAME	CONSUMERS	SITUATION
Sterkstroom Local Supply Scheme	4,000	Not sufficient water presently
Tarka River Government Water Scheme	Unknown	Not sufficient water presently
TOTAL	4,000	People

Source: DWAF (1999a).

Table 1.10: Water supply situation analysis - the Amatola District

SCHEME NAME	CONSUMERS	SITUATION
Adelaide Local Scheme	16,000	Not sufficient water presently
Amatola Water Resources System	790,000	Demand exceeds resources in 2008
Butterworth Water Supply	15,000	Demand exceeds resources in 2009
Centane Water Supply	800	Demand exceeds resources in 2004
East Coast Water Supply Schemes	Unknown	Not sufficient water presently
Idutywa Local Scheme	12,000	Not sufficient water presently
Kat River Dam Water Supply Scheme	45,000	Demand exceeds resources in 1998
Mooiplaas Water Supply Scheme	30,000	Demand exceeds resources in 2000
Ncera Coastal Water Supply Scheme	Unknown	Not sufficient water presently
Nqamakwe	2,700	Not sufficient water presently
Peddie Regional Water Supply Scheme	10,000	Not sufficient water presently
West Coast Water Supply Schemes	Unknown	Not sufficient water presently
TOTAL	921,500	People

Source: DWAF (1999a).

Table 1.11: Water supply situation analysis - the Western Region District

SCHEME NAME	CONSUMERS	SITUATION
Alexandria Local Scheme	27,000	Demand exceeds resources in 1996
Algoa System	782,000	Demand exceeds resources in 2003
Graaff-Reinet	34,000	Not sufficient water presently
Groot River Government Water Scheme	Unknown	Not sufficient water presently
Kenton-on-Sea/Bushmans River Mouth Local Scheme	10,000	Demand exceeds resources in 2005
Oesterbaai	1,000	Not sufficient water presently
Pearston	7,000	Not sufficient water presently
Port Alfred	25,000	Demand exceeds resources in 2010
TOTAL	886,000	People

Source: DWAF (1999a).

The Amatola District (see Table 1.10) and Western Region District (see Table 1.11), if one takes into account the number of affected people (DWAF 1999a), are facing the most severe crisis. The annual runoff per square kilometre is significantly lower in these districts than those of the Drakensberg, Wild Coast and Kei districts (DWAF 1999a). Stormsberg, although it has a similarly low runoff (DWAF 1999a), is not facing the same impending water crisis due to the influence of the Orange River Scheme, use of boreholes and the lack of any major development nodes in the district (DWAF 1999a).

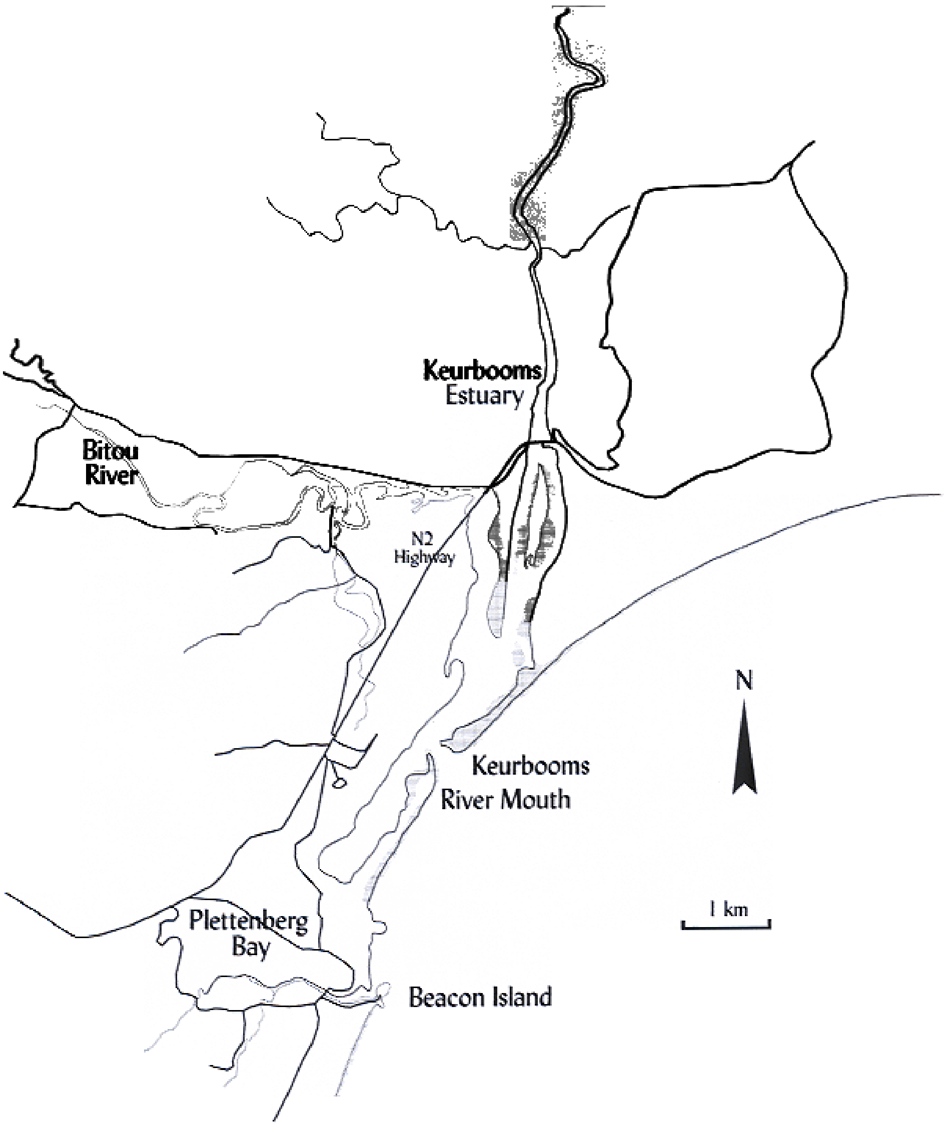
1.8 A DESCRIPTION OF THE KEURBOOMS AND BITOU ESTUARIES (see Appendix G)

1.8.1 LOCATION

The estuary of the Keurbooms River opens to the bay at 34^{o} 02’ S, 23^{o} 23’ E. A major tributary, the Bitou, joins the Keurbooms a short distance upstream of the mouth (Figure 1.7).

The national road (N2) crosses the Keurbooms and Bitou Rivers respectively six and five kilometers north-east of Plettenberg Bay. Bridge and embankment construction on the Keurbooms covers approximately 45% of the river width, and a large quantity of rubble still remains downstream of the bridge. Only a narrow channel 10m wide remains navigable in this area of the estuary (Duvenage & Morant 1984). Similarly, bridge and embankment construction on the Bitou to accommodate the N2 road, diverts the flow of tidal waters to a secondary channel.

Figure 1.8: The Keurbooms and Bitou estuaries



1.8.2 <u>ABIOTIC FEATURES</u>

(a) Climate

The Keurbooms and Bitou catchments receive rain almost equally in all seasons with peaks in autumn and spring (Duvenage & Morant 1984). Rainfall in the Outeniqua and Tsitsikamma mountains may exceed 1 100 mm per year. On average, 8 – 10 rainy days can be expected per month. The rainfall pattern is mainly cyclonic and orographic.

(b) Area of river catchments

The area of the catchment of the Keurbooms and the Bitou Rivers is 859km^2 and 237km^2, respectively (Reddering 1981). The combined area of 1 096km^2 is slightly less than that estimated by Heydorn and Tinely (1980) (1 188km^2).

(c) Geology

Keurbooms

The main tributaries of the Keurbooms River arise on the steep slopes of the Outeniqua, Langkloof and Tsitsikamma mountains. The river forms a deeply incised gorge in the coastal plateau while the estuarine section lies on the very narrow coastal plain. Bedrock of the river and major tributaries consists mainly of Table Mountain quartzite that resists erosion and weathering extremely well (Reddering 1996). This results in very little sediment supply to the estuary.

Bitou

The Bitou differs from the Keurbooms with respect to geological substrate in that only about half of the catchment is made up of Table Mountain quartzite. Enon Formation underlies about one third of the catchment area while some Bokkeveld slate occurs in the middle reaches of the river. Sediment derived from the latter two geological units provides more silt and clay than the Keurbooms system (Reddering 1996). Consequently, the Bitou Estuary has a higher content of mud in the sediment than the Keurbooms does.

(d) River lengths

The length of the Keurbooms River from the mouth to the source at Spitskop in the Outeniqua mountains is 70km (Duvenage & Morant 1984). A number of tributaries join the Keurbooms River and include the Hartbees, Duivelsgat, Palmiet, Klein, Diep, Witels, Kwaai, Peters, Bos and Kykoerie Rivers. The Palmiet is one of the larger tributaries (35km long) and joins the Keurbooms River approximately 15km from the estuary mouth. The Bitou River is 23km long, from the source to the confluence with the Keurbooms River.

(e) Land ownership and catchment uses

The major part of the Keurbooms River catchment (859km^2) is made up of privately owned farms. In the upper mountain catchments, vegetation consists mostly of natural vegetation used for cattle and goat farming (Duvenage & Morant 1984). The vegetation type includes Mesic and Dry Mountain Fynbos, with large areas of Wet Mountain Fynbos along the middle reaches of the river. These middle reaches also have cultivated lands and orchards along the riverbanks. Privately owned indigenous forests occur lower down the catchment on the southern side.

The catchment of the Klein Palmiet River (a tributary of the Palmiet) and the area from the Palmiet River up to the N2 Keurbooms bridge falls under state control. This area includes the Keurbooms River State Forest and is covered both by indigenous forest and exotic plantations.

The Keurbooms River Nature Reserve (128,5 hectares) extends upstream for about 6km from the N2 bridge, mostly on the western side of the river. The banks of the river are steep and covered with indigenous forests. Features of this reserve are hiking trails, camping sites and holiday accommodation. Angling and bait collecting are permitted within the reserve but are subject to control measures (method of capture, quantity, and in the case of fish caught, minimum length). Boating within the reserve is also strictly controlled, with a maximum speed of 10km per hour imposed, except within 2km of the N2 bridge on the northern side and between the hours of 10:00 and 16:00, when water skiing is permitted.

The upper reaches of the Bitou River (catchment 257km^2 in area) and its tributaries run through three state forests that consist mostly of indigenous vegetation. Remaining parts of the catchment are privately-owned farms. These are covered by indigenous forests and cultivated lands. The upland reaches of this river system include some of the best agricultural areas in the region (Duvenage & Morant 1984). Farms produce mostly wheat, dairy products and vegetables. In the Hillview area 3 500 hectares of arable land is used for mixed farming on the smaller units and dairy farming on the larger plots. In the Wittedrift area, plots are too small to be economically viable farming units (Duvenage & Morant 1984).

(f) Runoff and flow records

The mean annual runoff for the Keurbooms and Bitou catchments is about 70 to 120 million m^3 per annum. The following table (Table 1.12) summarises available data (Duvenage & Morant 1984).

Table 1.12: Summary of available information on river runoff in the Keurbooms and Bitou catchments

Catchment	Annual runoff ($\times 10^6$ m^3 per annum)	Reference
Keurbooms and Bitou (combined)	160	Noble & Hemens (1978), as quoted in Duvenage & Morant (1984).
Keurbooms Bitou	127 32	Midgley & Pitman (1969), as quoted in Duvenage & Morant (1984).
Keurbooms	72,9	Reddering (1981)
Keurbooms (1960 – 1970)	64	Department of Water Affairs. Measured 15 km from mouth, as quoted in Duvenage & Morant (1984).
Keurbooms (October 1970 – June 1981)	71	Department of Water Affairs. Measured 15 km from mouth, as quoted in Duvenage & Morant (1984).

Note: The discrepancy between the estimate of Midgely and Pitman (1969) and lower values for the Keurbooms is probably due to the source of the data (rainfall vs gauging plate measurements – as quoted in Duvenage and Morant (1984)).

In a recent study on the estuarine freshwater requirements of the Keurbooms Estuary, mean annual runoff was estimated as 102×10^6 m^3 (Plettenberg Bay Catchment Study, Huizinga & Slinger 1996). In the same study the mean runoff for the Bitou catchment was estimated at 32×10^6 m^3.

(g) Hydrological impact of alien plant infestations

Data in this section were obtained from a report compiled by the Division of Water, Environment and Forestry Technology of the CSIR for the Department of Water Affairs and Forestry, WfW Programme. The project team was Scott et al. (1999). The objectives of the study team were to:

- Determine the extent of invasive alien plants in the Keurbooms catchment, which spp. of alien plants occur there, where, and in what densities.
- Determine the current impact of alien plants on streamflow.

- Estimate the amount of additional water that would be generated by clearing existing infestations.
- Estimate, assuming infestations are not cleared, the rate of expansion and the effect this would have on future runoff into the Keurbooms catchment.

Only a summary of relevant findings is presented in this report (the reader should refer to the original document for full details). Six land-use categories were identified and the degree of invasion calculated from Table 1.12 in Scott et al. (1999) was as follows (Table 1.13):

Table 1.13: Summary of the invaded area (%) of the six identified land use categories identified in the catchments of the Bitou and Keurbooms catchments

Land-use category	Total area (ha)	Invaded area (%)
Natural forest	16194	26
Fynbos	80661	81
S & SWC Renosterveld	1820	50
Grazing	3278	20
Plantation	5940	3
Transformed (e.g. farm crops)	4542	Nil

Note: The degree of infestation is variable within land-use categories while the ongoing invasion rate also differs according to invader spp. in the different categories. The extent of invasion also differs along the respective river lengths

In estimating streamflow reduction by alien plantations, plant biomass (a function of vegetation age) of specific invader spp. must be known. Biomass development models differ in shape, with some plant spp. attaining a high biomass at an early age (compared to other spp.).

The product of the model developed for the Keurbooms and Bitou suggests that, in the riparian zone (immediately adjacent to the river) and in upslope areas of the catchment, the condensed coverage of invader plants was about

9% and 24% respectively in 1996. This condensed coverage increases to 36% and 65% by 2020 if alien infestation is not controlled and streamflow reduces from the present 567 million m^3a^{-1} to 1564 m^3a^{-1} in 2020 (a 176% increase). In order to sustain water resource availability in the river, it is vital that adequate control measures be taken against the spread of tall, woody, alien invasive plants (Scott et al. 1999).

(h) Description of the two estuaries

The Keurbooms-Bitou estuarine complex can be divided into three main components (see Figure 1.7):

- The lower 3,5 km lagoon behind a coastal barrier dune. The southern sector of the lagoon forms a blind arm, the extent of which depends on the position of the dynamic tidal inlet. In January 2000 the tidal inlet opened to the sea 0,5 km to the east of the Lookout Rocks beach.
- The Bitou that connects with the main estuary just above the lagoon. The Bitou Estuary is 6,7 km long from its head at Wittedrift to its confluence with the Keurbooms Estuary.
- The Keurbooms Estuary extends for 7 km above the Bitou confluence to Whisky Creek at the head of the tidal influence.

(i) Water supply and demand in the Plettenberg Bay area

The Plettenberg Bay Area and surrounding local authorities and communities are supplied with fresh water from various sources.

The major sources of water are the rivers in this coastal region. The only major dam in the area is the Roodefontein Dam. Other schemes comprise direct abstractions from rivers by pumping from low weirs or natural pools. In some instances groundwater is also utilised.

The Plettenberg Bay supply area is comprised of the Plettenberg Bay Municipal area, Kranshoek, Bossiesgift, Welkom, Hillview and the coastal strip up to the west bank of the Keurbooms River. Water is also supplied to Wittedrif. Most of the water supplied to this area is drawn from the Keurbooms River. This supply is supplemented by an allocation of water from the Roodefontein Dam, an artesian well on the golf course and two boreholes in town (Geldenhuys pers. comm. 2001).

Raw water is abstracted from an impoundment formed by a disused flow gauging weir in the Keurbooms River downstream of the confluence of the Keurbooms and Palmiet Rivers, approximately 16km north of the center of Plettenberg Bay (Geldenhuys pers. comm. 2001).
The pump station on the Keurbooms River bank pumps raw water to two raw water balancing reservoirs. The reservoirs have a capacity of 3 000m^3 and 181m^3 respectively.

From the balancing reservoirs water gravitates to the water purification works in Plettenberg Bay.

In terms of a Water Court Order dated 23 October 1972 the Plettenberg Bay Municipality is entitled to draw 8 640m^3 per day from the Keurbooms River (Geldenhuys pers. comm. 2001).

Early in 1978 the owners of Roodefontein Stud Farm, the Gardiner Ross Group, started the construction of a dam on the Piesang River. The work on this dam was stopped shortly after it started pending the redesign of the dam to provide additional capacity for an irrigation scheme on the farm Jakkalskraal which had been purchased by the House of Representatives. The irrigation scheme was intended as a resettlement area for members of the Griqua community, but the resettlement scheme did not materialise. The real water demand of the farm is thus significantly lower than was originally anticipated. In December 1987 the Department of Water Affairs issued a permit for the construction of a dam with a capacity of 750 000m^3 on the Piesang River. During 1988 the Roodefontein Dam was constructed and commissioned. The dam was built on land belonging to the Gardiner Ross Group, but ownership of the water was vested in the then Department of Local Government, Housing and Agriculture of the House of Representatives. The original abstraction rights from the dam were determined as follows:

a) Jakkalskraal Project : 1,02 million m^3 per annum

b) Plettenberg Bay Municipality : 0,15 million m^3 per annum

c) All overflow from the small dam on the Roodefontein Stud Farm, which is fed from the existing artesian well behind the golf club house was required to be directed to the Roodefontein Dam. Furthermore, the owners of the farm Roodefontein were given the right to abstract this overflow water from the Roodefontein Dam for use on their farm (Geldenhuys pers. comm. 2001).

The Plettenberg Bay Municipality may only, with the agreement of the dam owner, use their portion of the water to meet peak demand in the period from 15 November to 15 March each year.

The Municipality of Plettenberg Bay is also prohibited from drawing any water from the dam if there is less than 492 000m^3 of water in the dam.

The water transfer Roodefontein Dam to the Plettenberg Bay Municipal Water Treatment Works is achieved with two pumps and in peak season is 8 467m^3 per day (98 ℓ/s). Provision has been made for a third pump which will increase the capacity of this supply to 13 500m^3 per day (156 ℓ/s) (Geldenhuys pers. comm. 2001).

There is also an artesian well situated behind the golf club house which belongs to the Roodefontein Stud Farm. The average flow from the artesian well is estimated at 1 820 m^3 per week (3,0 ℓ/s).

In an agreement concluded between the owner of the Roodefontein Stud Farm and the Municipality it was agreed that 25% of the artesian well water belongs to the Municipality, i.e. 25% of 1 820m^3 per week or 65m^3 per day (0,75 ℓ/s). The relatively small volume of artesian well water does not warrant a complex and expensive system to make full use of this artesian water (Geldenhuys pers. comm. 2001).

Great potential exists for groundwater abstraction from the hard fractured sandstone formation of the Table Mountain Group which occur both in the immediate proximity of Plettenberg Bay as well as regionally.
Two boreholes have been sunk by the municipality. These boreholes have an installed capacity of 10 ℓs each and are operated on a basis of 8 hours on/8 hours off over periods of peak demand. Another two boreholes will in the near

future be incorporated into the supply system. Two of the four boreholes will supply water to the water treatment works while the other two will pump water directly into the supply system (Geldenhuys pers. comm. 2001).

The maximum annual yields or allocations and peak supply capacities from the existing sources of water supply are summarised in Table 1.14.

Table 1.14: Existing sources of water supply to Plettenberg Bay

	Source	Yield ($10^6 m^3/a$)	Peak week capacity (Mℓ/d)	Remarks
1	Keurbooms River	2,16(1)	6,5(3)	Existing pipe capacity (7,1 Mℓ/d)
2	Roodefontein Dam	0,150(2)	7,8(3)	Maximum draw off 98 ℓ/s over 24 hours at present to meet peak demand (8,47 Mℓ/d)
3	Artesian Well	-	-	Municipality entitled to 25 % of yield of 1 820 m^3/week (65 m^3/d)
4	Boreholes	0,26(1)	1,7(3)	Four existing boreholes yielding 430 m^3/d each over 5 months
	Total	3 080 Mℓ/a (8,44 Mℓ/d)		

(1) Based on supply effectively utilised 20 hours per day.
(2) Present allocation.
(3) Based on supply effectively utilised 22 hours per day.

1.9 ORGANISATION OF THE REMAINDER OF THE REPORT

Chapter Two provides an overview of the nature, extent and distribution of alien infestations on six WfW Programme project sites in the Eastern and Southern Cape. Chapter Three discusses the methodology applied to the estimation of water use by alien plants. In Chapter Four the environmental services provided by the Keurbooms Estuary are discussed. Chapter Five classifies the costs and benefits associated with the WfW Programme. The methodology relating to the valuation of the benefits (discussed in Chapter Five) is outlined in Chapter Six. Chapter Seven values the environmental services provided by the Keurbooms Estuary. Cost-benefit analysis methodology is applied to the selected WfW Programme sites in Chapter Eight and conclusions are drawn and recommendations made in Chapter Nine.

CHAPTER TWO: THE NATURE, EXTENT AND DISTRIBUTION OF ALIEN INFESTATIONS AT SIX WORKING FOR WATER PROJECT SITES IN THE EASTERN AND SOUTHERN CAPE

2.1 INTRODUCTION

The area of infestation at the six selected WfW Programme sites in the Eastern and Southern Cape (see Chapter One) was estimated and a density class allocated to it by information supplied by the respective project managers of these sites (see Appendix E). The following density classes were used for this purpose:

(1) Rare (<< 0,1% infested). These are known individual plants but they are few and far between.

(2) Occasional (< 5%). Plants are widely spaced, occurring here and there and are on average 3 or more canopy diameters apart.

(3) Scattered (5 - 25%). The plants are on average 1 to 3 canopy diameters apart.

(4) Moderate (25 - 75%). There are gaps between the canopies of plants and other vegetation is still present. Plants average 0,1 to 1 canopy diameters apart.

(5) Dense (> 75%). Plant canopies are closed, touching or overlapping and other vegetation is generally suppressed, sparse or lacking. The plants average less than 0,1 canopy diameter apart.

2.2 QUANTIFICATION OF THE INFESTATION LEVELS ON SIX WORKING FOR WATER PROJECT SITES IN THE EASTERN AND SOUTHERN CAPE

The main invaders in the Tsitsikamma mountain catchment are *Acacia mearnsii*, *Pinus* spp., *Hakea sericea*, *Acacia melanoxylon* and *Eucalyptus* spp. A total area of 128 783 hectares is infested. Only 82 402 hectares are being manually cleared. Biological control is being used on stands of *Hakea* covering approximately 46 381 hectares (the remainder). Table 2.1 below shows the infestation levels of alien invasives in the Tsitsikamma mountain catchment (Spies pers. comm. 1999).

Table 2.1: Tsitsikamma - Area of alien plant infestation (ha) presented per Genus and density class

	Species					
Density class	***Pinus***	***Hakea***	***Acacia***		***Euca-lyptus***	**Total**
			mearnsii	**Other**		
Rare (<< 0,1%)	0	0	0	130	380	510
Occasional (< 5%)	14 433	1 335	470	385	1 275	17 898
Scattered (5 – 25%)	47 585	8 438	510	605	469	57 607
Moderate (25 - 75%)	195	19 650	6 590	135	125	26 695
Dense (> 75%)	0	16 958	9 115	0	0	26 073
Total area infested	62 213	46 381	16 685	1 255	2 249	128 783

(Source: Spies pers. comm. 1999).

The main alien invader plants found in the Kouga mountain catchment are *Acacia mearnsii*, *Acacia dealbata*, *Acacia melanoxylon* and *Eucalyptus* spp. In the Kouga River and its tributaries the following spp., namely *Hakea gibbosa*, *Hakea sericea*, *Hakea drupacea*, *Pinus radiata* are found and *Pinus pinaster* have invaded the northern slopes of the Tsitsikamma mountain. Table 2.2 below shows the infestation levels of alien plant invasives in the Kouga mountain catchment. A total area of 158 678 hectares is infested. All is going to be manually cleared except for an area of 33 138 hectares invaded by *Hakea*, which is to be cleared using biological controls (Buckle pers. comm. 1999).

Table 2.2: Kouga - Area of alien plant infestation (ha) presented per Genus and Density class

Density class	Species						
	Populus	***Pinus***	***Hakea***	***Acacia***		***Eucalyptus***	**Total**
				mearnsii	**Other**		
Rare (<< 0,1%)	0	3 273	3 273	3 273	2 374	0	12 193
Occasional (< 5%)	694	16 714	3 899	12 951	3 439	2 526	40 223
Scattered (5 - 25%)	1 232	31 760	21 211	28 669	7 909	1 461	92 242
Moderate (25 - 75%)	172	2 578	4 755	5 597	143	698	13 943
Dense (> 75%)	0	0	0	77	0	0	77
Total area infested	2 098	54 3 25	33 138	50 567	13 865	4 685	158 678

(Source: Buckle pers. comm. 1999; McKelly pers. comm. 1999).

The Port Elizabeth area is invaded mainly by *Acacia* spp., namely *saligna*, *cyclops*, *mearnsii* and *longifolia* as well as *Eucalyptus* spp. An area of 8 700 hectares is infested but only 8 400 hectares are being cleared due to the presence of biological control agents. Table 2.3 below indicates the infestation levels for the Port Elizabeth area (Marsh pers. comm. 1999).

Table 2.3: Port Elizabeth - Area of alien plant infestation (ha) presented per Genus and Density class

Density class	Species					
	Pinus	***Hakea***	***Acacia***		***Eucalyptus***	**Total**
			mearnsii	**Other**		
Rare (<< 0,1%)	0	0	0	0	0	0
Occasional (< 5%)	100	0	200	500	0	800
Scattered (5 - 25%)	0	0	0	800	800	1 600
Moderate (25 - 75%)	0	0	700	2 000	400	3 100
Dense (> 75%)	0	0	0	3 000	200	3 200
Total area infested	100	0	900	6 300	1 400	8 700

(Source: Marsh pers. comm. 1999).

The following spp. constitute the main alien invaders in the Albany catchment, namely *Acacia longifolia*, *Acacia mearnsii*, *Eucalyptus* spp., *Hakea sericea* and *Pinus pinaster*. A total area of 11 500 hectares is infested. Table 2.4 below shows the infestation levels in the Albany area.

Table 2.4: Albany - Area of alien plant infestation (ha) presented per Genus and Density class

	Species					
Density class	***Pinus***	***Hakea***	***Acacia***		***Euca-lyptus***	**Total**
			mearnsii	**Other**		
Rare (<< 0,1%)	200	20	50	25	20	315
Occasional (< 5%)	300	25	150	75	80	630
Scattered (5 - 25%)	400	25	400	200	100	1 125
Moderate (25 - 75%)	700	130	700	800	200	2 530
Dense (> 75%)	100	300	3 100	3 000	400	6 900
Total area infested	1 700	500	4 400	4 100	800	11 500

(Source: Knipe pers. comm. 1999).

The most dominant alien invaders in the Kat River catchment are *Acacia mearnsii*, *Acacia melanoxylon* and *Eucalyptus* spp. A total area of 1 196 hectares is infested. Table 2.5 below shows the infestation levels in the Kat River catchment.

Table 2.5: Kat River - Area of alien plant infestation (ha) presented per Genus and Density class

	Species					
Density class	***Pinus***	***Hakea***	***Acacia***		***Euca-lyptus***	**Total**
			mearnsii	**Other**		
Rare (<< 0,1%)	0	0	0	0	0	0
Occasional (< 5%)	0	0	0	39	0	39
Scattered (5 - 25%)	0	0	0	0	91	91
Moderate (25 - 75%)	0	0	1 066	0	0	1 066
Dense (> 75%)	0	0	0	0	0	0
Total area infested	0	0	1 066	39	91	1196

(Source: Kameni pers. comm. 1999).

The most dominant alien invaders in the Pott River catchment are *Populus* spp., Crack Willow (*Salix fragilis*), *Acacia* spp. and *Eucalyptus* spp. A total area of 490 hectares is infested. Table 2.6 below shows the infestation levels in the Pott River catchment.

Table 2.6: Pott River - Area of alien plant infestation (ha) presented per Genus and Density class

Density class	**Species**				
	Populus	**Crack Willow**	***Acacia***	***Eucalyptus***	**Total**
Rare (<< 0,1 %)	0	0	0	0	0
Occasional (< 5 %)	0	0	0	0	0
Scattered (5 - 25 %)	10	20	0	0	30
Moderate (25 - 75 %)	10	10	110	70	200
Dense (> 75 %)	0	0	250	10	260
Total area infested	20	30	360	80	490

(Source: Shuttleworth pers. comm. 1999).

2.3 CONCLUSION

Invasions by *Pinus* spp. cover the largest area in the Tsitsikamma mountain catchment with *Hakea* a close second. The invasion of *Acacias* is lower because they occur mostly on wetter sites where water is not a limiting factor (Marais 1998). The majority of *Acacia* spp. occur in riparian zones. Biological control is exercised on *Hakea* spp. with great success in this area. According to Marais (1998) *Hakea* spp. have less of an effect on streamflow than Pines and *Acacia* spp. due to the fact that they are smaller than the latter spp.

The most dominant alien trees in the Kouga area are *Acacia* spp., of which *Acacia mearnsii* (Black Wattle) is the most prevalent, followed by *Pinus* spp.

As with the Tsitsikamma project, *Hakea* spp. are not being cleared manually because biological controls are currently preferred.

Invasions by the genus *Acacia* cover the largest parts of the other four project areas: P.E. Driftsands, Albany, Kat River and Pott River. Biological control agents now exist in the form of the seed eating snout beetle for controlling the *Acacia mearnsii*, the most common *Acacia* spp. present on these areas, but the dominant form of clearing currently in place is manual removal.

CHAPTER THREE: THE ESTIMATION OF THE INCREMENTAL WATER USE BY ALIEN PLANTS

3.1 INTRODUCTION

Exotic invasive plants have been shown to severely affect mountain catchment areas by displacing indigenous vegetation and substantially reducing surface runoff (Van Wilgen, Trollope & Everson 1990; Le Maitre, van Wilgen, Chapman & McKelly 1996; Van Wilgen, Cowling & Burgers 1996). Alien plant and tree infestations consume more water than the indigenous vegetation that they replace. The invader plants and trees are generally taller, faster growing, evergreen, adapted to optimise water consumption, and possess a high reproductive capacity (Briers & Powell 1993), especially when compared to the indigenous fynbos and grassveld that occurs in most of the mountain catchments in the Eastern and Southern Cape.

Information pertaining to the influence of alien vegetation on water yield was originally derived from plantation forestry research (Briers & Powell 1993). Early studies by Wicht (1943), Banks & Kromhout (1963), Van der Zel and Kruger (1975), Van Wyk (1977) and Bosch (1979) showed that rainfall runoff could be reduced by up to 50% due to plantation afforestation, depending on the extent of afforestation (Chapman, Scott & Le Maitre 1995).

Bosch and Hewlett (1982) estimated the influence of alien invasion on water yield for 94 catchments studied. Water yield was reduced in proportion to the growth rate of the stand. Moreover, increases in water yield following clear felling diminished in proportion to the recovery rate of the alien plants and trees (Bosch & Hewlett 1982).

Bosch and Hewlett (1982) estimated that coniferous and eucalypt trees reduce annual water yield by approximately 400mm per 10% change in forest cover. Deciduous hardwoods gave a 25mm change in annual water yield per 10% change in cover, while only 10mm change in water yield was estimated for a 10% change in grassveld cover.

Smith and Scott (1992) studied the effects of afforestation on streamflow in various regions of South Africa. A paired sampling approach was used to estimate the effect of plantations on five catchments in winter and summer rainfall areas of South Africa. They showed that afforestation had a highly significant effect on flow in all the catchments studied. In some cases, dry-period flows were reduced by 100% (Smith & Scott 1992).

More recently, Le Maitre et al. (1996) developed a model to calculate streamflow reduction by alien plants and applied this model to catchments in southern Africa. They calculated the water use of alien plants in 11 primary catchments in the Eastern Cape and report a reduction of mean annual runoff ranging from 0,06 to 42,26% for these.

Le Maitre et al. (1996) and Van Wilgen, Little, Chapman, Görgens, Willems & Marais (1997) developed a model to simulate streamflow reduction as a result of alien invasions. Their hypothesis is that a statistically significant relationship exists between aboveground biomass of alien plants and reduction in streamflow. Long-term catchment experiments were conducted in the Western Cape in catchments of differing degrees of infestation. Data obtained from these studies were used to present a relationship that was significant (r^2 = 0,75, n = 9, p = 0,005; Versveld et al. 1998). The exact mechanism of streamflow reduction is not completely understood (Van Wilgen et al. 1996) but includes increased transpiration and interception of precipitation by alien plants. The principle observation/conclusion is that the greater the aboveground biomass of the vegetation, the more water it will consume. Versveld et al. (1998) contend that, although the model is reasonable for fast-growing vegetation types, it may be inaccurate for mature vegetation.

The model is based on data of streamflow decline after alien invasion. According to Versveld et al. (1998), streamflow reduction is indirectly related to water use (evaporation and transpiration) because streamflow differs from year to year, depending on the amount and timing of precipitation, as well as changes in the amount of water removed from the catchment by aliens. Streamflow reduction is an indirect estimate of the additional water used/abstracted by alien trees over that used/abstracted by the indigenous vegetation, and is called the incremental water use. Incremental water use is less than the aggregate water use (Versveld et al. 1998).

The model does not make provision for the impact of drought years and for the possibility that reductions in minimal flow may proportionately exceed those of aggregate annual flow (Versveld et al. 1998).

3.2 METHODS

The streamflow reduction by indigenous vegetation was calculated on the basis of post-fire age. The model used by Versveld et al. (1998) to relate post-fire biomass to streamflow reduction was used in this study with the addition of a “rate of spread” component as suggested in Le Maitre et al. (1996), although rate of spread is applied in a different way to the raster-based method of Le Maitre et al. (1996). Data from O’Callaghan (1981) and Mitchell, Coley, Webb, and Allsopp (1986) was used to determine the relationship between post-fire age and biomass of fynbos (as suggested by Stock & Allsopp 1992). The relationship between post-fire age and biomass was found to be linear (Figure 3.1) and this equation was used to calculate fynbos biomass in the absence of exotic invaders. The mean fire cycle of each catchment was taken from questionnaire data.

The model uses five factors to estimate the reduction in stream-flow due to the presence of alien vegetation:

- Rainfall and runoff
- Fire frequency
- Change in biomass between fires
- Rate of alien spread
- Effect of biomass on stream-flow

3.2.1 RAINFALL AND RUNOFF

Chapman et al. (1995) examined the response of runoff to precipitation through the analysis of the mean annual runoff compared to the mean annual precipitation for nine fynbos catchments. The following predictive equation for runoff under conditions of minimum vegetation cover as given by Chapman et al. (1995) is used in this model:

$$\mathbf{MAR = 0{,}74\ MAP - 368} \quad \text{(3.1)}$$

where MAR = mean annual runoff (mmy^{-1})

MAP = mean annual precipitation (mmy^{-1})

The MAR given by this equation is the base runoff and represents runoff under conditions of minimum vegetation cover. This equation is used for high rainfall areas. A modified equation as recommended by Chapman et al. (1995) was used for those catchments with low runoff (Kouga, Port Elizabeth Driftsands and Albany) where the rainy season is not winter:

$$\mathbf{MAR' = 0{,}74\ MAP - \{368*(MAP/MAP')\}} \quad \text{(3.2)}$$

where MAR = mean annual runoff (mmy^{-1})

MAP = mean annual precipitation (mmy^{-1})

MAP' = 1347 mmy^{-1} (Chapman et al. 1995)

3.2.2 FIRE FREQUENCY

The average fire frequency in fynbos is estimated to be 15 years (Van Wilgen et al. 1996). Considering that the entire catchment does not burn with each fire, the mean age of fynbos vegetation is 7,5 years, assuming an even distribution of post-fire ages between 1 and 15 years (Versveld et al. 1998). Marais (1998) estimated that the average fire cycle for coastal fynbos catchments was 12 years and that inland catchments would burn every 15 years. All fynbos catchments in this study were in the coastal zone and a 12-year fire cycle was used in the model.

No estimates of mean age of vegetation are available for the summer rainfall regions. Versveld et al. (1998) estimate that grassveld burns every 1 to 4 years. Similarly, Buckle (pers. comm. 1999) estimates the average fire cycle for grassveld in high rainfall areas to be 3 to 4 years. In this study the mean fire frequency was estimated to be 4 years for the Albany, Kat River and Pott River Programmes.

The mean post-fire age of vegetation occurring in riparian zones is different to other areas because fire frequency differs (Versveld et al. 1998). These fires, however, do not burn the trees in riparian zones and the alien vegetation can be considered to be mature, with a post-fire age of 20 years (Versveld et al. 1998). In this study the exotics found in the Albany, Kat River and Pott River catchments were found to occur in the riparian zone and as a result were taken to have a fixed post-fire age of 20 years. As a result fires do not cause as much variation in the water yield from these catchments as they do from those of the Tsitsikamma, Kouga and Port Elizabeth Driftsands (see Figures 3.4 to 3.9).

These fire cycles were used in preference to those supplied by the WFW managers (see Appendix E) because some of these managers confused the time between the occurrence of a fire in the catchment and the time between fires for each patch of vegetation.

3.2.3 CHANGE IN BIOMASS BETWEEN FIRES

Alien plant invasions lead to an increase in aboveground biomass. This increase can be estimated by calculating the additional biomass of alien invasive plants as a function of their cover and age since last fire (Versveld et al. 1998). Numerical models have been developed for three growth form groups of alien invasive plants (Le Maitre et al. 1996). These are presented in Table 3.1.

Table 3.1: The aboveground biomass (b) in g m^{-2} calculated from post-fire age (a) in years for three growth forms of alien invasive plants

Growth form	Equation	Equation number
Tall alien shrubs	$B = 5\ 240 \log_{10}(a) – 415$	3.3
Medium alien trees	$B = 9\ 610 \log_{10}(a) - 636$	3.4
Tall alien trees	$b = 20\ 000 \log_{10}(a) - 7\ 060$	3.5

The alien invasive plant spp. found in the six catchments studied and their growth forms are listed in Table 3.2.

Table 3.2: The growth form of alien invasive plant spp. with the equation number used to calculate biomass from post-fire age for each

Species	Growth form	Equation number
Acacia cyclops A. Cunn *ex* G. Don	Medium alien trees	3.4
Acacia dealbata Link	Tall alien trees*	3.5
Acacia longifolia (Andr.) Willd.	Medium alien trees	3.4
Acacia mearnsii De Wild	Tall alien trees	3.5
Acacia melanoxylon R. Br.	Tall alien trees	3.5
Acacia saligna (Labill.) Wendl.	Medium alien trees	3.4
Eucalyptus spp.	Tall alien trees	3.5
Hakea spp.	Tall alien shrubs	3.3
Populus spp.	Tall alien trees	3.5
Salix fragilis L. var. *fragilis*	Medium alien trees	3.4
Pinus spp.	Tall alien trees	3.5

The relationship between post-fire age and biomass of fynbos and grassveld was taken from available literature (as suggested by Stock & Allsopp 1992). Fynbos data was taken from O'Callaghan (1981) and Mitchell et al. (1986) and was found to be linear (Figure 3.1). Grassveld data was taken from Materechera, Mandiringana, Mbokodi & Nyampfene (1998). In this case the data showed an exponential trend (Figure 3.2).

3.2.4 RATE OF ALIEN SPREAD

Boucher (1984) showed that undisturbed fynbos would take over 200 years to become completely infested. By contrast Richardson and Brown (1986) reported that, in the absence of control, alien infestations could reach 100% cover in 60 years. Le Maitre et al. (1996) found an increase in alien plant cover from 2,4% to 62,4% in 100 years in the Kogelberg area.

Marais (1998) reported that the spatial rate of spread of alien invasive plants was between 4% and 7% per annum for the period 1938 to 1989 on the southern Cape Peninsula. The average rate of spatial expansion of the infestation was 4,7% with most rapid increases occurring during the early states of invasion. This implies that the relationship between rate of spread and level of infestation is negatively exponential (Figure 3.3). The relationship between time and area invaded, as presented by Higgins, Richardson and Cowling (2000), supports the validity of this relationship. (Our relationship is the inverse of their increase in area invaded data.)

In order to account for this relationship the average rate of spread reported by the WFW managers (see Appendix E) was multiplied by a factor dependent on the level of infestation (Table 3.3) for use in the model. The initial level of infestation was taken as that reported by the WFW managers for each class of cover as listed in Table 3.3 (see Appendix E). The different rates of spread (scaling factors) were applied annually to each of the areas that were reported to have different levels of infestation.

Figure 3.1: The relationship between post-fire age and biomass in fynbos

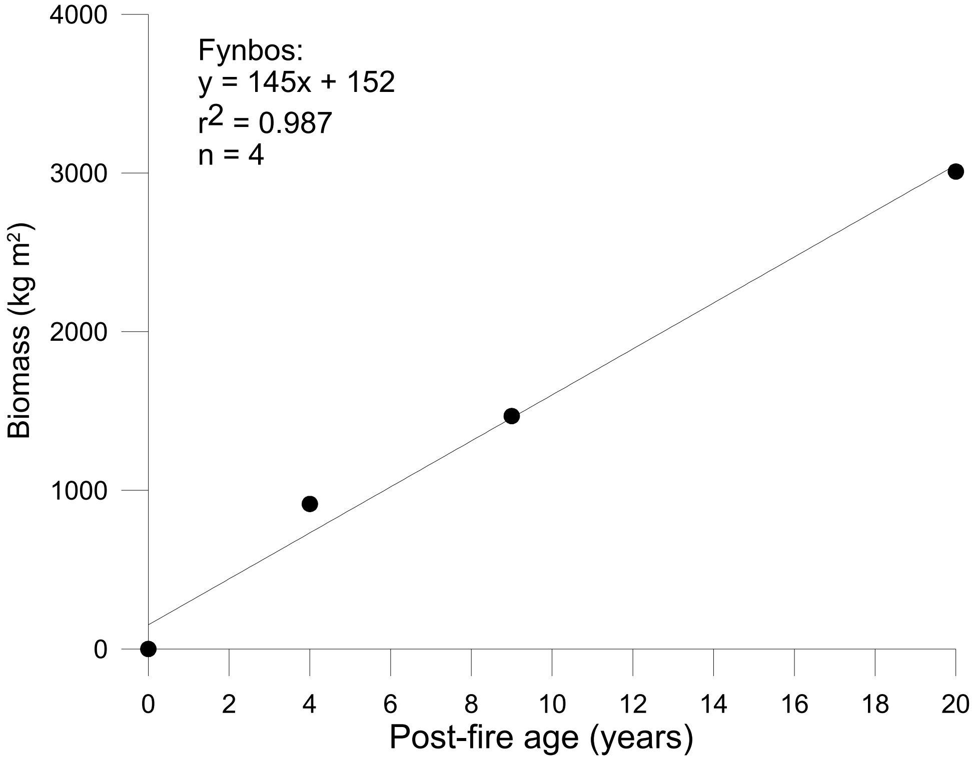


Figure 3.2: The relationship between post-fire age and biomass in grassveld

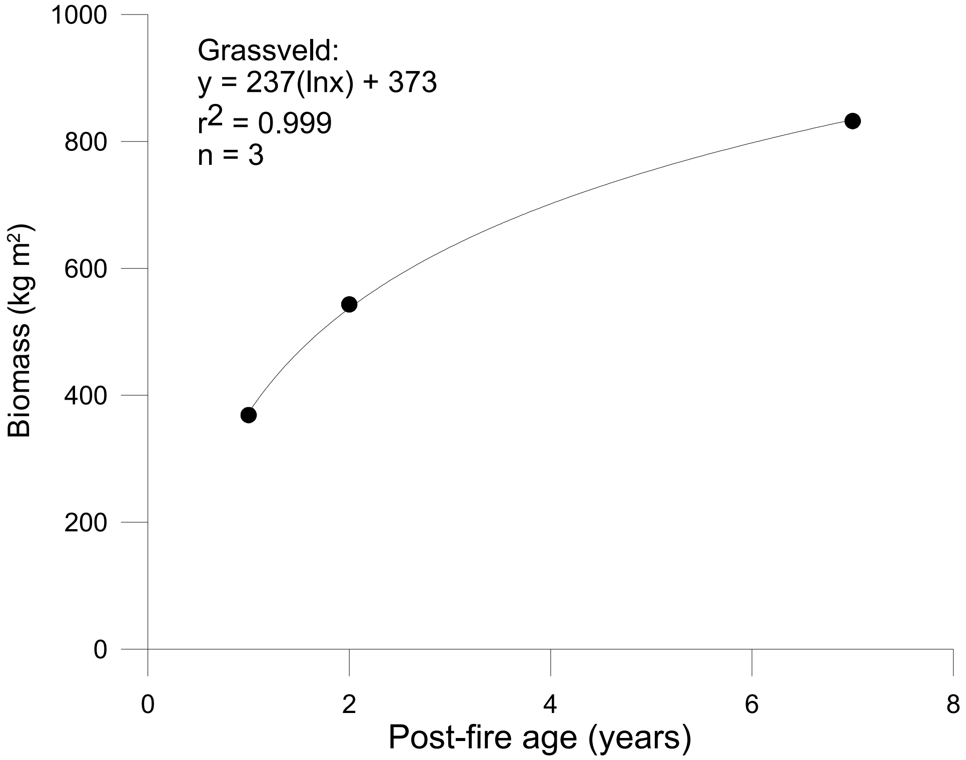


Figure 3.3: The theoretical relationship between rate of spread and level of infestation

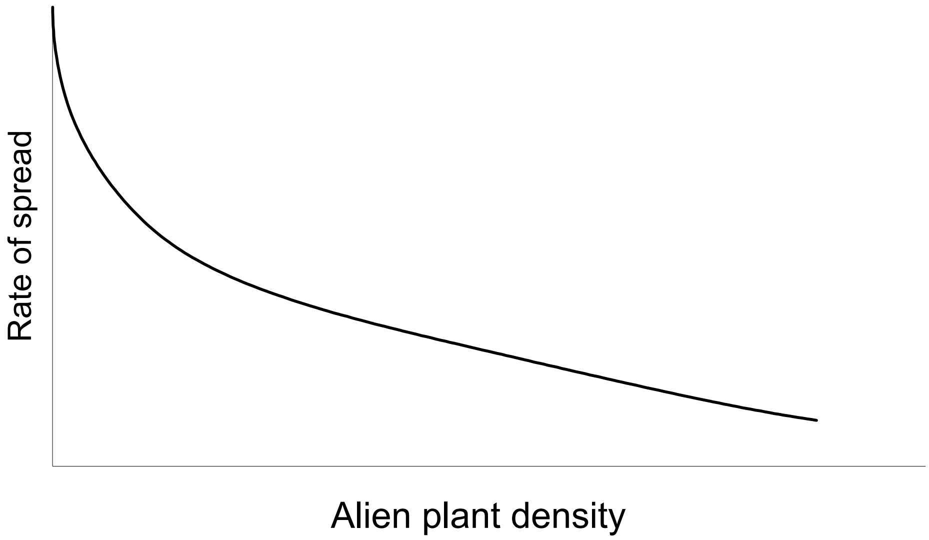


Table 3.3: The scaling factors used to adjust average rate of alien spread reported by WfW managers based on the level of infestation. The factor is derived from the theoretical relationship between rate of spread and level of infestation as presented in Figure 3.3

Level of infestation (% cover)	Scaling factor
< 0,1	1
0,1 - 5	0,75
> 5 - 25	0,5
> 25 - 75	0,25
> 75	0,1

3.2.5 EFFECT OF BIOMASS ON STREAMFLOW

Biomass calculated was adjusted for the extent of the infestation. WFW managers reported (see Appendix E) infestation in five classes (Table 3.3). Incremental streamflow reduction was calculated assuming a canopy cover of 100%. In order to account for the different levels of infestation, the size of the invaded area was reduced proportionally to its level of infestation. For example, an area of 10 hectares with 50% cover is mathematically equivalent to 5 hectares with 100% cover. The area of each cover abundance class was converted to an equivalent area of complete cover in this way and the biomass of each spp. then calculated from equations 3.3 to 3.5. The biomasses of the different spp. was then summed to give the standing biomass (b) of exotics.

Estimates of alien plant biomass were converted into estimates of streamflow reduction using the linear relationship used by Versveld et al. (1998):

Streamflow reduction (mm) = 0,0238 b .... (3.6)

Where Streamflow reduction = rainfall equivalents (mm^{y-1})

b = standing biomass of invading plants ($g\ m^{-2}$)

Values where equations 3.3 to 3.5 deliver negative aboveground biomass values (usually for the first and second years) were excluded as these give an overestimation of streamflow (Van Wilgen, Little, Chapman, Görgens, Willems & Marais 1997). The equation was also adapted to pass through the origin because when aboveground biomass is zero, streamflow reduction should also be zero (Van Wilgen et al. 1997).

Because this equation is based on pine plantations the streamflow reduction by indigenous vegetation was calculated in a similar way but adjusted in accordance with the ratio of water use efficiency of either fynbos or grassveld to pine trees. The ratio of water use efficiency of pine trees compared to fynbos spp. is 1,65 while that of pine trees compared to grasses is 1,18 (Scott & Le Maitre 1998).

3.3 RESULTS

3.3.1 MODEL PARAMETERS

The mean annual rainfall reported by WFW managers and the resultant mean annual runoff calculated from rainfall are presented in Table 3.4. The fire frequency reported by WFW managers is also given in Table 3.4. The fire cycle used in the model and the resultant post-fire age/s are also given. The rate of spread of alien invasive plants, as provided by the WFW managers and the area (ha) where the WFW Programme has cleared, or is planning to clear, is also given (Table 3.4).

Table 3.4 The area where WfW has cleared, the mean annual rainfall and fire frequency reported by WfW managers for each of the six catchments investigated°

Catchment	Area of WFW control (ha)	Mean annual rainfall ($mm\ y^{-1}$)	Mean annual runoff (mm)	Fire frequency (years)	Fire cycle (years)	Post-fire age (years)	Rate of spread ($\%\ y^{-1}$)
Tsitsikamma	128 783	960	342	10	12	1-12	5,5$
Kouga	158 678	547	255#	8-15	12	1-12	15+
Albany	11 400	650	113#	3	4	20	5,5
Port Elizabeth Driftsands	8 700	490	229#	4	12	1-12	2
Kat River	1 196	950	335	3	4	20	2,5
Pott River	490	939*	327	2	4	20	13

* from Forsyth et al. 1997
\# modified equation (Chapman et al. 1995)
\+ Buckle (pers. comm. 2001) argued that the rate of spread in the case of the Kouga site is unrealistically high.
$ average for Fynbos (Marais 1998)
° The calculated mean annual runoff (in rainfall equivalents), assumed fire cycle and post-fire age used in the model is also given.

3.3.2 INCREMENTAL WATER YIELD DURING INITIAL CLEARING PERIOD

The incremental water yield of the area cleared by the WfW Programme (as reported by the manager, see Appendix E) was calculated as the difference between water yield with the removal of aliens and the water yield in the absence of clearing operations. The incremental water yield represents the primary benefit of the WfW Progrmame – it was used to compile the benefit profile (see Chapter Eight).

The study sites are broken up into management units which means the incremental water yield increases proportionally annually as more units are cleared for the first time. The duration of the initial clearing periods in years for the Tsitsikamma, Kouga, Port Elizabeth Driftsands, Albany, Kat River and Pott River sites were determined to be 20, 20, 18, 20, 18 and 5 years respectively.

The incremental water yield benefit stream (m^3/a) over these initial clearing periods are shown in Table 3.5 below.

After the completion of initial clearing operations on all the management units the maximum incremental water yield achievable at each project site is realised (see section 3.3.3).

Table 3.5: Incremental water yield benefit stream over the initial clearing period

Years	Incremental water yield benefit stream (m^3/a)					
	Tsitsikamma	**Kouga**	**Port Elizabeth Driftsands**	**Albany**	**Kat River**	**Pott River**
1	207 500	12 765	30 525	27 795	125 040	183 906
2	1 245 000	82 110	183 315	2 108 700	198 985	236 857
3	3 112 500	576 240	516 460	3 905 980	253 530	419 268
4	6 900 000	1 219 200	1 022 120	4 291 900	279 990	491 563
5	12 925 000	3 106 480	1 582 890	4 960 590	301 600	515 000
6	19 710 000	5 722 245	2 183 115	5 773 350	360 995	-
7	27 177 500	9 065 690	2 818 800	6 578 580	425 160	-
8	35 260 000	13 159 235	3 532 980	7 393 090	442 000	-
9	43 942 500	18 044 305	4 275 000	7 998 420	454 160	-
10	53 175 000	23 813 510	4 999 500	8 837 400	523 005	-
11	62 920 000	30 523 065	5 774 895	9 661 200	596 700	-
12	73 200 000	38 285 815	6 599 340	10 495 950	604 095	-
13	2 697 500	685 170	397 210	11 034 615	606 640	-
14	8 715 000	2 254 920	1 283 205	11 901 450	685 100	-
15	15 562 500	5 974 920	2 583 230	12 745 480	768 240	-
16	27 600 000	12 304 000	4 088 480	13 597 140	766 105	-
17	43 945 000	19 181 760	5 383 080	14 070 810	759 120	-
18	59 130 000	26 402 325	6 550 000	14 967 150	850 000	-
19	73 767 500	34 248 970	-	15 828 100	-	-
20	88 150 000	42 850 000	-	16 700 000	-	-

3.3.3 MAXIMUM INCREMENTAL WATER YIELD

In Figures 3.4 to 3.9 differences are shown in streamflow (mm rainfall equivalents y^{-1}) (as calculated in Appendix B) and water yield (m^3 y^{-1}) (as calculated in Appendix C) with and without the project at the respective sites. The total incremental water benefit stream associated with each project over their respective fire cycles is given in Table 3.6. This benefit stream only accrues once all initial clearing operations of the entire area have been carried out. The integrated water yield for each catchment is given in Figure 3.10 (also see Appendix A).

Figure 3.4: The calculated streamflow and water yield of the WfW control areas of the Tsitsikamma catchment should exotic invader trees be removed (solid line) or should no clearing take place (dashed line)

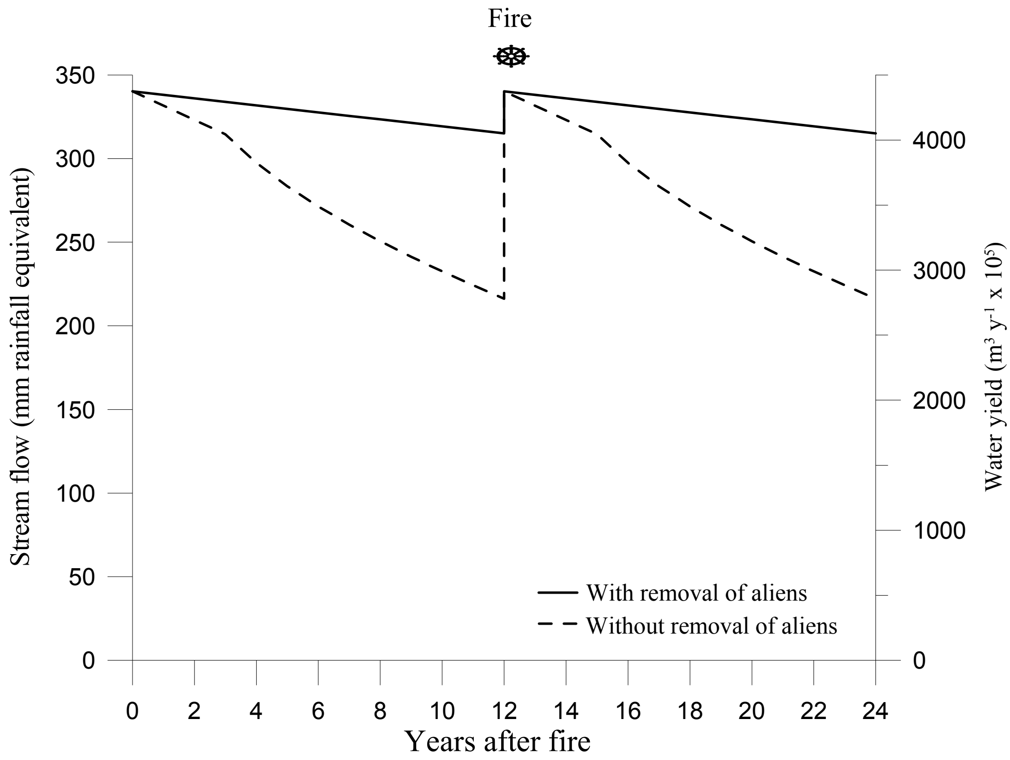


Figure 3.5: The calculated streamflow and water yield of the WfW control areas of the Kouga catchment should exotic invader trees be removed (solid line) or should no clearing take place (dashed line)

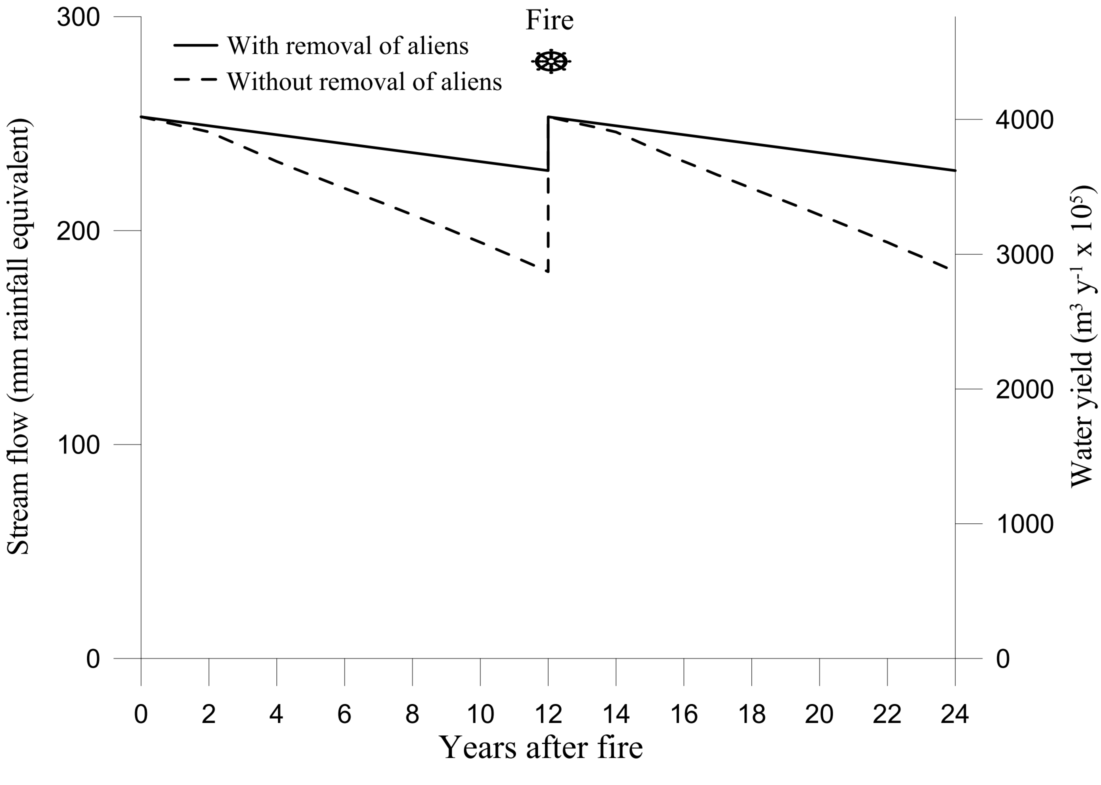


Figure 3.6: The calculated streamflow and water yield of the WfW control areas of the Port Elizabeth Driftsands aquifer recharge area should exotic invader trees be removed (solid line) or should no clearing take place (dashed line)

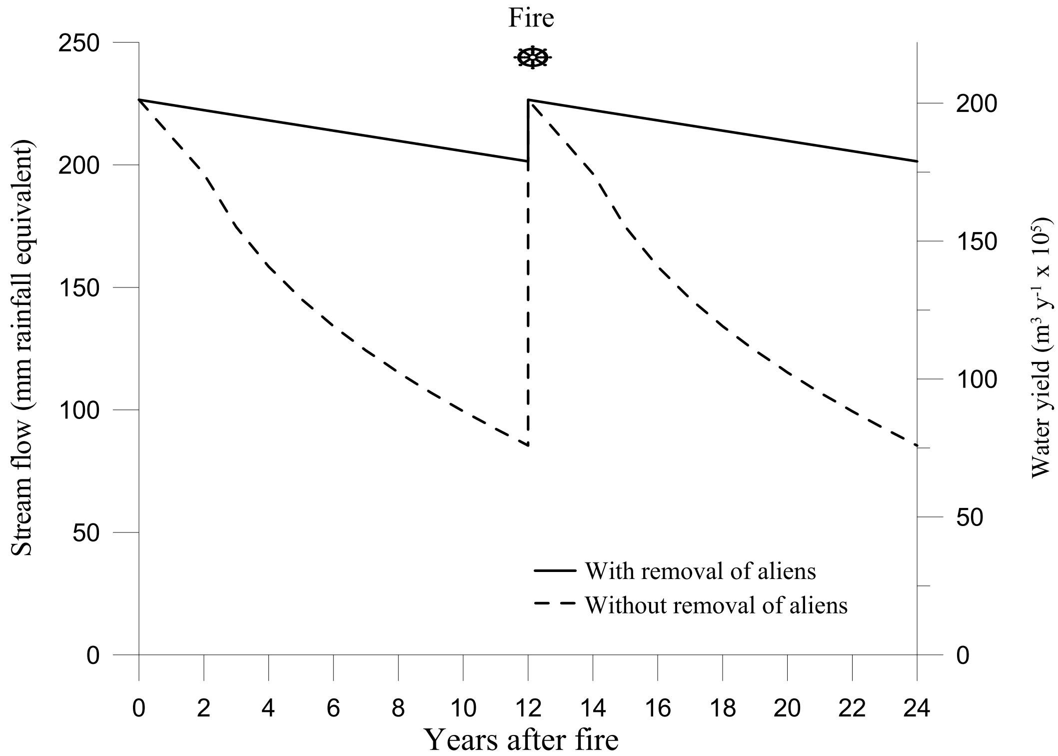


Figure 3.7: The calculated streamflow and water yield of the WfW control areas of the Albany catchment should exotic invader trees be removed (solid line) or should no clearing take place (dashed line)

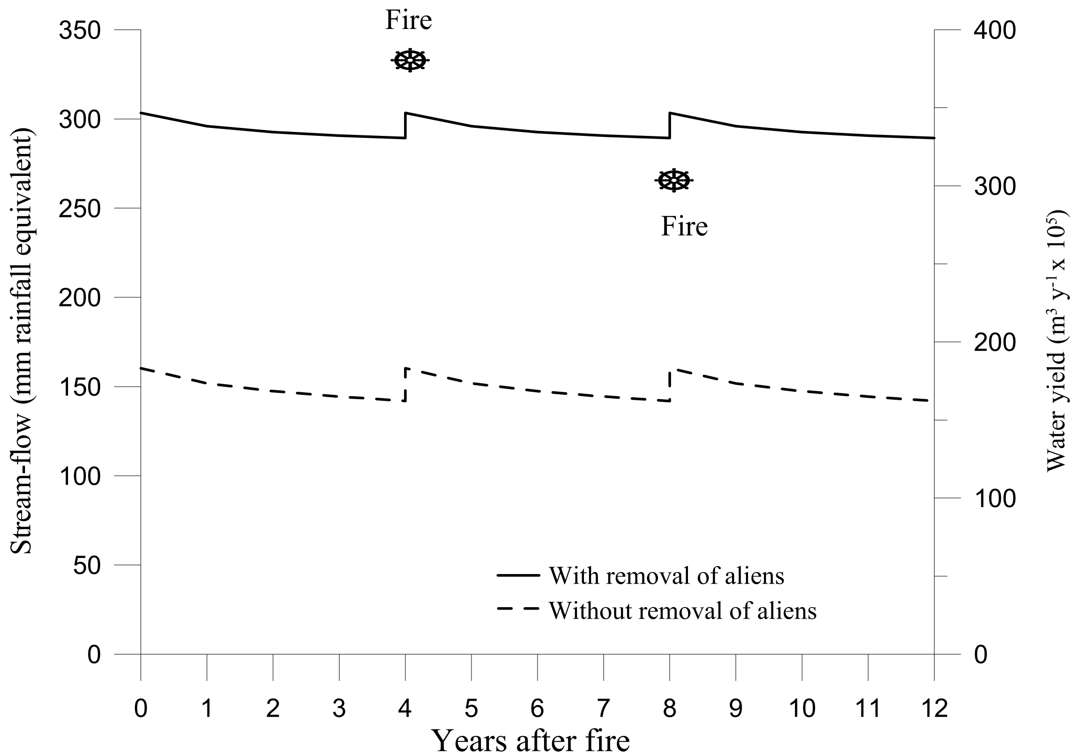


Figure 3.8: The calculated streamflow and water yield of the WfW control areas of the Kat River catchment should exotic invader trees be removed (solid line) or should no clearing take place (dashed line)

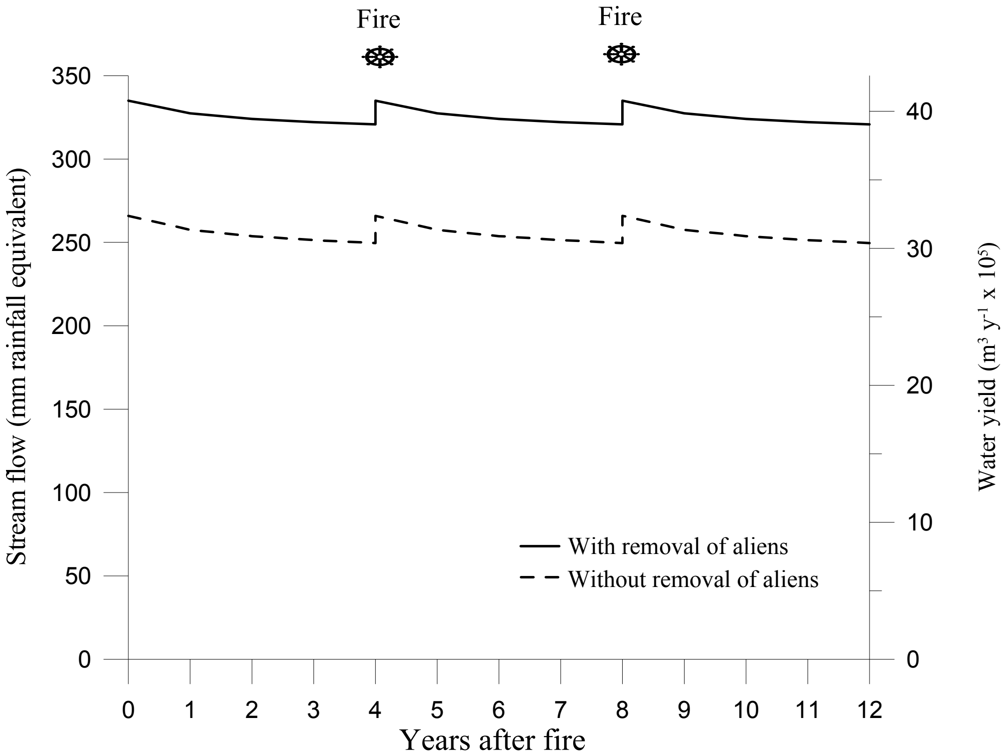


Figure 3.9: The calculated streamflow and water yield of the WfW control areas of the Pott River catchment should exotic invader trees be removed (solid line) or should no clearing take place (dashed line)

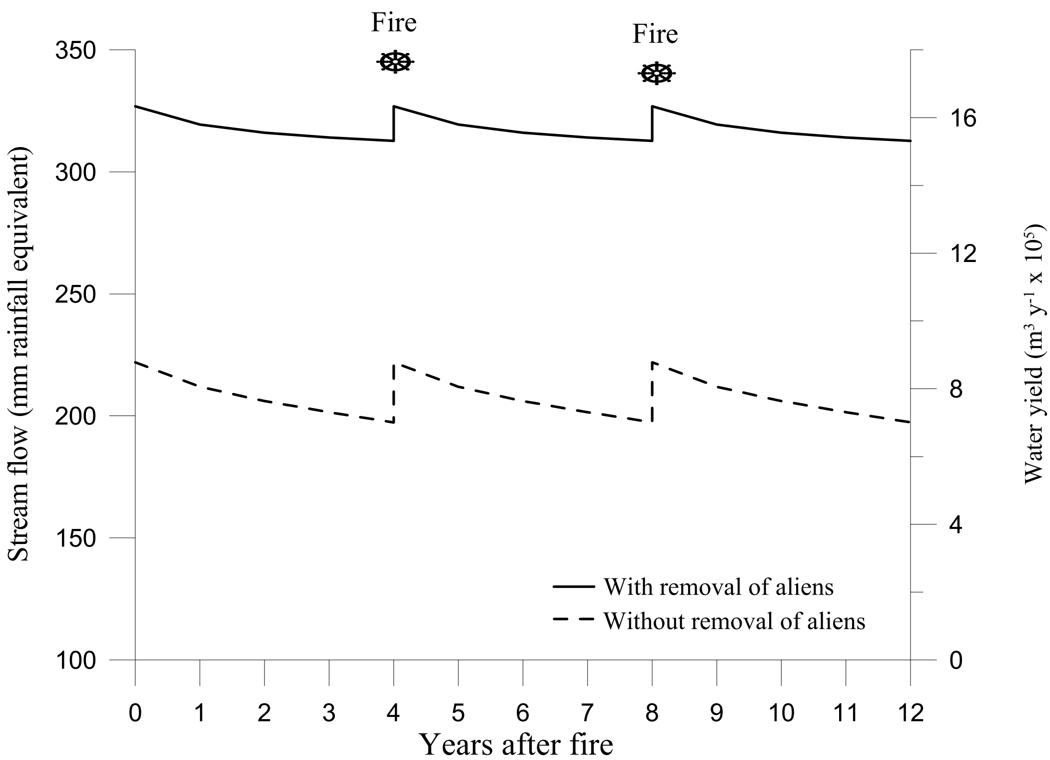


Table 3.6 below shows the maximum annual net incremental water benefit stream in m^3 at the six project sites over their respective fire cycles.

Table 3.6: Annual net incremental water yield m^3 at the six project sites*

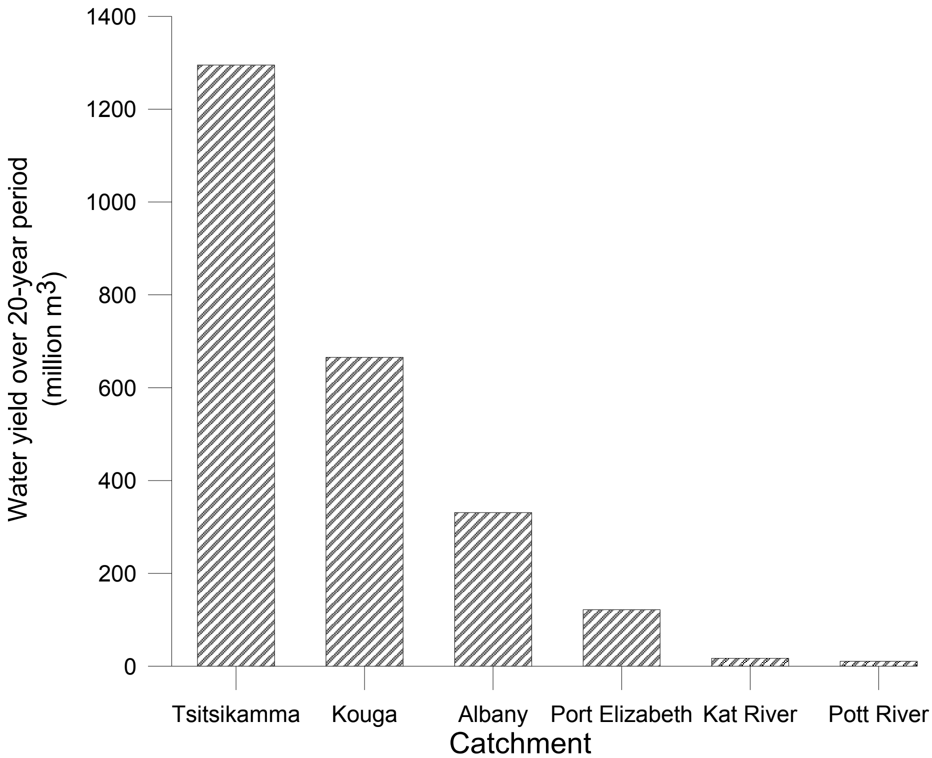
Year	Tsitsikamma m^3	Kouga m^3	Port Elizabeth Driftsands m^3	Albany m^3	Kat River m^3	Pott River m^3
1	4 150 000	1 150 000	550 000	16 350 000	800 000	515 000
2	12 450 000	3 450 000	1 650 000	16 500 000	850 000	530 000
3	20 750 000	8 400 000	3 100 000	16 600 000	900 000	545 000
4	34 500 000	16 000 000	4 600 000	16 700 000	850 000	555 000
5	51 700 000	23 200 000	5 700 000			
6	65 700 000	29 850 000	6 550 000			
7	77 650 000	36 350 000	7 250 000			
8	88 150 000	42 850 000	7 950 000			
9	97 650 000	49 450 000	8 550 000			
10	106 350 000	56 350 000	9 000 000			
11	114 400 000	63 550 000	9 450 000			
12	122 000 000	71 150 000	9 900 000			

* These estimates were derived from Appendix C. They are averages for the year (estimate at beginning of year plus estimate at end of year divided by two).

3.4 CONCLUSION

This chapter calculates the incremental water use by invasive alien plants over indigenous vegetation. The volume of water yielded per annum through these projects is substantial (see Table 3.6), especially at the Tsitsikamma and Kouga sites. Over a 20 year period about 1 300 million m^3 would be yielded through the Tsitsikamma project alone (see Figure 3.10 below).

Figure 3.10 The integrated water saving for the area cleared by the WfW Programme in each catchment investigated



Note: The water saving was calculated after completion of the clearing of the area and includes the spreading of the infestation expected to follow. (It was not based on the removal of exotics from the entire catchment).

The information generated in this chapter is used in Chapter Eight to compose the benefit profile component of the cost-benefit analysis.

CHAPTER FOUR: ENVIRONMENTAL SERVICES PROVIDED BY THE KEURBOOMS ESTUARY

4.1 INTRODUCTION

The WfW Programme has a positive impact on the healthy ecological functioning of the Keurbooms Estuary in the Southern Cape through increased streamflows. This chapter describes the services that would be threatened, drawing on Appendix G, where the ecology of the Bitou and Keurbooms Estuaries are described.

The Keurbooms and Bitou estuaries near Plettenberg Bay share a common mouth that opens to the sea along Lookout Beach. The Keurbooms-Bitou system is recognised as one of the most important estuaries along the South African coast (one of approximately 250 estuaries), and is ranked sixteenth in conservation importance (Wooldridge 2000). Conservation importance is calculated on the basis of weighted size, type, bio-geographical zone in which it occurs, habitat types and biota present (plants, invertebrates, fish and birds).

The future conservation status of the Keurbooms-Bitou estuaries is dependent primarily on adequate freshwater inputs. Both baseflow and flood events are important in maintaining estuarine structure and function. Ever-increasing human demand for freshwater in the region is a serious threat facing the estuary and further abstraction schemes could negatively alter the present functioning and status of the system.

Although the tidal inlet has not been known to close, the mouth sometimes becomes very shallow and constricted. Mouth closure, even temporarily, would have a dramatic effect on the structure and functioning of the two estuaries.

For example, reduced estuarine scouring, as a consequence of flood attenuation, would lead to progressive shallowing, especially nearer the mouth. Tidal flows would decrease leading to greater potential for mouth closure.

Moreover, a reduction or changes in freshwater supply would alter the hydrodynamic character of the estuaries. This would lead to changes in the persistence and distribution of salts and affect the flushing and renewal of saline water. Impacts would increase if the estuary mouth closed.

Even a small reduction in freshwater supply in the future has the potential to lead to mouth closure, since the mouth has come close to closing on a number of occasions in the immediate past.

4.2 ENVIRONMENTAL SERVICES

As mentioned above, adequate freshwater supplies into the Keurbooms Estuary can prevent the estuary mouth from closing. If these supplies are forthcoming then a number of environmental services are provided by the estuary. If not, the following negative ecological impacts could occur:

- Shallowing of the estuary due to increase in sedimentation. A major consequence of human abstraction of freshwater via river impoundments and alien tree invasion is reduced estuarine scouring which leads to progressive shallowing, especially nearer the mouth. Tidal flows would decrease leading to greater potential for mouth closure. An increase in sedimentation adversely affects boating and related activities, and also results in a shortage of water frontage space.

- Tidal action into the estuary mouth would disappear if the mouth closed which in turn leads to a loss of the inter-tidal area available for foraging birds, such as fish eagles and waders like grey plovers, curlew sandpipers and black-winged stilts. The Plettenberg Bay Birdwatcher's Association undertake frequent trips to the estuary to view these birds which are found only at this location. Tourists and other visitors also enjoy birdwatching in the estuary area.

- A reduction of fauna in the Keurbooms Estuary. The Keurbooms is dominated by marine fish spp. that utilise the estuary as a nursery area before returning to the sea as adults. The most common life history pattern is spawning in the marine environment followed by immigration of larvae or early juvenile stages into estuaries. After remaining in estuaries for varying periods of time, fish emigrate back to the marine environment prior to, or after attaining sexual maturity.

Five major categories of fishes that utilise estuaries are:

(a) estuarine spp. that breed in estuaries;

(b) eurytaline marine spp. that usually breed at sea and whose juveniles show varying degrees of estuarine dependence;

(c) marine spp. that occur in estuaries in small numbers but are not dependent on these systems;

(d) eurytaline freshwater spp., whose penetration into estuaries is determined primarily by salinity tolerance. Some spp. may breed in both freshwater and estuarine systems.

(e) Obligate catadromous spp. (must spawn at sea to complete their life cycle).

Migration into the estuary is significantly influenced by the longitudinal salinity gradient that influences the magnitude of juvenile fish recruitment into the nursery areas. Consequently, a reduction in freshwater supply to the Keurbooms-Bitou estuaries will negatively impact on the nursery value of the two systems. If the estuary mouth closes during spring and summer (period of maximum fish recruitment), the value of the nursery function of the estuary decreases by about 75%. In winter, the value decreases by about 25%.

Inadequate freshwater supplies, and hence mouth closure, could influence estuarine fish in the following ways:

- possible extinction of fish and estuarine invertebrates that have a marine phase of development such as the gobiids and the blenny – successful larval efflux and subsequent post larval return of these resident estuarine spawners is dependent on synchronisation of the open phase of the tidal inlet with the breeding season;
- loss of important angling spp., such as the spotted grunter and other spp. that utilise estuaries as nursery areas. Other spp., such as the round herring, are totally dependent on estuaries;

- loss of catadromous spp., such as eels and the freshwater mullet, that migrate through estuaries to complete their life cycles;
- loss of marine fish spp. – prolonged closure of the estuary mouth leads to mass mortality of entrapped marine fish spp. and are probably due to low salinity water;
- loss of bloodworm, pink prawn, mudprawn and pencil bait which are used by fishermen for bait. Mudprawn, for instance, is also an important part of the food web in the estuary, and are absent from estuaries that have closed off from the sea. Fishermen are permitted to collect five bloodworm and fifty of each of the other spp. per day. Currently there are approximately 65 million mudprawn and 70 million sandprawn in the estuary, but 25% of mudprawn populations would die off per year on closure of the mouth (no recruitment). After four years the whole prawn population will have been wiped out.

Plant activity/services in the estuary would also be reduced which would lead to the following:

- an increase in turbidity
- a reduction in purification due to less reed bed action
- a reduction in oxygen generation
- a reduction in food for freshwater and marine fish spp.

From an aesthetic point of view the estuary and the mouth shoreline would become less attractive and mudflats may appear where water has receded. The build up of a sand bar at the mouth of the Keurbooms would also make a natural dam wall, thereby increasing the potential for flooding of adjacent residential areas.

4.3 CONCLUSION

The Keurbooms Estuary is an important estuary in South Africa from a conservation perspective. The healthy functioning of this estuary is, however, dependent on adequate freshwater flowing into it. A reduction in freshwater supply has the potential to lead to mouth closure. Should this happen, the conservation status of the estuary will change dramatically – many of the environmental services of the estuary will be reduced or disappear completely. In this regard, the WfW Programme can play a very positive role because the clearance of the Keurbooms catchment of alien invasives will lead to increased freshwater streamflow into the estuary.

CHAPTER FIVE: A CLASSIFICATION OF THE COSTS AND BENEFITS OF THE WORKING FOR WATER PROGRAMME ON SELECTED SITES IN THE EASTERN AND SOUTHERN CAPE

5.1 INTRODUCTION

This chapter identifies and classifies the costs and benefits of the WfW Programme on selected sites in the Eastern and Southern Cape. Identifying and forecasting of cost and benefit flows, associated with a public sector programme, over the life of the project, is one of the most important aspects of investment analysis. The four main elements that need to be identified are (Hanley & Spash 1993):

(a) the investment cost, which include site preparation, buildings and equipment;
(b) the operating costs, which include labour, raw materials, spares, and fuel;
(c) the revenue, which depends upon the volume of output and their unit value; and
(d) the life of project, which determines the period over which the cost and benefit flows are analysed.

The elements described in (a), (b) and (c) above are called primary costs and benefits.

In addition to these, other secondary ones may also become important. First, there are those that occur indirectly upon the immediate vicinity of the project, for instance, due to a change in demand or cost of input. Second, there are the effects that have a marginal impact on the economy as a whole.

Secondary costs and benefits are more difficult to measure, and for this reason are often left out of the final cost benefit analysis. This problem also arose in the CBA carried out as part of this research programme.

5.2 A CLASSIFICATION OF THE COSTS

Cost information was obtained from the project managers of the selected initiatives of the WfW Programme in the Eastern and Southern Cape.

5.2.1 PRIMARY COSTS

The primary costs associated with the WfW Programme are those for capital equipment (chain saws, vehicles, tools and computers), herbicides (herbicide, diesel, dyes and wetters), protective clothing (gloves, masks, overalls, boots and helmets), wages and salaries, transport (including subsidised transport and repairs), clearing work contracted out to private institutions, and running expenses, including machinery running expenses (filters and replaced parts), fuels and oils, and stationery, printing and telephone expenses. The acquisition of equipment is an investment cost, whereas the other costs mentioned are operating costs.

5.2.2 SECONDARY COSTS

In addition to the abovementioned primary costs, a reduction in the availability of alien tree spp. as a source of firewood is a secondary cost (Buckle pers comm. 1999). Marais (1998) argues this cost can be reduced by encouraging small local industries to supply the community with alternative sources of firewood from indigenous sources.

5.3 A CLASSIFICATION OF THE BENEFITS

5.3.1 PRIMARY BENEFITS

The primary benefit of clearing alien vegetation in the areas selected is increased water yield. The primary hypothesis of the WfW Programme is that removing the alien plant invaders and restoring indigenous vegetation increases runoff because the latter consume less water than the former. The basis for this theory is plantation forestry research into decreased water yields resulting from afforestation (controlled and uncontrolled) with alien tree spp. (Briers & Powell 1993). This benefit was more fully described in Chapter 3.

5.3.2 SECONDARY BENEFITS

(a) Training of workers and social upliftment

Economic empowerment and training goes hand in hand with the creation of employment opportunities. The following educational aspects are addressed during the training process: operating of cutting equipment, managerial, first aid and primary health care (Marais 1998). The total number of person days spent on training in 1995/6, 1996/7 and 1997/8 respectively were 14 548, 30 901 and 75 910.

This non-water benefit is closely related to social development and poverty alleviation. As mentioned before, to be successful, public works programmes must equip participants with skills that they can use after the discontinuance thereof (Barker 1999). Due to the nature and extent of the WfW Programme, workers are often required to work high in the mountains. For this reason they must be taught the correct safety procedures for such a job (ropes, etc.). These skills are utilised outside of the WfW environment, e.g. in the rigging industry (Tromp pers. comm. 2000). The existence of secondary enterprises also contributes to employment creation, thus "reflecting government's commitment to create jobs and combat poverty" (www-dwaf.pwv.gov.za/projects/wfw/social%development.htm).

Training in the WfW Programme is divided into six categories: environmental awareness, machinery, herbicide, health and safety, management and contracting and mountaineering. These training projects are developed with costs and benefits in mind (Marais pers. comm. 2001: SEGA model, WfW project).

The value of training given by the WfW Programme outside the project varies. Even mountaineering has been shown to yield an earnings return for workers (Marais pers. comm. 2000), although only 1% of trainees enter this specific training programme. More trainees enter the programme on machinery (for example operating a chain saw), herbicide control, health and safety and general environmental awareness.

Social development and poverty alleviation are also secondary benefits of the WfW Programme. The Programme focuses primarily on marginalised groups such as women, the disabled and youth. The WfW Programme follows a policy of providing childcare in areas where it recruits workers (www-dwaf.pwv.gov.za/projects/wfw/ secondary%htm). This enables women, especially in rural areas, to become economically active.

Pilot education projects about family planning and health issues were launched in the Eastern Cape, providing communities involved in the WfW Programme with information about tuberculosis, AIDS, nutrition, violence, pregnancy and abuse. The WfW Programme has formed partnerships with the United Nations Populations Fund and the Planned Parenthood Association of South Africa (PPASA) (www-dwaf.pwv.gov.za/projects/wfw/social%development.htm).

Partnerships with the Department of Welfare and Correctional Services have also been formed to introduce ex-offenders to the WfW Programme in order to help them find work and equip them with useful skills (www-dwaf.pwv.gov.za/projects/wfw/social%development.htm).

(b) Biodiversity

Arguably, one of the most important secondary benefits of the WfW Programme, is the conservation of biodiversity.

Biodiversity is “the variety of the world’s organisms, including their genetic diversity and the assemblages they form” (www.wri.org.wri.biodiv/bri-ntro.html). Another definition is that of Dr Peter Haven of the Missouri Botanical garden: “At the simplest level, biodiversity is the sum total of all plants, animals, fungi and micro-organisms in the world, or in a particular area; all of their individual variations; and all of the interactions between them” (www.acnatsci.org.erd/ea/biodiv2.html).

Calculating the gains of biodiversity is an enormously difficult task.

Studies have been conducted on the biodiversity benefit due to alien plant and tree control. In 1965 the fynbos vegetation of Biesiesvlei, Jonkershoek was surveyed and described, and a reassessment of the vegetation in 1984 was made using the same methods. According to the reassessment of Richardson et al. (1986) afforestation with Pine spp. decreased the indigenous vegetation cover (i.e. fynbos) from 75 to 20% and decreased the aggregate number of spp. by 58% from 298 to 126.

At least 190 spp. found in 1945 were not found in 1984 and at least 18 spp. were added to the list. The mean plant density was decreased from 260 plants/m^2 to 78 plants/m^2. Only streambank vegetation, comprising mainly large-leaved sprouting shrubs, persisted in a relatively unmodified state. Dominant spp. in the pre-afforestation flora were not resilient to afforestation.

Some spp. had been eliminated. It seems possible that certain groups may re-establish after clearfelling, but others, notably various groups of shrubs may be permanently eliminated (Richardson et al. 1986:309). It is concluded from these findings that afforestation results in a reduction in the number of plant spp., but that removal of the forest may lead to some spp. reestablishing themselves, provided that this removal does not occur too long after afforestation.

The reduction in plant spp. can be ascribed to a number of factors. Pines are more efficient users of the resources that are available. They grow faster, they reach a much greater size than the indigenous plants (i.e. Fynbos and Grassy Fynbos), litter fall from Pines leads to a substantial suppression of the understorey vegetation and shading affects photosynthesis and the germination of understorey plants. The comparative contribution of each individual limiting factor to the suppression of elements of the natural vegetation is unknown, but the combination of these factors has without a doubt led to the demise of several (groups of) spp. (Richardson et al. 1986:309-315).

Biodiversity is closely associated with the preservation of indigenous vegetation. This vegetation yields direct and indirect benefits. The indigenous vegetation found in the mountain catchments of South Africa, especially the fynbos, has economic value. It is exploited for flowers. The cut-flower industry in the Western Cape alone realised US$ 18-19,5 million in 1993, whilst providing employment for between 20 000 and 30 000 people (Van Wilgen et al. 1997:409). Other consumptive outputs of indigenous fynbos vegetation include rooibos and honeybush tea, boegoe, herbs and traditional medicines. The non-consumptive benefits are difficult to measure, e.g. ecotourism. The management of South Africa's visual resources, of which fynbos is one, play an important role in promoting tourism and through this also the economy (Britton 1995).

(c) Water quality

Another secondary benefit associated with the increase in water runoff as a result of the clearing of alien vegetation is the increase in water quality. Very little is known about the effect of dense infestations of alien trees or plants on water quality. However, there is strong evidence of a significant reduction in runoff and hence a reduction in streamflow (Bosch & Hewlett 1982). The indirect effects of the reduction in streamflow will be a reduction in the dilution of natural occurring chemicals and hence a decrease in water quality (Gale & Day 1995). The naturally occurring chemicals referred to above are total dissolved salts (TDS). A reduced dilution capability leads to an increase in TDS.

A measure of this benefit would be long-term savings in terms of water purification but has yet to be determined (Egan pers. comm. 2000).

(d) Downstream industry

Downstream industrial development is also a secondary benefit of the WfW Programme. Secondary industries are defined as those firms "making saleable items from the wood that is cleared, or developing subsidiary initiatives such as ecotourism around the clearing project" (www-dwaf.pwv.gov.za/projects/wfw/secondary%.htm). Although no in-depth research has been done on this topic, it is widely believed to have substantial potential, especially in the creation of jobs (Marais, Eckert & Green 2000; www.environment.gov.za/soer/nsoer/issues/land/conclude.htm; Magadlela 2000).

Due to the length of the WfW Programme (currently at 20 years), these downstream industries have the prospect of developing into established enterprises. Some of the projects and products that have already been established are:

- Charcoal production with Shell SA and exporters
- Walking stick processing
- Firewood production for local markets
- Whitewood (debarked Black Wattle trees) extraction for SAPPI pulp production
- Items (customised) for the arts and craft market, including wooden toys
- Screens, benches and garden products
- Community based tourism
- Fynbos products for floral markets
- Charcoal and eco-brick production (www-dwaf.pwv.gov.za/projects/wfw/secondary%.htm).

In some cases the felled invasive trees have been used for building material such as drop-poles, fences, beams, planks and tomato stakes. In other cases wood chips are mixed with cement to create bricks and panels. There are, however, also problems in incorporating these downstream industries as benefits. They do not depend on the WfW Programme per se. Indeed they are unsustainable in terms of the WfW Programme, but could be made sustainable at lower rates of alien tree extraction. In fact, were these industries to really develop they would reduce the desirability of the WfW Programme in the relevant areas.

(e) Flood control and prevention of soil erosion

Another secondary benefit associated with the WfW Programme is that of flood control and the prevention of soil erosion. Invasion by high biomass alien plants lead to fuel and litter build-up (Versfeld 1995). Very high fire intensities occur in areas with a very high biomass (fuel) load and this leads to erosion (Versfeld 1995).

The WfW Programme has started to carry out wetland rehabilitation as part of the programme. For this reason, benefits now include flood attenuation and water flow regulation.

Riverbank erosion also occurs due to presence of alien spp., most notably *Acacia mearnsii*, in the river courses (Marais 1998). According to Beyers (1994) streambanks are particularly prone to invasion compared to terrestrial environments due to their exposure to periodic natural and human related disturbances, the perennial availability of moisture, reliable dispersion of seeds by water and the role of streambanks as a seed reservoir.

Beyers (1994) conducted an investigation of an area on the Kouga River system in the Baviaanskloof region to assess the extent to which vegetation controls channel stability. The Rachels and Huis Rivers are tributaries to the Kouga River system. The area is well known for its flash floods which produce high runoff over short time periods. The Huis River catchment is vegetated with fynbos while the riparian zone is characterised by small indigenous woody spp., as well as grasses, sedges and ground creepers. The Rachels River catchment is also largely vegetated with fynbos, but the riparian zone is invaded by *Acacia mearnsii*.

Acacia mearnsii establishes and grows up through the indigenous vegetation in riparian zones. It is able to outgrow the natural vegetation that is well adapted to flash floods. The alien trees, however, are not able to withstand these floods and are ripped out, often dislodging mats of indigenous vegetation and this leads to bank instability and soil erosion.

Floods of similar proportion which caused much erosion on the streambank of the Rachels River (invaded by *Acacia mearnsii*), but not on the Huis River, which has indigenous vegetation, were observed in September 1993. The invasive vegetation on the Rachels River played a major role in the damage caused during the flood event. In comparison, this river did not show any sign of bank instability, and the vegetation in the riparian zone has recovered completely after approximately one year (Beyers 1994).

In newly cleared areas, erosion may also become a problem when cattle start grazing on these areas as they opt to do (Campbell pers. comm. 2001). It has been observed that in the Eastern Cape Drakensberg cattle are inclined to graze in these areas (direct observation by the members of the project team).

Little research on the matter has been done, other than decision-makers being aware of the fact that rehabilitation is necessary after clearing.

(f) Fire hazard reduction and soil erosion

The control of alien plants also leads to fire hazard reduction. As a result of infestations by alien plants the vegetation structure changes and biomass increases. The latter increases the available fuel load and thus fire intensity (Van Wilgen et al. 1997:409). Moreover, difficulty is experienced with the construction and maintenance of fire breaks which become expensive and ineffective.

As with most of the secondary benefits, little knowledge is available on the impact of fires on alien and indigenous vegetation and the role of the WfW Programme therein. A positive correlation is believed to exist between the erosion of soil and very hot fires (Marais pers. comm. 2001). There is a loss in ground soil (upper soil) due to water runoff after extremely hot fires in fynbos and other areas. A few research projects on this subject are currently running – one in Table Mountain Sandstone (TMS), which is not very good soil, and one in limestone areas ("kalksteen"), which is a better quality soil.

In order to determine the reduction of fire hazard benefit of the WfW Programme, the following would need to be quantified:

- fire regimes
- fire cycles
- intensity of fires
- severity of fires
- risk of damage to infrastructure
- protective measures (fire breaks)
- fire fighting costs (helicopters versus manual fire fighting)

(Versveld 1995).

Other variables which also influence the fire hazard are the biomass involved (comparison of the burnability of various areas, e.g. grassland versus Black

Wattles) and the level of infestation. For instance, an area 90% infested will have a substantial biomass, and the bigger the biomass, the more severe the fire in that area (Campbell pers. comm. 2000). The physical outlay of the area also plays a role, as valleys do not burn as readily as other areas (Campbell pers. comm. 2000).

(g) Livestock holding capacity

Another secondary benefit is the gain in the livestock holding capacity of land.

(h) Improved river system services

Yet another secondary benefit of the WfW Programme is the positive impact of increased streamflow on the functioning of rivers and estuarine systems. The WfW Programme in the Keurbooms River catchment, for example, adds volume to fresh water flows into the Keurbooms estuary. Sufficient fresh water supplies into the Keurbooms estuary prevent the estuary mouth from closing, as well as a number of negative ecological impacts from occurring (see Chapter Four).

5.4 CONCLUSION

The most important primary benefit of the Programme is the increase in water yield and most important primary costs are those for capital, operating and maintenance. Secondary costs and benefits, although numerous and important, are difficult to quantify and value. Many of the secondary costs and benefits discussed above require more research than done here before they can be incorporated into cost benefit analyses.

CHAPTER SIX: THE VALUATION OF WATER BENEFITS FOR URBAN AND AGRICULTURAL USE

6.1 INTRODUCTION

The output from a project may be valued in one of two ways: its current price in the market or a proxy value related in some indirect way to current market prices. Both of these approaches are used in this cost-benefit analysis.

The main output of the WfW Programme was forecast based on modelling exercises of the amount of water produced by a catchment with and without the programme (see Chapter 3). The difference is the net incremental benefit per year that accrues to the project. As it is the main output careful attention has to be paid to using the correct method of valuing it.

This chapter values the water benefit from different WfW Programme projects in the Eastern and Southern Cape.

6.2 PRICING OF WATER FOR CONSERVATION PROJECTS IN SOUTH AFRICA – PRINCIPLES

There are two options for valuing water generated by conservation projects in South Africa: marginal cost of equivalent water supply (for urban demand) and excess of marginal willingness-to-pay over marginal cost of water (for agricultural demand). In Chapter Seven a pricing for ecological demand is presented (for the needs of river systems and estuaries). Not considered in this investigation is pricing for forestry demand or the realisation of socio-political objectives (see DWAF 1999b). The Department of Water Affairs and

Forestry (DWAF) set water prices in South Africa in terms of a number of criteria - relative scarcity being only one.

6.2.1 DWAF POLICY ON PRICING OF RIVER WATER

Prior to 1998 water rights in South Africa were allocated on the basis of a mix of riverbank ownership, historical use and water right allocations by the DWAF. This way of allocating water rights was considered to fail to adequately take into account social needs in South Africa and in 1998 a new National Water Act was passed which revised the methods of allocation. South African water legislation was brought more into line with practice in other countries where severe water constraints are encountered, like Australia and the western half of the United States (Field 2000:298). The Act abolished riparian water rights and replaced it with a system of government administered water rights.

In terms of this Act water rights are allocated for a 'reasonable' period rather than permanently. Users are required to register the water resources on their property with the DWAF and obtain licenses in order to use it. The issuing of licenses is administered by the DWAF and it is required that it be based upon the criterion of public interest. These licenses are granted on a five-year cycle with a maximum duration of forty years. Provision is made for the transfer or trade of these water rights, subject to Ministerial consent (National Water Act No 36, Section 25(2) and Section 26(1)). This consent is subject to various requirements being met; the most important being that the new use of the water entitlement is approved in the original license issued.

The effect of the Act has not been to make historical use irrelevant (even though these are explicitly rejected in the Act). In practice historical use continues to be a key factor driving applications for water licenses and their allocation (Backeberg pers. comm. 2001). Although provision is indeed made for water right trading, it is felt by some authorities that this may have been undermined by the Act because of limits placed on the duration of the right and the scope for transferring them (Armitage 1999). Very apparent from the Act and other DWAF policy statements is that the need to conserve and carefully manage water resources is a cornerstone of environmental and resource policy in South Africa (DWAF 1999b).

In economic terms this means allocating water efficiently and getting prices 'right'. DWAF recognises that failing to price water efficiently can result in two kinds of misallocation of water:

- an inadequate incentive to conserve water. The resultant over-use necessitates the expansion of infrastructure prematurely, tying up the country's limited capital resources when they could be better utilised for other purposes.
- some water being used for low-value production instead of high-value production. In the absence of efficiency related water pricing the scope is limited for market reallocation of water supplies from low-value to high-value use.

Getting prices 'right' is interpreted at a macro level as supplying water at a tariff (price) equal to average cost (DWAF 1999b). It is required that sufficient revenue be generated to cover the annual cost of the management of water resources, the operation and maintenance of existing schemes, the rehabilitation of existing schemes and the development of augmentation schemes (DWAF 1999b).

6.2.2 MARGINAL COST PRICING

The most popular approach currently taken to pricing water generated through conservation projects in South Africa is that of a reference value price (see, for example, Marais 1998; van Wilgen et al. 1997; Hosking & du Preez 1999). It refers to the marginal cost of generating water for urban demand. It is not an average cost in that it relates to the unit cost of bringing additional water into urban areas. The average cost is the unit cost of all water brought into urban areas.

The marginal cost price of river water is defined here as the cost of getting an additional cubic metre of water to a point of demand - where it is purchased by bulk buyers, mainly local authorities and agricultural associations. The costs being referred to here are capital, operational and maintenance costs (Sampath 1992). After purchase, the buyers of water add further value in the form of pumping, treatment, distribution and so on. The rationale for using these per unit costs as the price for water generated through WfW Programmes is that this is what additional water would otherwise cost. Examples of unit reference values that have been calculated by various researchers are shown in Table 6.1.

Table 6.1: Selected reference value price estimates of water used in South Africa

Study	Price of water / m^3 (unit reference value)
Van Wilgen et al. (1997) – Skuifraam development	R0,57* / R0,59+
Marais (1998) - Skuifraam scheme	R0,59
Hosking and Du Preez (1999) - Kouga / Krom River scheme	R0,89

*Unit reference value with clearing operations
+Unit reference value without clearing operations

Sources: Marais (1998); Van Wilgen et al. (1997); Hosking & Du Preez (1999).

Van Wilgen et al. (1997) based their calculations of reference value on the Skuifraam Dam development; the next one scheduled to be constructed for the Cape Town metropole. The development cost of this water supply scheme was estimated at R400 million and the operating costs at R2 million/a. Van Wilgen et al. (1997) generated two unit reference values: R0,59/m^3 on the basis that no control of alien plants took place and R0,57 on the basis that it did. The second value of R0,57/m^3 was estimated by incorporating the costs of clearing alien plants and maintaining the catchment in a cleared condition, and benefits of increased water flow from an uninvaded catchment. By way of contrast with the Skuifraam Dam project, Van Wilgen et al. (1997) estimated the cost of alien weed control in the Theewaterskloof conservation project to be R0,08/m^3. Marais (1998) also based his estimate of the unit reference value on the Skuifraam Dam scheme.

Hosking and Du Preez (1999) also used a variant of the unit reference value approach to value water generated from an alien vegetation-clearing project; the one they assessed being in the Tsitsikamma Mountain catchment. They used a price of R0,89/m^3 in their valuation study - the tariff charged for bulk, untreated water from state water supply schemes in the Southern Cape

Coastal Drainage Region to urban and industrial users during 1993/94. Their rationale for using this as the price for water generated through the removal of alien vegetation was that no additional cost of water storage (dams) and transfer was necessary in this case. Their justification was that this infrastructure already existed and had the capacity to accommodate the extra supplies of water runoff generated in this catchment area.

The appeal to all of these authors of using marginal cost as a reference for pricing was that marginal cost is an efficient price - net social benefits are maximised (Sampath 1992; Bate, Tren & Mooney 1999).

The net social benefits associated with an economic activity can be represented by the following equation:

$$NB = \int_0^q P(Q)dQ - C(q) \quad \text{.........(6.1)}$$

where P(Q) represents the demand curve for the commodity or resource Q and C(q) is the cost associated with supplying q amount of commodity Q. The maximisation of net benefits requires:

$$P - \frac{\partial C}{\partial Q} = 0 \quad \text{.........(6.2)}$$

or

$$P = \frac{\partial C}{\partial Q} = MC \quad \text{.........(6.3)}$$

In other words, the maximisation of net social benefit requires price to be brought into equivalence with marginal cost.

However, although marginal cost pricing is efficient, the way it is applied in the above studies begs many questions (Marais 1998; Van Wilgen et al. 1997; Hosking & Du Preez 1999). Two aspects are problematic: (1) in all of these studies unit reference values are constant, and (2) storage projects are treated as alternatives to new water generating ones.

Data relating to the Port Elizabeth area provide evidence in support of a constant marginal cost theory (Table 6.2). The data is of average costs and quantities of water supplied to local authorities in the Port Elizabeth/Uitenhage metropolitan area during the 1980s and 1990s. The trend was for the average real cost of water to remain constant as quantity supplied increased during this period (see Table 6.3).

In the Port Elizabeth/Uitenhage metropole the average real cost price of untreated water from 1978 to 2000 (22 years) was 152,1096 cents/m^3 with a standard deviation of 16,71929. A test for autocorrelation, the Durbin-Watson Statistic, was carried out due to the fact that the data are a time series regression. This statistic showed that autocorrelation did in fact exist. Therefore, a Cochrane-Orcutt regression was carried out to correct this problem. The results of the transformed regression are shown in Table 6.3. Regressing quantity of water on real bulk water prices (MC) yields a statistically insignificant slope coefficient of -0,0008624519 (see Table 6.3).

Table 6.2: Inflation adjusted water tariffs (bulk) for the years 1978 to 2000 for the Port Elizabeth/Uitenhage metropole

Year	**Month**	**CPI Index (a)**	**Conversion factor to 1995 price levels (b)**	**Nominal Bulk Tariffs (c/m^3) (d)**	**Real Bulk tariffs (c/m^3) (d) x (b)**	**Quantity of water purchased million m^3 (excl. PEM)**	**Quantity of water purchased million m^3 (incl. PEM)**
78	Jan	11,0	12,5954	15,08	189,94	8,241	N/A
79	May	12,7	10,9094	17,82	194,41	8,112	N/A
80	May	14,5	9,5551	17,82	170,27	9,968	N/A
81	Jan	16,1	8,6055	17,01	146,38	9,487	N/A
82	Oct	20,6	6,7257	18,23	122,61	18,165	N/A
82	Dec	20,8	6,6610	22,68	151,07	18,165	N/A
83	Jan	21,0	6,5976	24,74	163,22	12,192	N/A
84	June	24,6	5,6321	26,30	148,12	13,379	N/A
85	Jan	26,4	5,2481	30,04	157,65	21,07	N/A
86	Jan	31,9	4,3432	34,35	149,19	15,423	N/A
87	July	39,7	3,4899	38,41	134,05	17,313	N/A
88	Jan	42,3	3,2754	41,81	136,94	17,917	50,445
89	Jan	47,9	2,8924	49,27	142,51	17,13	43,250
90	Jan	55,2	2,5099	63,82	160,18	21,132	52,735
91	Jan	63,1	2,1957	72,18	158,49	17,591	41,062
92	Jan	73,3	1,8901	79,40	150,07	19,612	43,551
93	Jan	80,4	1,7232	87,30	150,44	22,454	50,292
94	Jan	88,4	1,5673	98,90	155,01	17,39	50,015
95	Jan	96,9	1,4298	108,60	155,28	21,341	56,565
96	Jan	103,6	1,3374	108,60	145,24	22,93	57,452
97	July	116,9	1,1852	108,60	128,71	21,279	57,189
98	July	123,8	1,1191	126,00	141,01	20,324	55,075
99	July	131,3	1,0552	140,00	147,73	16,65	52,848
00	July	138,5	1	151,00	151,00	N/A	N/A

Sources: http://www.statssa.gov.za/Economic%20Indicators/CPI.htm; Raymer (pers. comm. 2000).

Table 6.3: Relationship between price of untreated water and quantity of untreated water, 1978-1999[4]

	Intercept	**Quantity (m^3)**	**Adj - R^2**	**F-Stat**	**P-value of F-Stat**
Average cost	163,9	-0,0008624519	0,01	1,26	0,28
	(11,5)	(-1,12)			

Note: t-statistics are shown in parenthesis.

[4] The function estimated cannot be a demand function due to the fact that the prices given were based on cost recovery and were not through revealed willingness-to-pay.

The flat slope of this regression suggests that the average cost of water remains the same as quantity of water supplied to the Port Elizabeth metropolitan area increases (Table 6.3). It follows that the marginal cost of water provision must have been equal to the average cost.[5]

However, constant average costs do not seem likely to continue for much longer. Historically, water supply problems have been resolved through the construction of additional storage and conveyance facilities, but as water resources located further and further away have had to be appropriated, these facilities have become more and more expensive (Armitage 1999). As could be expected, many water supply experts are predicting that most of South Africa's local authorities will now encounter increasing marginal costs (DWAF 1994).

Another curious aspect of the studies in South Africa, using unit reference values is their treatment of water storage projects, like dams, as alternatives for water-generating ones, like alien vegetation-clearing ones. It is because they are treated as alternatives that dam project unit reference prices are posited as opportunity cost prices for water generated through alien vegetation-clearing projects. *A priori*, this practice is peculiar - these are complementary rather than alternative type projects.

When projects are complementary, the efficiency issue is one of whether marginal costs are lower with or without alien vegetation removal. Use of a unit reference value approach to valuing water benefit is inappropriate in this

[5] The fact that average costs tend to be constant over time for this case suggests that marginal costs and average costs are equivalent. In these types of cases pricing by reference to marginal and average costing of water amounts to the same thing.

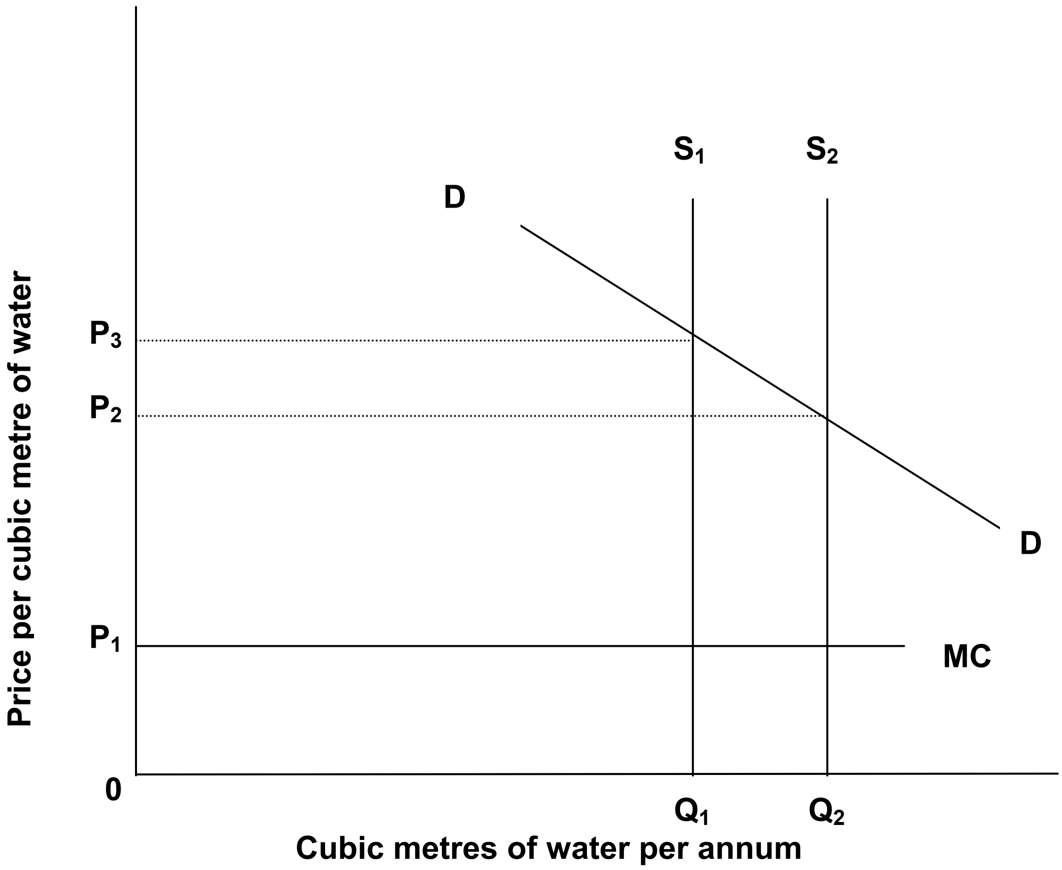
case. To find a unit reference value an alternative type project should be found, one which generates additional water supply and preferably the equivalent amount of it. This is not done in the above cited studies.

6.2.3 WILLINGNESS-TO-PAY APPROACH (FOR AGRICULTURAL USERS)

In cases where additional water is generated for agriculture, pricing with respect to marginal cost is unlikely to be efficient because the marginal cost referred to excludes external costs associated with water generation and abstraction – higher costs imposed on urban consumers, *inter alia*. Typically marginal cost in agriculture refers to dam storage cost and the private costs of pumping and distributing an allocation (quota) of water to farmers by pipe or canal. These costs are unlikely to change as a result of an alien vegetation-clearing programme and almost certainly do not reflect the real worth of the extra water generated for the farmer by this programme.

Farmers are willing to pay more for this quota of water than the private marginal cost. The vegetation- clearing programme releases additional water into the river, not onto the land. To get this additional water from the river onto the land the private marginal cost referred to above must be incurred. The real marginal worth to agriculture of the additional water supply generated is therefore, the excess marginal willingness-to-pay over private marginal cost.

Figure 6.1: A willingness-to-pay approach to pricing water



In Figure 6.1 one demand curve, two short run supply curves (S_1 and S_2) and one long run private marginal cost (MC) curve for agricultural users are shown. The supply curve S_1 is the DWAF administered allocation of water to an agricultural area in the absence of an alien vegetation-clearing project, while the supply curve S_2 is the DWAF administered allocation of water available with an alien vegetation-clearing project. In the absence of an alien vegetation-clearing programme a farmer would be willing to pay P_3 for water (it will vary according to the prices charged for the crop produced), i.e., P_1P_3 above the marginal cost of water supplied ($0P_1$). If, as normally appears to be the case, the water supplied is not directly charged for in water right payments, the willingness-to-pay rate will exceed the marginal cost.

In this case the excess benefit to the buyer (P_1P_3x OQ_1) constitutes a benefit to land ownership and can be expected to be capitalised into land values. For this reason it has become common practice to determine the willingness-to-pay prices by reference to this capitalised portion in the land value (Backeberg pers. comm. 1996). However, there are a number of problems associated with the use of this method of valuing water. First and foremost, the capitalised component of water right value is difficult to estimate because it is typically incorporated within the composite good, the farm. Secondly, unless demand is highly elastic, price P_1P_3 is not the value of the water benefit of an alien vegetation-clearing (Q_1Q_2). With the increase in water supply the willingness-to-pay price may drop. In this case a more appropriate price to value the water benefit of the alien vegetation-clearing programme is $[(P_2 + P_3) / 2] – P_1$.

Although the new National Water Act of 1998 abolished riparian water rights, the water entitlements generated prior to this time have largely been accommodated within the new allocative system (see Section 6.2.1 above for discussion). For this reason water pricing in South Africa by reference to capitalised land values remains relevant, even if undesirable (Backeberg pers. comm. 1996). It is undesirable because the onus for improving the efficiency of water allocations falls on the farm sale market and this mechanism may be too slow and clumsy for this to be achieved. Where recognised existing water right allocations are traded directly, opportunities also have arisen to price water demand using this information (Bate et al. 1999, discussed later).

Agricultural willingness-to-pay prices for water are typically estimated from the difference between the value of land under irrigation (less the value of improvements to make the land suitable for irrigation) and under use for dry (livestock) farming (Backeberg pers. comm. 1996). The approach is summarised in equations 6.4 and 6.5 below.

$$WR = \frac{(W_1 - M - W_2)}{Q} \qquad (6.4)$$

$$W_1 = \frac{I}{r} \qquad (6.5)$$

In the above equations:

WR[6] is the capitalised current value m^3 water right value in Rands

W_1 is the value of irrigation land per hectare,

M is the cost of improvements to irrigated land per hectare,

W_2 is the cost of 'dry' land per hectare (in best alternative use),

Q is the m^3 of water allocation (quota) per hectare,

I is the net annual income that is generated through irrigation and crop production per hectare, minus interest on operating capital and depreciation (and assuming I is received in perpetuity because the water right is granted forever), and

r is the private opportunity cost rate of money income (the discount rate).

When these equations are applied to Backeberg's (pers. comm. 1996) data on an 87,7 hectare piece of irrigated land in the Vaalharts scheme:

WR = 112 c/m^3 (at 1995 price levels) or 160 c/m^3 (at 2000 price levels)[7].

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6 WR could also be expressed as the rental value m^3: WR = $\frac{r}{Q}$ (W_1 - M - W_2).

There have also been many other water right estimates calculated for South Africa in excess of marginal cost of abstraction. For instance, Bate et al. (1999), using information on water right trading in the Crocodile River catchment, Mpumalanga, found that prices paid for water rights ranged widely, with the prices paid for permanent trades being less variable than for temporary trades. They estimated that the future values of each trade discounted back to an average present value of the permanent and temporary trades were R0,0225 and R0,0305/m^3 of water respectively, with a discount rate of 12%. With a higher rate of discount of 16% the relevant NPVs were R0,0302 and R0,016/m^3 respectively.

In a different study, Armitage (1999) estimated the rental value of water on the Lower Orange River (a per annum rate equal to rWR). According to his calculations, based on income capitalisation, the values ranged from R104,50 to R524,50/15000m^3/a employing a 10% real discount rate. Using a higher real discount rate of 15% the values ranged from R144,50 to R774,50/15000m^3/a. In this study average rental rates for irrigation were also calculated, namely 362,39/15000m^3/a at a real discount rate of 10% and R531,33/15000m^3/a at 15%.

Interestingly, average water rental values in the Lower Orange River are similar to those in the Western United States, although there are significant differences concerning the range in prices, time periods over which they are calculated, land use practices, and the discount rate used (Armitage 1999). Values calculated for the United States ranged from R92,43/15000m^3 (or

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[7] Follow-up studies of this work are currently being carried out by the Water Research Commission but the results have yet to be released.

\$1,52/acre/foot) in Oklahoma to R507,72/15000m^3 (or \$8,35/acre/foot) in New Mexico in the Ogalla acquifer in the Western United States over the period from 1979 to 1986 (Torell, Libbin & Miller 1990).

Trade in water rights also occurs to a limited extent in the Sundays River Valley and the Fish River area, situated in the Eastern Cape Province, but information on these trades is difficult to obtain. According to Engelbrecht (pers. comm. 2001) water rights trade for on average R2000/ha in the Sundays River (the water quota being 9000m^3/a) as well as in the Fish River area (the water quota being 13500m^3/a).

These and other estimates are reported in Table 6.4 below.

Table 6.4: Selected willingness-to-pay capital and rental estimates in cents of water used in South Africa at 2000 price levels

Study	Price of water/m^3 (willingness-to-pay value)	
	Capitalised value	Rental value per annum
Backeberg (1996) – Vaalharts Scheme	160,00[1]	12,01
Bate et al. (1999) – Crocodile River Catchment	19,75 / 19,94 26,83 / 10,56	2,37[2] / 3,19[3] 3,22[4] / 1,69[5]
Armitage (1999) – Lower Orange River	28,9 / 28,00	2,89[6] / 4,20[7]
Engelbrecht (2001) – Sundays River Valley	22,2	2,22[8]
– Fish River	14,8	1,48[8]

[1] The values generated by Backeberg (1996) for the Vaalharts Scheme are substantially higher than those for the other studies listed, due to the fact that gravity irrigation is conducted at this study site. The Crocodile River Catchment and the Lower Orange River estimates include high pumping costs
[2] Based on the average present value of a permanent trade at a discount rate of 12%
[3] Based on the average present value of a permanent trade at a discount rate of 16%
[4] Based on the average present value of a temporary trade at a discount rate of 12%
[5] Based on the average present value of a temporary trade at a discount rate of 16%
[6] Average rental rate at a 10% discount rate
[7] Average rental rate at a 15% discount rate
[8] Average rental rate at a 10% discount rate

6.2.4 INCORPORATING RATIONAL EXPECTATIONS

There are many factors which influence the price of water and they change over time - both on the supply and the demand sides (Michelsen, Booker & Person 2000). Ideally, these factors need to be taken into account. This method entails estimating water prices on the basis of expectations of demand and supply over time. It generates a series of different prices for different periods, rather than one.

The main problem with respect to this approach is that the pricing of water becomes subject to speculative forecasting for which the information requirements are great but the margins of error are virtually unknown. Michelson et.al. (2000) found that a large number of factors influenced the value of water rights (in the United States) over time. These included economic growth, population growth, the prime interest rate, farmers' debt-to-asset ratio, price expectations, market share holdings of water rights and changes in the water supply for the region. The information problem is compounded further by substantial variations that exist in water market situations between and within regions.

Michelson et al. (2000) observe that water-right prices vary widely between different regions because of differences in the utilisation of water resources and institutional constraints. Price variations within a given region are mainly due to heterogeneity of the product. Water rights are heterogeneous with respect to water right priority and supply reliability and transfer impediments (Michelson et al. 2000).

Even when water rights are homogeneous in character (the same characteristics in terms of their size, priority and source, and transfer impediments) they also are often subject to large price variation over time (Michelson et al. 2000). These variations are usually due to differences in the net returns to irrigated crop production and make water rights a speculative or risky asset to trade in.

6.2.5 DEDUCTIONS

In pricing the water generated through a conservation project it is important to determine which measure is most likely to reflect an efficient price and identify for whom the water has been generated. A marginal cost measure is probably efficient if the water is being saved for a local urban authority. However, if the marginal cost concept is unlikely to reflect external costs, willingness-to-pay is probably the efficient choice of measure for price. This situation appears typically applicable when the water is generated for agriculture.

Ideally, prices also should be adjusted to take into account expected changes in demand and supply and differences between and within regions. Both marginal cost and willingness-to-pay approaches have their deficiencies, but are consistent with DWAF's (1999b) new water pricing strategy that water should be priced in order to promote the efficient allocation and beneficial use of water (see Section 56(2) (c) of the National Water Act 1998). Their pricing strategy provides for administrative as well as market-related measures to achieve this goal.

Currently the main method used to value the benefit of the water saved through conservation projects is the marginal cost approach. The average of selected estimates cited in this section was 56c/m^3 (at 1995 price levels or 77c/m^3 at 2000 price levels) in the Western Cape. These estimates are based on the costs of water storing rather than water-generating projects. In cases where a willingness-to-pay approach is appropriate the average of selected estimates cited in this section was 7,30c /m^3 (at 2000 price levels).

Given the significant differences in prices generated from different areas and different methods used, it is clearly very important in water project investment analyses that great care be taken in relating the price of water to the specifics of the various locations where the conservation projects are being implemented.

6.3 VALUING WATER GAINS IN THE EASTERN AND SOUTHERN CAPE'S WORKING FOR WATER PROGRAMME – IMPLEMENTATION OF PRICING PRINCIPLES

The principles discussed in the previous section are applied in this section. A procedure for pricing water generated by WfW projects is recommended and applied to six Eastern and Southern Cape projects - those of the Tsitsikamma, Kouga, Port Elizabeth Driftsands, Albany, Kat River and Pott River. The nature of South Africa's water markets is taken as a given. No attempt is made to argue for changes to these markets, e.g. for increasing the scope for the trading of water rights.

6.3.1 A PROCEDURE FOR PRICING WATER GENERATED

If the objective of water pricing for WfW projects is to reflect relative scarcity, the following procedure may be useful.

(a) The time horizon over which one is interested in the price needs to be defined and differences in purchasing power between different years should be defined.

(b) The bulk raw water purchasers and suppliers of the water should be identified.

(c) The question of how information on water pricing is revealed though the interaction of these agents should be examined. Calculations of water prices should be made on this basis.

(d) Changes in demand and supply that are expected to impact on future prices of water should be explicitly taken into account.

Steps (a) and (b) are intended to put the factors on the table that need to be addressed in steps (c) and (d).

The most technical of these steps is (c). As was mentioned in the previous section, if water is to be used to satisfy urban demand, the only available approach is marginal cost pricing.

On the other hand, where additional water supply is generated for agriculture, the real marginal worth is the excess willingness-to-pay over private marginal cost.

Finally, the idea of including procedural step (d) in the list above was to draw attention to the fact that prices are set in a dynamic context.

6.3.2 APPLYING RELATIVE SCARCITY PRICING TO WfW PROJECTS IN THE EASTERN AND SOUTHERN CAPE

These requirements are applied below to six WfW project sites in the Eastern and Southern Cape – the Tsitsikamma, Kouga, Port Elizabeth Driftsands, Albany, Kat River and Pott River sites. In all six cases, the time horizon over which price information was required was set at 100 years, prices were adjusted to 2000 levels (step a), and were assumed to remain constant over this period (step d).

(a) Tsitsikamma site

Primary purchasers and providers (step b)

The runoff produced by the Tsitsikamma mountain catchment that does not flow into the sea is used for agricultural purposes (irrigation farming and livestock watering). A limited amount of water is abstracted by informal settlements for domestic use. No charge is levied on these users except on 12 farmers who pay the Klipdrif Irrigation Board for water they receive from a storage dam.

The 12 farmers who make up of the Klipdrif Irrigation Board in the Tsitsikamma area receive an annual water quota of 6 000m^3/ha at a cost of R320/ha. This translates into a user charge of R0,053/m^3 of water (Van der Merwe pers. comm. 2000). This user charge was agreed upon by the farmers concerned, and covers the capital, maintenance and operational costs of the scheme. This user charge is one for a water storage project and not an environmental water creation project.

How water pricing information is revealed (step c)

The Klipdrif Irrigation Board is a private initiative, but Van der Merwe (pers. comm. 2000) maintains that the annual charge (i.e. R0,053/m^3) represents the true cost of supplying water in this catchment area. The Klipdrif Dam was constructed as a joint venture by local farmers. The Landbank financed (via a private loan) the capital cost of building the dam.

The money paid by members of the Klipdrif Irrigation Board in the Tsitsikamma area is not a purchase of water from a public authority but a private cost associated with adding value. The water resources (water sources and storage facilities on individual farms) in the Tsitsikamma area were registered with the Department of Water Affairs and Forestry in accordance with the new Water Act. The farmers in the area anticipate that in the future water rights in the area will be allocated on the basis of current shares. Currently water rights are not traded in this area.

For reasons already discussed, marginal cost is inappropriate for this case, and a willingness-to-pay approach preferable. Using this approach (income capitalisation)[8] it was calculated that farmers in the Tsitsikamma region were willing to pay up to an average of 12,5c/m^3 of water excluding storage and transfer costs (Van Zyl pers. comm. 2001). This study did not make provision for valuing smaller incremental units of water. For this reason 12,5c/m^3 should be considered a high estimate of the value of the water (assuming a declining marginal willingness-to-pay).

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8 The average net farm income/m^3 of water was used in this approach.

(b) Kouga site

Primary purchasers and providers (step b)

Three main dams store water inflows from the Kouga and Krom River mountain catchments: the Churchill and Mpofu Dams on the Krom River and the Kouga Dam on the Kouga River.

These three dams respectively, have capacities of 33 x 106 m^3, 105 x 106 m^3 and 130 x 106 m^3. On average the dams' capacity is exceeded by inflow once every 3 to 5 years. These dams form the main water supply source for the Algoa Bay region, including the Port Elizabeth/Uitenhage metropole. They are responsible for more than 80% of the water supply to the Nelson Mandela metropolitan area and the Langkloof and Patensie irrigation schemes (Eastern Cape Ministry of Agriculture and Environmental Affairs 1994). In the year 2000 the principal purchasers of the water produced by these catchments were local authorities who purchased it from the Port Elizabeth Municipality (PEM). The value of water is determined in this section with reference to information supplied by the PEM.

How water pricing information is revealed (step c)

The supply tariff for water from the Kouga area, which is levied to local authorities in the Nelson Mandela metropole, is set by the PEM.

The tariff of bulk, untreated water from the Kouga catchment, paid by the local authorities in the Nelson Mandela metropole amounts to R1,51/m^3 (at 2000 price levels). This tariff does not include the local storage and purification costs (Raymer pers. comm. 2000) and was determined on the basis of cost recovery by the PEM.

The tariff of bulk, untreated water from the Kouga catchment, is determined by the Nelson Mandela Metropolitan authority. This water is sold to local authorities in the Nelson Mandela metropolitan area. It is the average cost price of getting untreated water to the point of demand. In accordance with the Department of Water Affairs and Forestry's pricing policy, this price covers capital, maintenance and operational costs (DWAF 1999b).

Several new water development schemes are under consideration or being implemented in the Kouga area, e.g. the WfW projects, the Tsitsikamma Scheme and the Guernakop Dam.

Clearing the Kouga and Krom River catchments (WfW) from riparian invaders has been estimated to yield approximately 9 million m^3 water/a (Briers & Powell 1993). No additional cost for water storage, transfer and treatment is necessary in this case because this infrastructure already exists and has the capacity to accommodate the extra supplies of water runoff generated in this catchment area (Raymer pers. comm. 2000). Based on a unit capital cost of R3 000/ha for initial clearing and R200/ha/a for follow-up operation, the estimated cost of clearing the 7 000 hectares of invaded areas in the riparian zone is R21 million for initial clearing, plus R1,4 million/a for six years of follow-up clearing (Briers & Powell 1993). Using this cost and assuming that follow-up clearing will be required once in every year to prevent re-infestation and a cost of capital rate equal to 8%/a, they estimated the unit reference value to be R0,21/m^3 water. For the purpose of this study, this value was adjusted for inflation to arrive at a current (2000 price level) cost of R0,34/m^3. This scheme can be seen as one of new water creation.

Two alternative ways of getting bulk, untreated water to the point of demand (the Nelson Mandela metropole) are also currently being explored. One proposal is that runoff from the seaward side of the Tsitsikamma Mountain catchment be captured and piped to the Kouga/Krom water supply system (known as the Tsitsikamma Scheme). This scheme has a unit reference value of R0,57/m^3 at 1996 price levels. At 2000 price levels this unit reference value amounts to R0,74/m^3. This option would yield approximately 10 million m^3/a extra flow into the Nelson Mandela Metropole's current storage dams. Another proposal is to construct an additional storage dam to supply the Algoa Bay region, the Guersnakop Dam. This dam would yield approximately 26 million m^3/a. The unit reference value at 1996 price levels for this option is R0,62/m^3 (Perez pers. comm. 2000). At 2000 price levels this reference value is R0,80/m^3.

The Tsitsikamma Scheme is a water-creating one, whereas the Guernakop Dam is a storage-and-transfer one. It would be an error to use the Guersnakop Dam option as an alternative to the WfW project because it is a different type of water project (as already discussed).

It is deduced that the value of water yielded by conservation projects in this area is the unit reference value of the Tsitsikamma Scheme, 74 c/m^3 (cost saved of not having to have water-basin transfer from the Tsitsikamma to the

Kouga System). The Tsitsikamma Scheme is an alternative water-creating project and would supply approximately the same amount of water as the WfW project. It is the lowest cost alternative water supply scheme currently under consideration to satisfy the Nelson Mandela metropolitan area's demand.

(c) Port Elizabeth Driftsands site

Primary purchasers and providers (requirement b)

The water in the Port Elizabeth Driftsands area is not currently being abstracted and no purchaser currently exists for this water, or is envisaged in the immediate future (Raymer pers. comm. 2000). The most likely potential buyer of this water would be the Nelson Mandela Metropolitan authority (NMM).

How water pricing information is revealed (step c)

The WfW project in the Port Elizabeth Driftsands area focuses on the removal of alien vegetation, most notably *Acacia* spp., where it is believed that a sustainable groundwater resource (aquifer) exists. Studies conducted by Lomberg, Rosewarne, Raymer & Devey (1996) indicate, however, that in terms of yield and water quality, the TMGS aquifer in the NMM area is not a potential source of municipal supply, unless untapped aquifers exist at greater depths than so far exploited. Raymer (pers. comm. 2000) observes that the pockets of water that do collect in the fractured rock base of this aquifer are too small for the abstraction of this water for the PEM (in order to augment local supply) to be economically feasible.

In addition there are contamination problems with this water. Barbour, Rosewarne & Lomberg (1996) conducted a study to investigate the possible contamination of groundwater resources due to the existence of the Arlington Waste Disposal Site. They installed boreholes in the area and analysed water samples. It was found that the only occurrence of groundwater within the sand succession is related to perched water of limited extent (Barbour et al. 1996). No other incidence of groundwater occurrence in the upper formations has yet been reported in the Port Elizabeth area. Moreover, no water strikes yielding in excess of 0,5 l/s[9] were encountered in the Peninsula Formation.

In an attempt to establish the water quality of the groundwater resource Lomberg et al. (1996) processed approximately 800 samples over a three-year period from 48 boreholes selected to cover as much of the Cape Recife Peninsula as borehole distribution would allow. The groundwater was found to be of relatively poor quality. Furthermore, quality tended to be spatially erratic with water unable to be used for irrigation in close proximity to boreholes with marginally potable water. Electrical conductivity and chloride values tended to be high and exceeded maximum allowable limits for domestic water supply in many unrelated boreholes. Nitrates also commonly exceeded recommended limits.

All boreholes within the PEM area south of Cape Road, Port Elizabeth, derive groundwater from the same aquifer. Approximately 220 private boreholes exist, many of which pump low volumes for garden irrigation. Very few are

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9 Raymer (pers. comm. 2000) argues that 0.5 l/s is a negligible amount of water.

used for domestic needs and some are sporadically used for drinking water supply (Lomberg et al. 1996).

The area to the south and east of Arlington, Port Elizabeth, comprising the Driftsand State Forest belongs to NMM and is at present undeveloped. Even if this land is in future developed, the Churchill Pipeline, which supplies water from the Churchill Dam on the Krom River, traverses the land and will in all likelihood be preferentially used (Lomberg et al. 1996).

The findings of the Lomberg et al. (1996) study can be summarised as follows:

- borehole yields on the Cape Recife Peninsula only average between 0,55 and 1,1 l/s;
- borehole water quality is generally poor, highly erratic and seldom potable;
- the aquifer in the Port Elizabeth area does not form a strategic water supply to supplement the city's needs;
- groundwater does form an indirect resource as it reduces reliance on the municipal supply for garden irrigation in times of drought; and
- widespread contamination of groundwater is thought to occur through diffuse sources related to urbanisation in Port Elizabeth.

Based on the study conducted by Lomberg et al. (1996) it is concluded that further exploitation of groundwater resources in the Port Elizabeth Driftsands area is unlikely. For this reason it is deduced that water added through water conservation projects in this area to this aquifer has zero value, i.e., that the appropriate value of water added by this project is R0/m^3.

(d) Albany site

Primary purchasers and providers (requirement b)

The additional water produced in the Kowie mountain catchment situated in the Albany area, due to the WfW project, is mainly used for agricultural purposes (livestock watering). The water of the Kowie River has a high salinity and is unsuitable for irrigation, although it is used to limited extent for this purpose. Currently the farmers in this area do not pay for the use of this water.

How water pricing information is revealed (step c)

There is no catchment management charge for the use of the water from the two rivers in the Albany area: the Kowie and Kariega Rivers. Moreover, no water rights are currently being traded. The only costs incurred are private in nature - costs associated with the pumping and storage of water by farmers (Penny pers. comm. 2000). These private costs differ from farm to farm depending on the distances the water needs to be piped as well as the capacity of storage facilities.

As mentioned above, there are no water rights market in this region and almost no information on specific irrigation land prices exists. For this reason no estimate of the willingness-to-pay value could be made. In cases like this one the best option is to seek information on willingness-to-pay relating to a region with similar characteristics (Backeberg pers. comm. 2001). However, due to the unique and site specific features of the Albany area, this proved an almost overwhelming task. As the water from the Kowie River is mostly used for livestock watering while it has a high salinity content and is unsuitable for irrigation, our estimate is that the agricultural value of water currently being generated through the WfW in the Albany area is very close to R0/m^3.

However, the river water may yield value in the estuary, as this estuary supports many recreational activities. Our only value reference for estuary inflows was derived for the Keurbooms River (see Chapter 7).

(e) Kat River site

Primary purchasers and providers (requirement b)

The water in the Kat River mountain catchment, which flows through the Kat River area, is used by community farmers located in the informal settlements near the town of Balfour (Kakana pers. comm. 2000) as well as citrus farmers situated downstream from these informal settlements. These farmers do not pay for this water unless they belong to the Kat River Irrigation Board (which has 12 members).

Members of the Kat River Irrigation Board receive an annual quota of 7 000m^3/ha at a cost of R120, which translates into R0,017/m^3 of water (Roberts pers. comm. 2000). This user charge/tariff was agreed upon by the farmers concerned, and covers the cost of capital, maintenance and operations. It is a private cost. Their water is extracted from the Kat River Dam, a dam with a capacity of 25 million m^3. As already stated, other farmers in the area (mainly citrus farmers abstracting directly from the river) do not pay for water they abstract.

How water pricing information is revealed (step c)

No public charge for Kat River water is levied and water rights are not traded in the area. The preferred way of valuing this water is in terms of a willingness-to-pay approach, by calculating land value differences using the income capitalisation method. This was done for the Kat River area, and it was found that farmers were willing to pay up to 15,75c/m^3 of water in excess of abstraction costs (Roberts pers. comm. 2001).

(f) Pott River site

Primary purchasers and providers (requirement b)

Water from the Pott River catchment is used only to a limited extent for irrigation farming, domestic consumption and livestock watering (Laverock pers. comm. 2000). Most of the water flows into the former Transkei region, where some of it is abstracted by informal settlements for subsistence farming. There is no storage dam on this river, and no payment is collected for the water that is abstracted from the Pott River. Most of the water flows into the Umzimvubu River and from there into the sea.

How water pricing information is revealed (step c)

No price is charged for water in the Pott River area (there are no catchment management charges and water rights are not traded) and almost no information is available on irrigation land prices. For this reason, a willingness-to-pay price for the water could not be calculated. However, this problem is not serious for this case because the water currently in the Pott River is not a scarce resource from either urban or agricultural perspectives. Any extra water currently generated in the Pott River will almost certainly end up in the Umzimvubu Estuary. This estuary is not used for recreational purposes as heavily as the Keurbooms and Kowie Rivers. For all of these reasons our estimate is that the price of water currently being generated through the WfW project in the Pott River area is R0/m^3.

6.3.3 DEDUCTIONS

In valuing the water benefit of WfW projects it is important that certain procedural steps be taken. These are as follows:

- The time horizon over which one is interested in the price needs to be defined and differences in purchasing power between different years should be defined.
- The bulk raw water purchasers and suppliers of the water should be identified.
- The question of how information on water pricing is revealed though the interaction of these agents should be examined. Calculations of water prices should be made on this basis.
- Changes in demand and supply that are expected to impact on future prices of water should be explicitly taken into account.

We have shown how these steps can be applied to selected sites in the Eastern Cape WfW Programme. Our conclusions with respect to water values are presented in Table 6.5 below.

Table 6.5: Values of water for WfW projects in the Eastern and Southern Cape Province[1]

Site	Value of water (c/m^3)[2]	Valuation Method
Tsitsikamma	12,5	willingness to pay[3]
Kouga	74	marginal cost[4]
Port Elizabeth Driftsands	0	potential user response[4]
Albany	0	user response
Kat River	15,7	willingness to pay[5]
Pott River	0	non-scarce resource

1 All prices other than that for the Kouga project were derived by reference to agricultural willingness-to-pay. The Kouga project's water was valued by reference to urban opportunity cost calculations.
2 All prices are at 2000 levels.
3 Derived using information supplied by Van Zyl (pers. comm. 2001) for the Tsitsikamma area
4 Raymer (pers. comm. 2000)
5 Derived using information supplied by Roberts (pers. comm. 2001) for the Kat River area

These values tell a story of their own. Briers and Powell (1993) generated a cost price in a Kouga WfW project of $21c/m^3$ at 1993 prices. Adjusted to 2000 price levels this cost would be $34c/m^3$. The latter value exceeds the values generated at all sites except for the one in the Kouga region, which is one generating additional water to satisfy NMM demand. It is concluded that cost-benefit analyses of WfW projects, whose primary purpose is generating water for demand other than metropolitan, are likely to yield negative results.

6.4 CONCLUSION

Chapter Six involved a discussion on the valuation of benefits. The methods of valuing the water (the primary benefit and output) were outlined. Moreover, a procedure was suggested for valuing water generated by the WfW Programme in terms of marginal cost and/or willingness-to-pay references.

Using these procedures water values were determined for the six projects selected in the Eastern and Southern Cape. These values were shown in Table 6.5.

CHAPTER SEVEN: VALUING THE FRESHWATER INFLOWS INTO THE KEURBOOMS ESTUARY

7.1 INTRODUCTION

The water of the Keurbooms River near the Southern Cape town of Plettenberg Bay is demanded both for use in the town and in the estuary, where its inflow is needed to preserve environmental services used for recreation. The estuary derives its freshwater supplies through inflows from the Keurbooms and Bitou rivers. These are influenced by discretionary dam water releases and the actions of the WfW Programme in the upper reaches of the catchments of these rivers. As a result of these inflows the estuary mouth is kept open. Should the mouth of the estuary close negative ecological impacts would occur. These negative ecological impacts would also have negative economic consequences; the primary one being that the residential and holiday recreational appeal of the Plettenberg Bay area would be reduced.

Measuring this reduction in rand terms can be done in several ways, e.g. through travel cost, hedonic pricing or contingent valuation methods. This chapter does it using the contingent valuation method (CVM). The advantage of CVM was that it could be better fine-tuned to the specific economic consequences of the mouth closing than the travel cost and hedonic price methods.

Contingent valuation is a survey technique that places monetary values on products and services for which market prices do not exist or do not reflect the real value of the good/service. Respondents are presented with hypothetical scenarios and asked questions about the amount of money they would be prepared to spend to make them become reality. The values that are derived are "contingent" upon the realisation of the scenarios.

7.2 THE DEMAND FOR WATER IN THE PLETTENBERG BAY AREA

There are three sources of demand for water in the Plettenberg Bay area: urban, agricultural and forestry. Urban demand is from both industrial and domestic users, while irrigation use is the main reason for agricultural demand. By forestry water demand is meant water use by plantations (not indigenous forests).

7.2.1 URBAN DEMAND

Urban water demand comprises of all demand arising from local authorities and communities. It includes water used for domestic and industrial purposes.

The area of Plettenberg Bay includes Kranshoek, Bossiesgift, Welkom, Hillview, Wittedrift and the coastal strip between Plettenberg Bag and the western bank of the Keurbooms River.

The estimated future urban demand for water in the Plettenberg Bay area is shown in Table 7.1 below. Estimated growth rates vary from 4% per annum to 6,85% per annum.

Table 7.1: Expected future urban water demand for the Plettenberg Bay area

Annual water demand growth rate		1992	1995	2000	2005	2010	2015	2020
6,85 %	Annual demand (million m^3/a)	1,93	2,35	3,27	4,56	6,35	8,84	12,32
	Sustained peak (Mℓ/d) (Estimated PF = 2,0)	10,58	12,88	17,92	24,99	34,79	48,44	67,51
5,5 %	Annual demand (million m^3/a)	1,93	2,25	2,96	3,87	5,05	6,60	8,63
	Sustained peak (Mℓ/d) (Estimated PF = 2,0)	10,58	12,38	16,22	21,21	27,67	36,16	47,29
4 %	Annual demand (million m^3/a)	1,93	2,17	2,64	3,21	3,90	4,75	5,78
	Sustained peak (Mℓ/d) (Estimated PF = 2,0)	10,58	11,89	14,49	17,59	21,37	26,03	31,67

Source: Geldenhuys 2001.

The growth rate may be reduced if water tariffs are raised.

The current water tariffs for the Plettenberg Bay Municipal area are shown in Table 7.2 below. Tariffs are grouped according to three user groups: domestic, business/commercial/other and rural. Water tariffs for each group increase as rates of consumption, measured in terms of kilolitres, increase. They include distribution costs as well as storage, transfer and treatment costs. The average cost of their raw bulk water supply could not be determined (Geldenhuys pers. comm. 2001).

Table 7.2: Water tariffs in the Plettenberg Bay Municipal area

User group	R/kl
Domestic	
0 – 20 kl	Free
21 – 25 kl	1,75
26 – 30 kl	2,10
31 – 40 kl	2,65
41 – 50 kl	3,20
51 – 60 kl	4,20
61 – 70 kl	5,30
Above 70 kl	10,50
Business/Commercial/Other	
0 – 60 kl	1,75
61 – 100 kl	3,20
Above 100 kl	5,30
Rural	
0 – 20 kl	Free
21 – 25 kl	1,75
26 – 30 kl	2,10
31 – 40 kl	3,20
Above 40 kl	10,60

Source: Geldenhuys 2001.

7.2.2 AGRICULTURAL DEMAND

Agricultural demand for water in the area is mainly for irrigation. It is estimated, using existing aerial photography, supplemented with ground truthing, that an area of 3 256 hectares land is under irrigation in the area: 70% for grazing, 4% in orchards and 26% under vegetables (Geldenhuys 2001). The annual water demand of these irrigated areas amounts to about 17,6 million m^3.

7.2.3 FORESTRY DEMAND

SAFCOL is the major forestry company in the study area, but there are also four other significant private forests in the area.

Forestry water usage in the area was determined using the Van der Zel/Nänni-curves (Geldenhuys pers. comm. 2001). The natural veld in the study area consists of a wet Protea/Restia type of veld with trees and grass intermixed. A well-managed plantation would, at maximum, use 50mm per annum more than this type of veld (Van der Zel & Kruger 1975). The effective incremental annual water demand of forestry plantations in this area may vary from 50mm to 100m depending on the management practices applied and the assumptions made with regard to the composition of the natural veld (Geldenhuys pers. comm. 2001).

There are at present 9 100 hectares of planted forests in the Plettenberg Bay area. According to Dr Van der Zel of the Department of Water Affairs and Forestry (Forestry Planning), forestry in this area is expected to grow at an average annual rate of about 60 hectares per annum. This growth will bring the estimated afforested area in 2020 to 10 600 hectares.

7.3 METHODOLOGICAL ISSUES

The contingent valuation method (CVM) generates values based on expressed preferences (Turner et al. 1993:122) by asking individuals explicitly to place values upon environmental goods and services. Ciriancy-Wantrup (1952) originally suggested the use of CVM. Davis (1963) used CVM to derive the recreational value of woodlands in the United States of America. It has been refined both theoretically and empirically during the 1970s and 1980s, mainly in the United States of America. It has been most frequently employed in the USA to generate values for environmental amenities (e.g. sport fishing) and public goods (e.g. national parks). In South Africa this method is being increasingly applied, even in the field of water pricing (see for example Veck & Bill 2000; Turpie & Joubert 2000).

In what follows the theoretical basis for the contingent valuation method is discussed, its application described, the problem areas with the method outlined, the choice of welfare measure discussed and the issue of non-use values addressed.

(a) The theoretical basis for the contingent valuation method (CVM)

Economic value can be captured by employing willingness-to-pay (WTP) or willingness-to-accept (WTA) responses as estimates of compensating variation[9] and equivalent variation[10]. The CVM is a survey technique that entails asking respondents their WTP and/or WTA for a change in the level of an environmental service or resource against the background of hypothetical market circumstances. The values generated are contingent upon these circumstances materialising. Estimates of compensating variation for welfare-improving activities and of equivalent variation for welfare-decreasing activities are obtained through the use of WTP responses. Information pertaining to compensating variation for welfare decreasing activities and equivalent variation for welfare-increasing activities are provided by WTA responses. The values generated through the CVM have come to be considered proxies for real prices where the technique is properly applied (Fishbein 1967; Ajzen & Fishbein 1970; Ajzen 1971).

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9 The compensating variation (CV) of a change in price is the change in income that would compensate for the price change.

10 The equivalent variation of a price change is the change in income that, with prices remaining at their old levels, would be equivalent to the proposed price change.

(b) The application of contingent valuation method (CVM)

The contingent valuation method (CVM) can be divided into six steps (Hanley & Spash 1993).

The first step is to establish a credible and realistic market-related reference for the environmental service flow concerned. The analyst must devise a hypothetical request for payment for services which bridges the gap as far as possible between theory and reality. A description should be provided of how funds to make the payment (the bid vehicle) will be raised. The following should be specified: whether all consumers will pay a fee if there is an alteration in environmental service flows, how the fee concerned will be established and how the decision will be reached on whether to proceed with the project. The bid vehicle can take the form of property taxes, income tax, utility bills, trust fund payments or entry fees.

The second step entails administering the survey. Contingent valuation surveys are different from conventional surveys in three ways. Firstly, respondents usually have no or little experience with the goods/services that the contingent valuation survey is aiming to value. Secondly, hypothetical markets are utilised in these surveys and these markets must be credible and realistic. Thirdly, respondents must take extra care in determining their preferences and valuing these preferences.

The determination of preferences can be done by personal interviews, telephonic interviewing or mail surveys. Personal interviews are a very good way of soliciting responses. Although a more expensive and time-consuming technique, it allows more complicated scenarios can be explained better. The conveyancing of information over the telephone is difficult due to time constraints, but has the advantage of being cheaper. Mail surveys tend to suffer from very low response rates, but have the advantage of avoiding interviewer-related biases.

In the survey people are asked either what they are willing to pay (WTP) in order to secure the preservation of an environmental asset or an environmental improvement, or what they are willing to accept (WTA) to live with the degradation of the asset (Turner et al. 1993:122). A WTP figure, for example, may be derived in the following ways: as a bidding game, a closed-ended referendum, as a payment card, as an open-ended question, as an auction or as a take-it-or-leave-it offer. Bid vehicles have a significant effect on WTP values and open bid formats should be avoided (Perman, Ma & McGilvray 1996). A structured bidding process such as a bidding game, may be preferable (Perman, Ma & McGilvray 1996).

- A bidding game entails suggesting an amount, and requiring either yes or no answers to bids until the respondent's maximum WTP is reached.
- A closed-ended referendum is conducted by suggesting a single payment to which the respondents either reply yes or no.
- A payment card system involves the presentation of a card listing a range of values to respondents. The respondent is asked to circle the value that represents their maximum willingness to pay for the good or service.
- The take-it-or-leave-it offer asks respondents to answer whether they would be willing to pay a set amount for a good.
- An open-ended question entails soliciting a response from an individual as to his/her WTP. No amount is suggested to the respondent to consider.

- In English auctions, bids are increased until the highest valuation is reached. In Dutch auctions, the initial price is set high and lowered until someone chooses to buy at that price (Mitchell & Carson 1989).

The third step entails calculating the mean and median bids once all responses have been collected. Typically some responses have to be excluded from this calculation because the respondents abstained from providing a WTP amount, or had an objection in principle to paying directly for environmental service flows. These respondents submit what are termed “protest bids” of zero (Hanley & Spash 1993:55). Also important in this step is the identification of outliers, that is, very large bids. They have to be assessed for plausibility. The problem of outliers can be avoided by using median rather than mean WTP or WTA (Hanley & Spash 1993:56).

The fourth step entails estimating a bid curve using WTP/WTA amounts as the dependent variable and a range of variables, such as income (Y), education (E) and gender (G) of the respondents (i) as the explanatory variables:

$$WTP_i = f(Y_i;\ E_i;\ G_i) \quad \text{.......} \quad (7.1)$$

Bid curves are used to test for theoretical validity or plausibility, i.e. whether the results are consistent with theoretical expectations/economic theory.

Step five entails benefit aggregation. There are three aspects to this. Firstly, the sample must be selected so that it represents the desired/target population. The sample frame includes everyone whose utility could be expected to be influenced significantly by the activity, or everyone within an appropriate political boundary who will be influenced by the activity (Hanley & Spash 1993). Secondly, careful consideration has to be given to the move from the sample mean to a mean for the total population. The average WTP (the mean bid) of respondents must be multiplied by the total number of people who enjoy the environmental service flow concerned in order to secure an estimate of the total value (consumer surplus) which people attach to that service flow (Turner et al. 1993). For this reason it is important that the sample not be a biased reflection of the target population (Hanley & Spash 1993). Thirdly, care must be taken to ensure that the time period is correct over which benefits are aggregated and that proper discounting procedures are used to standardise benefit flows over time.

The sixth step involves an assessment of the success of the application of CVM.

(c) Problems associated with contingent valuation method (CVM)

Four types of bias in CVM have been the main focus of attention: strategic bias, design bias, mental account bias and hypothetical bias (Tietenberg 1992:81).

Strategic bias

Strategic bias refers to a situation where the respondent intentionally provides a biased answer (understates WTP or overstates WTP) with the goal of influencing the amount of the good/service provided, the amount or system for collecting money to provide it, or in damage appraisals, the compensation (Mitchell & Carson 1989). This type of bias can also be ameliorated by declaring at the outset to the respondents that all will pay the average bid and by eliminating outliers, concealment of others' bids and making the environmental action dependent on the bid.

Design bias

The way the contingent market is designed and presented to the respondents will influence the individual's responses (Cummings, Brookeshire & Schultze 1986). Bias with respect to design relates to the following:

- The bid vehicle used can influence the mean bid. A bid vehicle should be chosen that will most likely also be used in practice, but this can also cause problems. If entry fees are charged to visit an environmental resource, e.g. a wildlife reserve, some respondents may feel this would debase their recreation experience and make protest bids. Protest bids might also be encountered if the bid vehicle used is a tax. It is recommended that the bid vehicle that is used not be controversial (it should be neutral).

- Starting point bias arises whenever a bidding game format is used. The problem is that the starting point (bid) given to respondents may be viewed by them as an approximation of the correct value. The payment card format was developed to correct for this kind of bias.

- Information bias may occur whenever respondents are asked for valuations of characteristics with which they have minimal or no experience (with the result that their valuation is based on false perceptions). Sufficient information should be provided to the respondents with respect to the environmental good or service in order for their bid to be an informed one.

Mental account bias

This bias relates to a two-step decision-making process (Hanley & Spash 1993). The first step in this process entails the decision on the amount of income, wealth and time to spend on environmental services and resources in general within a given time period. Respondents face a budget constraint. The sum of this income, wealth and time is a fixed total which is apportioned across all environmental goods and services. We can denote the gross environmental budget B, and the amount apportioned to any good or service i, B_i. This type of bias would exist if a CVM estimate of mean value for i is sought, when an individual bids an amount $\hat{B}_i$; where $\hat{B}_i > B_i$. In the extreme case $\hat{B}_i = B$; the whole budget is allocated to this one service. In order to avoid this bias it is important to remind respondents of their budget constraints (that spending on a good/service necessarily means a reduction in other kinds of goods/services that can be purchased).

Hypothetical bias

Hypothetical bias arises when the very fact that respondents are asked to provide valuations in a hypothetical market results in responses that are systematically different from value that would be generated in real market situations. The occurrence of hypothetical market bias depends on how questions are asked, the credibility and reliability of the market as perceived by the respondents, and on whether WTP or WTA are used. If the scenario, captured in the hypothetical market, is not familiar to the respondent, it must be easy to understand and explain.

(d) The choice of the welfare measure

WTA and WTP are normally used in CVM studies to measure welfare changes. These two measures are almost equivalent where the ratio of consumers surplus to income is low and the income elasticity of demand for the environmental good or service in question is low. If these conditions do not hold then a discrepancy between the values generated by these two measures can be expected. WTA questions generate relatively more protest bids than WTP questions and in most cases WTA bids exceed WTP bids (Hanley & Spash 1993).

The reasons why WTA bids normally exceeds WTP bids are as follows:

- Loss diversion – the difference in the WTA and WTP amounts may be rational in the sense that it reflects real underlying preferences. Respondents may well value a certain decrease in entitlements more highly than a similar increase in entitlements because they have diminishing marginal utility from income.
- Income and substitution effects – WTP bids are constrained by income, whereas WTA bids are not, and if substitution possibilities are limited, then WTA bids will exceed WTP bids;
- On average WTA will be overstated and WTP understated if most of the respondents are risk averse and given only one opportunity to value the environmental good or service (Hanley & Spash 1993). The individual is not sure how much he/she values the environmental good or service and, rather than face the possibility of loss, bids an amount in excess of the expected value of the loss in an attempt to reduce/eliminate the possibility.

The WTP measure tends to be preferred in the literature, all other things being equal, due to the fact that people experience difficulty with accepting compensation in the form of money for changes in the levels of environmental services and resources and there is less evidence of strategic bias in WTP than WTA (Perman et al. 1996). Herbelein and Bishop (1986) conducted research on behavioural intention versus observable buying and selling behaviour and found that willingness-to-pay relates well to social psychological theory due to the fact that consumers are heavily involved in buying transactions and therefore develop a sound frame of reference about willingness-to-pay for goods and services. If a willingness-to-pay format is used it should correspond to a potential future event, not one that has already occurred.

(e) Non-use values

An advantage of the CVM over other valuation techniques, e.g.travel cost method and hedonic pricing method, is that it can be adapted to capture non-use values. Utility may be derived by an individual due to the mere existence of an environmental service or resource, even if he/she does not physically frequent the site.

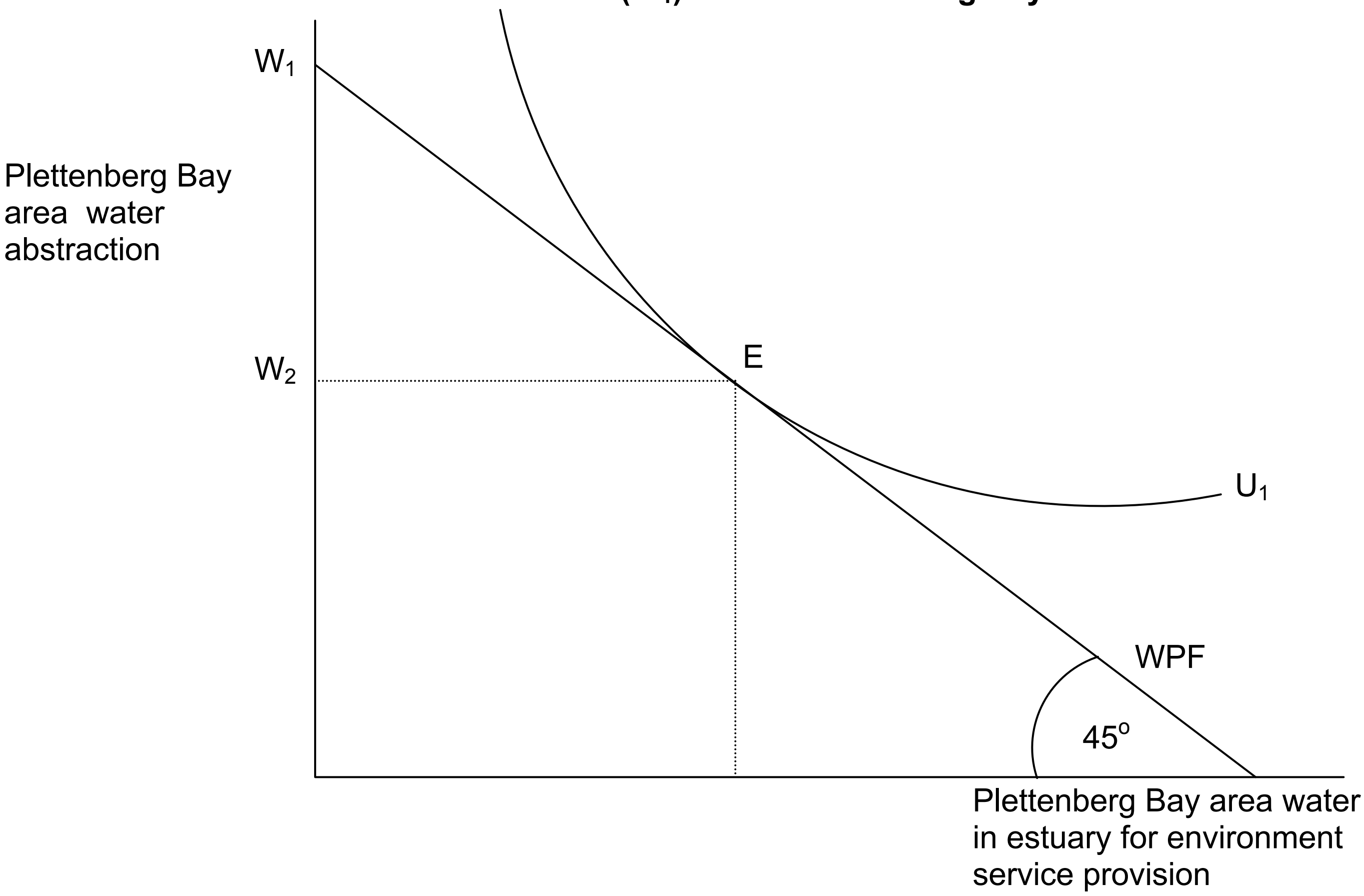
Early CVM studies described total value as consisting of four components: expected consumer surplus (use value), option value, existence value (or non-use value) and bequest value (Hanley & Spash 1993). Use values are derived from actual or potential future consumption of the environmental good or service. Option value can be defined as the value that comes about from retaining an option to an environmental good or service for which there is demand uncertainty (Perman et al. 1996). Bequest values arise because people wish to pass on environmental goods to succeeding generations. Proof of the existence of these values is provided by the general public's willingness to pay to preserve natural resources they themselves derive no direct or indirect benefit from, e.g. a flower spp. found in a remote land or fish in the sea (Perman et al. 1996).

7.4 THE THEORETICAL BASIS FOR APPLYING THE CONTINGENT VALUATION METHOD AS A WAY OF VALUING THE ENVIRONMENTAL SERVICES PROVIDED BY THE KEURBOOMS ESTUARY

As a consequence of reduced freshwater inflows into the Keurbooms Estuary and increasing consumptive demand for water in the Plettenberg Bay area (see Section 7.2) at some point (in the near future) the mouth of the Keurbooms Estuary will close. When this happens a whole range of environmental services on which recreation is dependent will be negatively affected (see Chapter 4).

The hypothesis of this study is that the people who use these services are prepared to pay to prevent these negative impacts from occurring. The amount they are willing to pay is $(W_1W_2) \bullet (P_w)$, where P_w is the price of water and W_1W_2 is shown in Figure 7.1 below.

Figure 7.1: The water allocation possibilities frontier (WPF) and social welfare function (W_1) for the Plettenberg Bay area



In Figure 7.1, WPF represents the water allocation possibilities frontier for the Plettenberg Bay Area – showing different allocations of water possible from the Keurbooms River inflow. U_1 is a welfare contour, representing part of the Plettenberg Bay area residents and visitors social welfare function. The optimum allocation of water is where WPF is tangent to U_1, namely at point E.

Point E and W_1W_2 can only be determined if the social welfare function in water use is specified. We made no attempt at doing the latter but instead relied on expert opinion (Wooldridge 2001) to guess at W_1W_2. Expert opinion was that W_1W_2 was the minimum water inflow required to keep the mouth of the

Keurbooms Estuary open (Wooldridge 2001). In order to estimate P_W the following CVM study was undertaken (see below).

7.5 RESEARCH DESIGN

7.5.1 POPULATION AND SAMPLE

To obtain a representative sample of the population of users of the Keurbooms Estuary, the following steps were taken: the target population was defined, the sampling frame was determined, a sampling technique was selected, the sample size was determined and the sampling process was executed. The sampling design process was as follows:

1. Target population: users of the Keurbooms Estuary in the Plettenberg Bay area (extent) during the survey period (time). The target population was determined through consultation with local authorities and pilot studies on the users of the estuary. It was deduced that the population of users was made up of the following groups: anglers (1 800), baiters (600), swimmers (5 400), water frontage/access (490), birdwatchers (60), boaters (1 400) and scenic benefit (3 500). The sample population amounted to 13 250.
2. Element: respondents – users (male or female).
3. Sampling unit: users.
4. Sampling frame: lists provided by the following institutions were used to determine the sample population: the angling club, the bird-watching club, town planners department, hotels, camp sites and B & Bs, and the Department of Nature Conservation.
5. Sampling technique: stratified sampling. The sample population was stratified by type of user. Five strata of users were utilized: fishermen, boaters,

swimmers/bathers, water frontage owners and others (for example bird-watchers). Proportionate sampling was conducted whereby the size of the sample drawn for each stratum was proportionate to the relative size of that stratum in the sample population. The proportional allocation formula was as follows:

$$n_{\hbar} = \frac{nN_{\hbar}}{N} \quad \text{...} (7.2)$$

where $n_{\hbar}$ = sample size for stratum $\hbar$

n = size of total sample drawn

$N_{\hbar}$ = size of stratum population

N = size of total sample population.

Proportional allocation assumes that the strata are independent.

6. Sample size: 150.[11]
7. Execution: The selected users of the Keurbooms Estuary were interviewed.

7.5.2 KNOWLEDGE AND INFORMATION

An important component of a contingent valuation survey is the respondents' knowledge and information about the service that they are valuing. For this survey it was decided that the following information needed to be conveyed to the respondents:

11 Due to the fact that personal interviews are time-consuming and expensive to conduct the sample size was limited to 150.

(a) Property rights

The benefits of effective catchment management, as carried out by the WfW Programme or increased dam water releases, would be available to all people who reside in Plettenberg Bay, or otherwise benefit from activities within the Keurbooms Estuary.

(b) The person expected to make contributions towards catchment management or dam water releases, users, was asked to respond.

(c) The nature of the public good

Effective catchment management, as carried out by the WfW Programme or increased dam water releases, would ensure an inflow of fresh water into the Keurbooms estuary adequate to keep the mouth of the Keurbooms Estuary open.

(d) Conditions for the provision of the services and payments for that provision

The municipality would ensure adequate water releases from the dams and the WfW Programme would continue their work in the catchment areas. Residents and tourists were asked to contribute financially to these programmes.

7.5.3 <u>FACTORS AFFECTING WILLINGNESS TO CONTRIBUTE</u>

The objective of the survey was to evaluate the support by the users of the Keurbooms Estuary for preserving its environmental services. The survey included questions on the following household variables:

1. Gender of the respondent

   Compared to male users, female users were expected to be less likely to have disposable income to contribute to ensure adequate dam water releases or the carrying out of the WfW Programme.

2. Location

   People living in close proximity to the Keurbooms Estuary were expected to be more willing to pay for river inflows into the estuary than people living in other locations.

3. Worth of owned fixed property

   People who own more expensive properties were expected to be more disposed to/capable of paying for river inflows into the estuary than people who own properties of lower worth.

4. Worth of vehicles and boats

   People who owned more expensive vehicles and boats were expected to be more disposed to/capable of paying for river inflows into the estuary than people who own vehicles and boats of lesser worth.

5. Education level of respondent

   Users with more education were expected to be better off and therefore more willing to pay for river inflows into the estuary.

6. Gross annual income of respondent

People with higher gross annual incomes were expected to be more willing to pay for river inflows into the estuary than low income earners.

These household variables (independent variables) were used to check whether the direction, magnitude, and strength of the relationships among variables were consistent with what would be expected, *a priori*.

7.5.4 INTERVIEWING TECHNIQUE

In this study personal interviews were used to determine the required information.

7.5.5 QUESTIONNAIRE (see Appendix F)

A pre-coded questionnaire was prepared with contingent valuation questions concerning people's willingness to pay to prevent the negative consequences of cutting off the fresh water inflow into the Keurbooms Estuary and hence closure of the Keurbooms mouth. This willingness-to-pay question corresponded to a potential future event and not one that had already occurred. The willingness-to-pay amounts were elicited by means of a payment card whereby respondents were asked to circle the value that represented their willingness-to-pay for the environmental services, given a range of numbers listed on the survey form. This elicitation mechanism was preferred because it is not subject to starting-point biases (Hanley & Spash 1993).

The questionnaire also contained an explanation concerning the bid vehicle (how the funds to make the payment were raised). It was stated that a levy would be collected from all users who derived benefit directly/indirectly, e.g. by providing visitors access to the Keurbooms Estuary. This levy would enable the release of sufficient dam water or enough extra water generation through the WfW Programme in the upper reaches of the catchment, to keep the mouth of the Keurbooms open.

Respondents were reminded by the enumerator of their budget constraints (that spending for this good/service necessarily meant a reduction in other kinds of goods/services that they could purchase). A question was asked on what the respondent would sacrifice in order to make this payment. This question was asked in an attempt to reduce mental account bias (Hanley & Spash 1993).

Respondents were also made aware of possible substitutes for the good/service that they were valuing. To determine the number of substitutes available, the respondents were asked how they would go about satisfying their demand for the services provided by the Keurbooms Estuary if the Keurbooms mouth were to close and if they were to lose the availability of its services.

The questionnaire was pre-tested by conducting a pilot survey and revised to clarify the questions, anticipate the responses and ensure that the average time taken to administer the questionnaire was less than 15 minutes. The respondents' prior knowledge of the ecological functioning of the Keurbooms Estuary was also tested by asking them what they thought would happen if no fresh water was allowed to flow into the Keurbooms Estuary and the mouth closed.

One enumerator administered the questionnaire (see Appendix F) to the 150 users during April 2001.

7.6 EMPIRICAL ANALYSIS AND DISCUSSION

As noted in our discussion of the methodological issues (see section 7.3), one of the important steps in CVM is to check if those who give invalid responses are in some ways different from those who do not, before deciding on whether or not to exclude invalid responses from the analysis. In section 7.6.1 the issue of invalid responses is discussed. Section 7.6.2 describes the empirical model and the data while section 7.6.3 presents results and discussion.

7.6.1 INVALID RESPONSES

Out of 150 completed questionnaires, about 20% (30) gave invalid responses to the valuation question. As is generally the case for in-person interviews, the item non-response was zero. The two main reasons for invalid responses were protest zeros and outliers. Responses stating that the Plettenberg Municipality should pay, (about 77% of the invalid responses), were considered protest responses. Outliers, which made up about 23% of invalid responses, were classified as those whose willingness-to-pay (WTP) was 3 or more standard deviations above (2 responses) or below (5 responses) the mean willingness-to-pay. A comparison of means of variables for respondents with invalid and valid responses to the valuation question was carried out to test for differences between the two groups. The results are shown in Table 7.3.

Table 7.3: Comparison of means of variables for respondents with invalid and valid responses to the valuation question

Variable	Mean for valid responses	Mean for invalid responses	t-statistic
Annual levies	205,67	174,50	-0,73
Distance	5,70	3,95	-1,58
Worth – fixed property	798 330	673 330	-1,24
Worth – boats/vehicles	134 380	113 330	-0,64
Income	168 210	147 000	-1,20
Number of observations	120	30	

The fact that the null hypothesis holds in the comparison of means tests suggests that there are no significant differences in terms of characteristics between those who gave valid and invalid responses.

A test of independence, namely the Pearson Chi-Square test, however, yielded different results. This test's results are shown in Table 7.4 below.

Table 7.4: A test of independence – Pearson Chi-Square test

Variable	Independence hypothesis
Information	Rejected at 95% C.L.
Annual levies	Not rejected
Freshwater worth	Rejected at 99% C.L.
Gender	Not rejected
Distance	Not rejected
Education	Rejected at 95% C.L.
Worth – fixed property	Rejected at 95% C.L.
Worth – boats/vehicles	Not rejected
Income	Not rejected

With four of the nine variables listed in Table 7.4 the null hypotheses (stating independence) are rejected. Having found evidence that those giving valid and invalid responses are different it could be argued that all responses should be included to calculate the mean willingness-to-pay, in order to avoid the occurrence of sample selection bias. *A priori*, there was no reason to believe that the sample that remained after exclusion of invalid responses was random. Inconsistency due to sample selection bias also applies to the issue of aggregation of benefits. This is because the existence of selection bias, due to the exclusion of invalid responses, implies that in addition to the parameter estimates of the willingness-to-pay (valuation) function, the mean willingness-to-pay for the sample measured using only valid responses may also be incorrect.

7.6.2 EMPIRICAL MODEL AND DATA DESCRIPTION

(a) Empirical model

An analysis of the determinants of willingness-to-pay (WTP) was made by regressing WTP on the variables expected to be the determinants of WTP. The model used took the following form:

$$Y = \sum_{i=1}^{n} \beta_i X_i + \varepsilon \qquad (7.3)$$

where Y = WTP (dependent variable)

X = vector of n explanatory variables (independent variables)

β = vector of n parameters

ε = disturbance term

(b) The dependent variable – mean WTP

The descriptive statistics relating to the estimation of the dependent variable (mean WTP) are shown in Table 7.5 below.

Table 7.5: Descriptive statistics relating to the estimation of the dependent variable (mean WTP)

Variable	Population	Mean	Standard deviation	Min	Median	Max	95% Lo	95% Hi
Willingness-to-pay in rands	150	273,67	262,26	0,00	150,00	1 500,00	231,35	315,98

(c) Independent (explicative) variables

The independent variables used were of a socio-economic and qualitative nature. The socio-economic variables (categories) and their representation in the sample are reported in Table 7.6.

Table 7.6: Independent variables forecast to influence the mean willingness-to-pay

Socio-economic variables	Classes	
Information	Well informed	48%
	Not clear	44%
	Poorly informed	8%
Annual levies	R 0	37,1%
	R 1 – 20	0,7%
	R 21 – 50	2,0%
	R 51 – 100	4,0%
	R 101 – 200	13,2%
	R 201 – 500	37,1%
	R 501 – 1 000	6,0%
	> R1 001	0%
Highest freshwater worth	Consumption	5,3%
	Same	15,2%
	Estuary	79,5%
Gender	Males	73,5%
	Females	26,5%
Distance from estuary	0 – 1 km	16,6%
	1 – 3 km	27,2%
	3 – 5 km	27,8%
	5 – 10 km	11,9%
	11 – 15 km	3,3%
	< 15 km	13,2%
Education of respondents	Matric	44,7%
	Post matric	3,3%
	Diploma	18,7%
	Degree	26,7%
	Postgraduate degree	6,7%
Worth – fixed property	R 0	0%
	R 1 000 – R 50 000	2,0%
	R 50 001 – R 100 000	2,0%
	R 100 001 – R 200 000	3,3%
	R 200 001 – R 500 000	34,4%
	R 500 001 – R1 000 000	30,5%
	> R1 000 000	27,8%
Worth – boats vehicles	R 0	0%
	R 1 000 – R 50 000	18,5%
	R 50 001 – R 100 000	45,0%
	R 100 001 – R 200 000	24,5%
	R 200 001 – R 500 000	9,9%
	R 500 001 – R1 000 000	1,3%
	> R1 000 000	0,7%
Income	R 0 – R 60 000	4,6%
	R 60 001 – R120 000	37,1%
	R120 001 – R250 000	47,7%
	> R250 001	10,6%

From Table 7.6 it can be seen that the majority of respondents were well informed on the ecological functioning of the Keurbooms Estuary. Given this level of awareness and the fact that all respondents were provided with the necessary information during the interviewing process, the scope for information bias was greatly reduced.

The majority of respondents (i.e. 63%) did pay annual levies, with most paying between R101 and R500, i.e. most of the respondents interviewed made use of the recreational services provided by the estuary (for boating, fishing etc.).

A significant finding was that almost 80% of the respondents interviewed preferred more water flowing into the estuary as opposed to abstracting the water for consumptive use in the Plettenberg Bay area.

Only 13% of the respondents interviewed had residences located more than fifteen kilometers from the estuary, i.e. the majority of the respondents live in close proximity to the estuary. About 55% of the respondents had a tertiary education – all of the respondents had obtained a matric certificate.

The majority of the respondents, namely 93%, owned fixed property worth in excess of R200 000.

About 45% of the respondents owned boats and vehicles worth between R50 001 and R100 000.

Only 4,6% of the respondents interviewed earned between R0 and R60 000 per annum. Almost half of the respondents (47,7%) earned between R120 001 and R250 000 per annum.

(d) Data description

The descriptive statistics for variables included in the estimation of model 7.3 are presented in Table 7.7.

Table 7.7: Descriptive statistics of independent variables

Variable	Mean	Std Dev.	Min	Max	Median
Annual Levies	198,11	207,90	0,00	750,0	150,00
Gender	-	-	-	-	-
Distance	5,36	5,43	0,50	17,50	4,00
Education	-	-	-	-	-
Worth – fixed property	773 180	494 020	25 000	1 500 000	750 000
Worth – boats/vehicles	129 800	161 260	25 000	1 500 000	750 000
Income	164 110	86 660	60 000	375 000	185 000

(e) Results and discussion

The empirical results of the linear regression (Equation 7.3) are presented in Table 7.8.

Table 7.8: Regression of factors affecting willingness to contribute money (n = 151)

Explanatory variable	Dependent Variable Money Contribution (Rand) R^2 = 0,3441 f-stat = 8,043			
	Estimated coefficient	Std error	t-statistic	P-value
Annual levies	43,5517	25,6030	1,70	0,09
Gender	25,1839	46,3417	0,54	0,59
Distance	-13,2906	23,1979	-0,57	0,57
Education	-7,8196	39,5858	-0,20	0,84
Worth – fixed property	7,1027	38,3607	0,19	0,85
Worth – boats/vehicles	74,9987	27,2785	2,75	0,01
Income	53,2494	41,6542	1,28	0,20

As can be seen from Table 7.8 several variables were insignificant in this analysis: gender, distance, education, worth – fixed property and income. If insignificant predictors are eliminated the results are as reported in Table 7.9.

Table 7.9: Regression of factors affecting willingness to contribute money (n = 150)

Explanatory variable	Dependent Variable Money Contribution (Rand) R^2 = 0,3213 f-stat = 23,043			
	Estimated coefficient	Std error	t-statistic	P-value
Annual levies	82,2038	20,9667	2,97	0,00

Worth – boats/vehicles	107 020	20,7103	5,17	0,00

The parameter estimate for annual levies indicates that those who pay higher annual levies were more willing to contribute money. The parameter estimate for worth of boats and vehicles was positive and significant, as expected, indicating that richer respondents are willing to pay more for river inflows into the estuary.

7.6.3 THE ENVIRONMENTAL VALUE OF FRESHWATER

To calculate the value (per cubic metre) of freshwater flowing into the Keurbooms Estuary the total WTP amount was divided by the minimum amount of freshwater inflows needed to keep the estuary mouth open (W_1W_2 in Figure 7.1). The latter amount of water is the water supply to the estuary – it was 78 540 000 m^3/a in 2001 (Wooldridge 2001). The total WTP was calculated as the product of the mean WTP per user (see section 7.6.2b) and the total number of users (see section 7.5.1). This product is shown in Table 7.10 below.

Table 7.10: Average and aggregated benefit measures

Mean user WTP	Total number of users of estuary	Total WTP
R273,67	13 250	R3 626 128

The recreational environment value of water per m^3 (P_w) was calculated as the total willingness-to-pay divided by the minimum required fresh water:

$$P_w = \frac{R3\ 626\ 128}{78\ 540\ 000} = R0{,}046/m^3/a$$

This value of water (R0,046) was deduced by us to be the environmental opportunity cost of abstracting water from the Keurbooms River above the estuary.

7.7 CONCLUSION

This chapter applied the contingent valuation method to value the freshwater inflow services yielded to recreation users by inflows of river water into the Keurbooms Estuary. It was concluded that this water was worth R0,046/m^3.

This value is lower than the willingness-to-pay value of the water for farming, namely 12,5c/m^3. However, this value is not the total value of recreational service yielded by the Keurbooms River, merely its value to the estuary users. To determine a total the value of recreational services, those yielded above the estuary would also need to be added to those yielded in the estuary.

In the absence of other information, and in cases where there is zero urban and agricultural demand for water, there may be a case for using this value of freshwater, namely R0,046/m^3, for other estuaries where mouth closure poses a similar threat to recreation demand. For instance, we argue there are grounds for valuing the Kowie River inflows into the Kowie Estuary in this way and on these grounds.

CHAPTER EIGHT: THE COST-BENEFIT ANALYSIS

8.1 INTRODUCTION

This chapter describes and applies the cost benefit methodology to the WfW Programme on six project sites in the Eastern and Southern Cape. The six project areas are identified and described in Chapter One. These areas differ in terms of location, the type of alien tree spp. present and the severity of infestation. For these reasons the methods of initial clearing, follow-up operations and maintenance efforts required for each project area differ. The effects of the projects were established by comparing the hypothetical situation predicted to exist in the absence of the project (the base case) with the situation predicted to exist as a result of the projects (the project case). The difference between the project case and the base case was deemed to be the net incremental benefit due to the project.

All estimated cost and benefit flows derived in this investigation are expressed in 2000 domestic prices (2000 is the base year). Three cost-benefit analysis decision criteria were used in the analysis: NPV, IRR and BCR. Social calculations are the only ones made in this analysis, because the information generated was intended to advise social decision-making.

A distributional weighting of one was used for all cross-sectional costs and benefits. This weighting amounts to assuming that a rand benefit is worth the same to all members of the population affected by the projects in question. The project period (time horizon of the project) was set at 100 years.

8.2 <u>CBA METHODOLOGY AND ESTIMATING THE DISCOUNT RATE FOR THE WORKING FOR WATER PROGRAMME</u>

8.2.1 <u>INTRODUCTION</u>

The outcomes of a cost-benefit analysis are significantly influenced by the choice of the social discount rate applied in the decision-making criteria. This section derives an estimate of this rate.

8.2.2 <u>A SHORT THEORETICAL OVERVIEW OF COST-BENEFIT ANALYSIS DECISION CRITERIA AND THE CHOICE OF THE SOCIAL DISCOUNT RATE</u>

Cost benefit analysis (CBA) is a method of comparing the social costs and benefits of alternative projects or investments. Costs and benefits are measured and then weighed up against each other in order to generate criteria for decision-making. Typically one or more of three decision criteria are used: net present value (NPV), internal rate of return (IRR) and benefit cost ratio (BCR). A project is deemed to be acceptable if the NPV is positive or the IRR exceeds the applicable discount rate or the BCR exceeds unity. Where more than one criterion is used and there is uncertainty over what discount rate is applicable, ambiguous results <u>may</u> occur - with one criterion indicating acceptance and another rejection.

The NPV is defined as follows:

$$NPV = \sum_{t=0}^{n} \frac{(Bt - Ct)}{(1+i)^t} \quad \text{......} \quad (8.1)$$

where:

NPV = net present value,

Bt = benefit after t years,

Ct = cost after t years,

n = the number of years over which to project runs, and

$(1 + i)^t$ = the factors by which the differences between Bt and Ct are discounted. The discount rate is i.

The IRR is defined as the discount rate, i, in the following equation:

$$NPV = \sum_{t=0}^{n} \frac{(Bt - Ct)}{(1+i)^t} = 0 \qquad (8.2)$$

The BCR is defined as follows:

$$BCR = \frac{\sum_{t=0}^{n} \frac{Bt}{(1+i)^t}}{\sum_{t=0}^{n} \frac{Ct}{(1+i)^t}} \qquad (8.3)$$

In all three of the CBA decision criteria described above the discount rate plays a crucial role. It serves dual purposes. Firstly, it is an indication of the social opportunity cost of capital and secondly, it is an indication of societies' time preference in consumption rate.

The role played by the discount rate in relating consumption in different periods may be described in a simple two period model. There are two aspects in this model: intertemporal consumption possibilities and intertemporal consumption preferences. The consumption possibilities are described first. Consumption in periods (t+1) and t respectively are given by

C(t+1) and Ct, where C(t+1) is a function of Ct. A negative relationship exists between consumption in these two periods. The less that is consumed in period t, and hence saved and invested, the greater the consumption that can take place in period (t+1),

$$C'_{(t+1)} = \frac{dC_{(t+1)}}{dC_t} = -(1+r);\ r > 0 \quad (8.4)$$

where r is the extra proportion of consumption yielded in year (t+1) over that saved (not consumed) and invested in year t.

From equation 8.4 it can be deduced that the consumption choices open to people are as follows:

$$C_{(t+1)} = C_0 - (1 + r)C_t \quad (8.5)$$

Equation 8.5 describes a person's intertemporal budget constraint. The value of r is determined in capital markets by the forces of demand and supply and is termed the social opportunity cost of capital. The most obvious measure for r is the government borrowing rate because of its long-term, risk-free nature and the fact that it defines the financial cost of government expenditure. Capital markets are, however, segmented and do not perfectly reflect the opportunity cost to society of investable funds.

The intertemporal consumption preferences of the individual are analysed with reference to that person's utility function. If[12]

[12] Reasons for assumption 6 include the higher probability of death argument according to which present consumption is preferred to future consumption because a person may not be alive in the future to benefit from his or her restraint (Turner et al. 1993:105) and a propensity amongst people to take short-run perspectives.

$$\frac{dU}{dC} > 0 \quad (8.6)$$

and

$$\frac{d^2U}{dC^2} < 0 \quad (8.7)$$

and

$$\frac{dU}{dC} \bullet \frac{C}{U} = 1\text{-}b \quad (8.8)$$

the person's utility function is of the following form:

$$U = aC^{1-b} \quad (8.9)$$

where a and b are constants and 1-b is the consumption elasticity of utility. As equation 8.9 will hold for both time periods:

$$U'(C_t) = (1-b)aC_t^{-b} \quad (8.10)$$

$$U'(C_{t+1}) = (1-b)aC_{t+1}^{-b} \quad (8.11)$$

If $C_t < C_{t+1}$ then

$$U'(C_{t+1}) < U'(C_t) \quad (8.12)$$

which implies when the person is maximising utility, the absolute value of the slope of the indifference curve (MRS) exceeds unity.

$$MRS = \left| \frac{U'(C_t)}{U'(C_{t+1})} \right| = (1+s);\ s > 0 \quad (8.13)$$

where MRS is the marginal rate of substitution of current consumption for future consumption and s is the rate a person would trade future consumption for (more) current consumption, that is, society's time preference in consumption rate (Hosking 1983:44). The optimum choice is defined where utility is maximised (equation 8.9) subject to the budget constraint defined by equation 8.5. Using Lagrangian optimisation methods it may be deduced that the person would always choose to save and borrow investable funds where:

$r = s$... (8.14)

If the capital market is competitive, savings and borrowing behaviour should ensure that this equivalence is indeed brought about. If $s > r$, some individuals in the society would be motivated to save less and borrow more because they would prefer current consumption to future consumption. As a result r would be bid upwards in the capital market until it was brought into equivalence with s, and vice versa for $r > s$. However, where there are capital market imperfections and multiple interest rates, this equivalence will not necessarily be brought about (Feldstein 1964:361) and s will not necessarily equal r.

The main imperfections are institutional barriers preventing the equilibrating process. These barriers include taxation on dividends (Baumol 1968), differences in risk and the existence of externalities. For these reasons r is not equivalent to s and the discount rate should reflect this. Under these circumstances it should be calculated as a composite rate based upon both r and s components (see Section 8.2.3 below).

8.2.3 A COMPOSITE SOCIAL DISCOUNT RATE FOR THE WORKING FOR WATER PROGRAMME

In order to determine the components of the social discount rate (i) of the WfW Programme average sources of funding for the Programme were investigated during the period 1996 to 2000. The following sources of funding were found (see equation 8.15):

$$i = (1-f)\, t[(1-s)(x_1-p) + (s)(x_2-p)] + (1-f)(1-t)(x_3-p) + f(x_4-p) \qquad (8.15)$$

where:

t	=	proportion of government expenditure funded through tax and duty collection;
$1-t$	=	proportion of government expenditure funded through borrowing;
s	=	proportion of disposable income saved;
$1-s$	=	proportion of disposable income consumed;
x_1	=	average of the predominant overdraft rate on current accounts and the term lending base rate (hire - purchase credit rate);
x_2	=	average of the dividend yield (%) and the capital growth of all listed shares on the JSE;
x_3	=	average of the government loan stock yield (10 years and over) and the Eskom bond rate;
x_4	=	interest rate cost of foreign funding;
f	=	proportion of foreign funding of total;
p	=	inflation rate (CPI).

Table 8.1: Cost of government borrowing, cost of household consumption borrowing, the return on savings and the annual inflation rate (1996-2000)

	Cost of government borrowing			Cost of household consumption borrowing			Return on savings			Average annual inflation rate as measured by consumer price index %
Year	Government stock - yields on loan stock traded on the bond exchange (10 years and over), % (a)	Eskom Bond Yield, % (b)	Average Yield, % $\frac{(a)+(b)}{2}$ x_3	Predominant overdraft rate on current accounts, % (c)	Long-term lending base rate (Hire - purchase credit), % (d)	Average rate, % $\frac{(c)+(d)}{2}$ x_1	Dividend* yield % (e)	Capital growth % (f)	Average % $\frac{(e)+(f)}{2}$ x_2	
1996	16,19	16,16	16,18	22,5	19,8	21,15	2,25	21	11,63	7,4
1997	14,14	14,19	14,17	22	19,25	20,63	2,45	3,3	2,88	8,6
1998	16,36	16,78	16,57	22,64	22,36	22,5	2,71	-5,6	-1,45	6,9
1999	13,96	14,45	14,21	18,10	18,69	18,4	2,62	5,9	4,3	5,2
2000	12,88	13,23	13,06	14,83	14,5	14,67	2,45	15,2	8,83	5,3

Notes: * All classes of shares

Sources: SARB Quarterly Bulletin (December 1998, September 1999, September 2001).
http://www.statssa.gov.za/Economic%20Indicators/CPI.htm.

There were three main sources of funds for the WfW Programme from 1996 to 2000: taxes, government borrowing and foreign aid. Tax funding requires consumption and savings to be sacrificed by households and companies. The cost of the consumption sacrificed is measured by the interest rates consumers are prepared to pay to borrow (X_1). The saving sacrificed is measured by foregone dividend yield and capital growth on their savings (X_2). Government borrowing also has a cost – the rate of interest paid on government bonds (X_3). Foreign aid does not carry any opportunity cost from the South African perspective unless the money would have been allocated elsewhere in the country. For this reason X_4 was set equal to zero.

The data used to calculate the discount rate i (via equation 8.15) are shown in Tables 8.2, 8.3 and 8.4. Table 8.2 shows the cost of government borrowing, the cost of household consumption borrowing, the return on savings and the annual inflation rate for the period 1996 to 2000. Table 8.3 shows the calculation of weights, t and 1-t, and Table 8.4 shows the calculation of weights, s and 1-s.

Table 8.2: The calculation of discount rate weights - (t) and (1-t)

Year	**Government borrowing requirement R millions (a)**	**Government revenue R millions (b)**	**Total R millions (c) = (a) + (b)**	**Borrowing proportion $\frac{(a)}{(c)}$ (1 - t)**	**Tax revenue proportion $\frac{(b)}{(c)}$ (t)**
1996	29 001	127 109	156 110	0,19	0,81
1997	31 501	145 999	177 500	0,18	0,82
1998	25 764	163 921	189 684	0,14	0,86
1999	20 862	183 166	204 028	0,10	0,90
2000	19 025	197 380	216 405	0,09	0,91

Source: SARB Quarterly Bulletin (September 2001).

Table 8.3: The calculation of discount rate weights - (s) and (1 - s)

Year	**Final consumption expenditure R million (a)**	**Gross savings R million (b)**	**Gross national disposable income (c) = (a) + (b)**	**Final consumption expenditure proportion** $\frac{(a)}{(c)}$ **(1 - s)**	**Gross savings proportion** $\frac{(b)}{(c)}$ **(s)**
1996	505 419	97 732	603 149	0,84	0,16
1997	566 671	99 074	665 744	0,85	0,15
1998	612 480	105 015	717 495	0,85	0,15
1999	657 568	116 498	774 066	0,85	0,15
2000	716 458	132 541	848 999	0,84	0,16

Source: SARB Quarterly Bulletin (September 2001).

Over the five year period (1996 - 2000) the proportion of foreign funding of the total funds procured by the WfW Programme averaged 1% (see f, equation 8.15) (DWAF 1999b).

Employing formula 8.15 and the information provided in Tables 8.1, 8.2 and 8.3, the discount rate for the WfW Programme was estimated at 10,1% per annum.

8.2.4 SELECTED SOCIAL DISCOUNT RATE MEASURES USED BY OTHERS

The World Bank normally employs the opportunity cost of capital as a theoretical basis for their choice of the discount rate (CEAS 1989). Typically they apply rates of between 8 and 15% for developing countries (CEAS 1989). The most popular choice is 12% per annum (CEAS 1989).

In the United States government institutions like the United States Fish and Wildlife Services and water-related federal agencies, normally use a discount rate equivalent to the long-term Treasury bond rate (CEAS 1989). In 1987 this rate was 8,75% per annum. This is a nominal rate but is applied as a real rate (CEAS 1989). More recently, a social discount rate of 8% per annum for use in South Africa was proposed by Mullins, Mokaila, Mosako and van Dijk (2000). The US Forest Services typically have used lower discount rates, e.g. 4% (Loomis 1993). Their rates are derived from the rate of returns on capital and corporate bonds (Loomis 1993).

In South Africa, the most frequently used social discount rate for the WfW Programme has been 8% per annum (see for example Marais 1998; van Wilgen et al. 1997). This rate is also used in other projects by the Department of Water Affairs and Forestry (Marais 1998).

A critique of our analysis has argued that the rate we used was too high because some agricultural projects in South Africa have used a discount rate of 5%, and that this lower rate was also used to calculate the pension payment to members of the AIP fund in 1995 (Antonites 2002). We were unable to establish the relevance of these other project decisions to the one we attempted to assess here. However, what was clear from our inquiry was that there were divergent views on what discount rates are appropriate to this, and indeed other social projects in South Africa. We attempted to incorporate the alternative views to our own by subjecting our results to a sensitivity analysis with respect to the discount rate.

8.2.5 DEDUCTIONS

The choice of a social discount rate for use in a cost-benefit analysis is a critical one. A high discount rate generally favours projects with a low initial capital cost and high current costs, whereas the opposite applies to a low discount rate. Various schools of thought exist regarding the basis for the choice of the social discount rate. For instance, there are those who argue that it should equal the opportunity cost of capital, there are those who advocate a social time preference rate, there are those who advocate the use of one long-term rate and there are those who advocate different rates for different periods. Due to imperfections in the market place the former two rates will rarely be equivalent and due to changing market circumstances the rates will change over time. Ideally allowance should be made explicitly for differences.

Our investigation makes allowance for differences in rates by source. Our deduction is that the social discount rate for South Africa's WfW Programme 1996 – 2000 was 10,1% per annum. Declining rates in savings and borrowing during 2001 will probably reduce this rate, but what the relevant rates will do after 2001 is a matter of speculation. We believe there is a case for applying discount rates below 10,1% for the purpose of generating CBA criteria, and for this reason also applied discount rates 2% and 5% below 10,1% (that is, 8,1% and 5,1%).

8.3 THE COST OF CLEARING ALIEN PLANTS ON SIX WORKING FOR WATER PROJECT SITES

The estimates of the cost of clearing alien infestations include the cost of initial clearing operations as well as intensive follow-up control and maintenance for about 5 to 10 years thereafter. These initial control costs can be regarded as equivalent to the capital costs of conventional water supply schemes.

Many factors influence the costs of clearing, for example, the density of alien plant cover, the type of alien invader, ease of access to the area and the maturity of the alien plants. According to Briers and Powell (1993), clearing dense stands of mature trees can cost up to R6 000 per hectare, whereas for stands of younger trees the cost is less than R2 000 per hectare. Follow-up operations can cost from R500 per hectare to less than R100 per hectare.

Le Maitre et al. (1996) estimated that the clearing of moderate infestations in the Kogelberg State Forest in the Western Cape Province cost approximately R500 per hectare prior to burning. Van Wilgen et al. (1997) argued that the cost of clearing alien plants was about R59, R354, R1 062 and R1 475 per hectare respectively, for occasional, scattered, medium and dense infestations of Pines and *Hakeas*.

Burgers et al. (1995) maintain that the control costs for *Acacia* spp. are substantially higher than in the case of *Hakea* and *Pinus* spp., because more intensive follow-up is required for the former due to the fact that *Acacias* regenerate from soil-stored seedbanks. A number of *Acacia* spp. also resprout and therefore require herbicide application which further augments control costs. Low, medium and high estimates are provided for control costs, namely R1 500 per hectare (low estimate) which applies to *Hakea* and young Pine infestations in accessible sites, R5 000 per hectare (medium estimate) for *Hakea* in inaccessible sites and old dense stands of pines, and R10 000 per hectare (high estimate) for *Acacia* stands. It is argued by Burgers et al. (1995) that for *Acacia mearnsii* stands the total clearing and follow-up control costs may even be greater than this.

Versveld et al. (1998) developed cost of clearing different density classes for the WfW Programme. These are shown in Table 8.4 below. Cost data on follow-up operations are also given.

Table 8.4: Costs of clearing and follow-up operations for different vegetation types

Species group	**Treatment**	**Costs by density class (R/ha)**		
		LIGHT (<25% COVER)	**MEDIUM (25-75% COVER)**	**DENSE (>75% COVER)**
Acacia	Initial (clearing) 1st follow-up 2nd follow-up	486 310 169	1 505 746 428	2 063 1 403 694
Eucalyptus	Initial (clearing) 1st follow-up 2nd follow-up	525 275 145	4 518 429 323	4 786 802 441
Pines & *Hakea*	Initial (clearing) 1st follow-up 2nd follow-up	585 249 200	1 112 512 300	3 844 818 400
Other tall trees	Initial (clearing) 1st follow-up 2nd follow-up	413 276 136	1 801 1 206 594	2 938 1 968 969
Tall shrubs and other spp.	Initial (clearing) 1st follow-up 2nd follow-up	350 235 116	456 305 150	582 390 192

(Source: Versveld et al. 1998).

Table 8.4 shows averages. The costs can vary widely about these averages. This variation is a reflection on the way in which operations against aliens are conducted. In some projects, the trees have been completely felled and left to rot on the ground. In other cases the trees are removed and sold. In yet others they are ring-barked and poisoned (especially Eucalypts because they re-sprout and are difficult to kill otherwise). Ring-barking is a less expensive operation, but the dead trees remain standing. This approach has advantages where invasions are fairly heavy and are located in sensitive ecosystems, such as riparian forests. Felling trees into these systems leads to significant damage – dead trees also fall in time but without the canopy and at widely varying intervals.

Regular follow-up control and maintenance of alien plant and tree invaders is required for approximately 5 to 10 years after initial clearing to prevent re-invasion of previously cleared areas.

The costs of alien plant clearing on the six selected project sites were based on the actual costs incurred since the inception of the various projects, as well as projections made by the various project managers.

8.3.1 <u>TSITSIKAMMA PROJECT AREA</u>

The cost figures were calculated as an average per hectare for the entire 84 402 hectares (infested mainly by Pine spp.) and are shown in Table 8.5 below. The estimated percentage of alien plant cover is between 10,1 and 20%. Seven teams comprising 18 people per team working on 10 day cycles (Monday to following Wednesday) are responsible for clearing, follow-up and maintenance. The personnel camp out on a permanent basis which leads to high overhead expenses being incurred. The personnel receive three meals per day (total of approximately 3 000 meals per camp). *Hakea* spp., which cover an area of 46 381 hectares, are cleared using biological control. Biocontrol agents contribute to clearing programmes by reducing the rate of infestation and by reducing the density of the stands (Marais 1998).

Spies (pers. comm. 1999) argued that a number of factors could impact on long-term costs, namely:

- price (not quantity) increases of herbicides, supplies and services;
- salary and wage increases;
- the occurrence of fires;
- drought or above-average rainfall;
- irregular funding (if funds are not available when follow-up is required, it could result in initial clearing having to be carried out again);
- the development of generic equivalents of some of the more regularly used herbicides such as Garlon;
- movement within the catchment area means that other communities would be involved (thus more training expenses and the like would be incurred); and
- the development of a seedless Pine by SAFCOL.

8.3.2 KOUGA PROJECT AREA

The average per hectare costs for clearing operations on 158 678 hectares invaded by Pine and *Hakea* are furnished in Table 8.5 below. The estimated percentage of invading alien plant cover is between 5,1 and 10%. Teams of men and women comprising 15-20 persons are responsible for clearing, follow-up and maintenance. The teams start to clear at the top of the tributaries and work their way down until eventually they clear the river courses/riparian zones.

Hakea spp. covering an area of 33 138 hectare are cleared using biological control. The arguments raised by Spies (pers. comm. 1999) regarding factors which could impact on long-term costs for the Tsitsikamma project, are also applicable to the Kouga project.

8.3.3 PORT ELIZABETH DRIFTSANDS PROJECT AREA

The average per hectare costs (averaged out by the relevant project manager) associated with the Port Elizabeth Driftsands project covering an area of 8 700 hectares are displayed in Table 8.5 below. The estimated percentage of invading alien plant cover is between 5,1 and 10%. The WfW Programme works in consultation with the Port Elizabeth Municipality and Parks and Recreation regarding clearing programmes. Priorities are linked with the Metropolitan Open Space System (MOSS) and fire prevention (in the upper catchments of river valleys). Initial clearing is undertaken by teams of 14 men and women using equipment such as chain saws and brush cutters. In the follow-up procedure more workers are required to saw up and transport wood, and do other ad hoc jobs. Maintenance of management units is carried out two years after the last follow-up operation.

Biological control will have an effect on follow-up and maintenance in the long run (Marsh pers. comm. 1999).

8.3.4 ALBANY PROJECT AREA

The average per hectare costs of the Albany project covering an area of 11 500 hectares are shown in Table 8.5 below. The estimated percentage of invading alien plant cover is between 5,1 and 10%. Clearing of state owned land is the WfW Programme's first priority in this area. Initial clearing, which is carried out by teams of men and women, is initiated at the upper parts of the catchments of the Kowie and Kariega rivers. The WfW Programme carries out the first and second follow-up operations, whereafter it becomes the responsibility of the land owner. The follow-up operations entail thoroughly and systematically sweeping previously cleared areas and conducting herbicide treatment (where applicable) and manual weeding.

8.2.5 <u>KAT RIVER PROJECT AREA</u>

The annual per hectare costs associated with the Kat River project covering an area of 1 196 hectares are shown in Table 8.5 below. The estimated percentage of invading alien plant cover is between 1,1 and 5,0%. The initial clearing strategy followed in this area entails clearing the upper sections of the catchment first and then moving downwards to the river courses of the Kat River. The initial clearing is done by teams consisting of men and women using mechanical equipment such as chain saws. Follow-up operations entail the application of herbicide treatment as well as manual weeding. Maintenance is carried out one year after the last follow-up.

8.3.6 <u>POTT RIVER PROJECT AREA</u>

The annual per hectare costs associated with the Pott River project covering an area of 490 hectares are shown in Table 8.5 below. The estimated percentage of invading alien plant cover is between 0,1 and 1,0%. The initial clearing strategy entails clearing the upper sections of the catchment first and then moving downward to the river courses of the Pott River. As with all other projects, initial clearing is carried out by teams comprising of both men and women. Chain saws and brush cutters are mainly used during initial clearing. Follow-up work includes herbicide treatment, manual weeding, collecting and transporting wood, burning of heaps of slashings and other ad hoc jobs. Maintenance of management units is carried out for four years after the last follow-up operation.

Table 8.5: Cost of clearing, follow-up operations and maintenance for six different project sites*+

Treatment	Tsitsikamma	Kouga	Port Elizabeth Driftsands	Albany	Kat River	Pott River
	Cost (R/ha)					
Initial (clearing)	1 236	2 300	2 650	2 440	1 440	1 435
1st follow-up	400	400	700	750	840	1 100
2nd follow-up	248	200	400	360	450	700
Maintenance (1st year)	140	50	200	170	255	100
Maintenance (2nd year)	65	20	70	140	110	50
Maintenance (3rd year)	25	20	20	70	60	0
Maintenance (4th year)	15	20	20	60	0	0
Maintenance (5th year)	0	20	20	50	20	30
Maintenance (6th year)	15	0	20	20	0	0
Maintenance (7th year)	0	0	0	20	20	0
Maintenance (8th year)	15	0	0	20	0	30

Notes: * The costs presented in Table 8.5 were provided by individual project managers and represent the average costs for all density classes

+ Management costs are included

8.4 THE BENEFITS OF CLEARING ALIEN PLANTS ON SIX WORKING FOR WATER PROJECT SITES

The benefits of the WfW Programme can be broken up into primary benefits and secondary benefits (see Chapter Five). The most important primary benefit is the increased water yield (m^3/ha/year) as a result of the programme.

Secondary benefits associated with the programme include conservation of biodiversity, improvement in water quality, secondary industry development, social development and poverty alleviation, flood control and the prevention of soil erosion, fire hazard reduction, improvement of scenic beauty, gains in potentially productive land and finally, the positive impact of increased streamflow (due to the programme) on the healthy functioning of estuary systems. Table 8.6 below shows the extent to which each of the abovementioned secondary benefits are dealt with in this report.

Table 8.6: Secondary benefits

Benefit	Identified	Quantified	Valued
Biodiversity conservation	✓		
Water quality improvements	✓		
Secondary industry development	✓		
Social development/poverty alleviation	✓		
Flood control/soil erosion	✓		
Fire hazard reduction	✓		
Scenic beauty	✓		
Carrying capacity improvement	✓	✓	✓
Estuary improvement*		✓	✓

* Note: This can be seen as a primary or secondary benefit but we have captured it as a primary benefit (as an alternative value of water).

As can be seen in Table 8.6, only two secondary benefits namely, gains in productive capacity of grazing land and the positive impact of the programme on an estuary system, were quantified and valued. The figures supplied for gains in productive capacity of grazing land are only preliminary and form part of research in progress.

8.4.1 PRIMARY BENEFITS

(i) Tsitsikamma project area

The incremental water yield benefit for this area was calculated in Chapter Three (see Table 3.6).

The revenue was calculated by projecting the net incremental yield (million m^3) over 100 years and multiplying it by the value of water (R/m^3). The value was estimated for the year 2000 to be $R0,125/m^3$. The decision-making criteria for the WfW in the Tsitsikamma mountain catchment, as calculated from the relevant costs and benefits, are shown in Table 8.10.

(ii) The Kouga project area

The incremental water yield benefit for this area was estimated in Chapter Three (see Table 3.6).

The revenue was calculated by projecting the net incremental yield (million m^3) over 100 years and multiplying it by the value of water (R/m^3). This value was estimated for the year 2000 to be $R0,74/m^3$. The decision-making criteria for the WfW in the Kouga mountain catchment, as calculated from the relevant costs and benefits, are shown in Table 8.10.

(iii) Port Elizabeth Driftsands project area

The incremental water yield benefit for this area was calculated in Chapter Three (see Table 3.6).

The revenue was calculated by projecting the net incremental yield (million m^3) over 100 years and multiplying it by the value of water (R/m^3). This value was estimated for the year 2000 to be R0/m^3. The decision-making criteria for the WfW in the Port Elizabeth Driftsands area, as calculated from the relevant costs and benefits, are shown in Table 8.10.

(iv) Albany project area

The incremental water yield benefit for this area was calculated in Chapter Three (see Table 3.6).

The revenue was calculated by projecting the net incremental yield (million m^3) over 100 years and multiplying it by the value of water (R/m^3). No agricultural or urban benefit could be determined for the Albany project, but it clearly yielded value as a freshwater inflow into service benefits in the Kowie Estuary. This value was not estimated directly, but indirectly. The estuary service benefit of freshwater inflow into the Keurbooms Estuary was used as a measure of this benefit, namely R0,046/m^3. The decision-making criteria for the WfW in the Albany catchment, as calculated from the relevant costs and benefits, are shown in Table 8.10.

(v) The Kat River area

The incremental water yield benefit for this area was calculated in Chapter Three (see Table 3.6).

The revenue was calculated by projecting the net incremental yield (million m^3) over 100 years and multiplying it by the value of water (R/m^3). This value was estimated for the year 2000 to be R0,157/m^3. The decision-making criteria forth WfW in the Kat River catchment, as calculated from the relevant costs and benefits, are shown in Table 8.10.

(vi) Pott River (Ugie) area

The incremental water yield benefit for this area was calculated in Chapter Three (see Table 3.6).

The revenue was calculated by projecting the net incremental yield (million m^3) over 100 years and multiplying it by the value of water (R/m^3). This value was estimated for the year 2000 to be R0/m^3. The Pott River does not directly deliver freshwater into an estuary system and hence an estuary service benefit of freshwater inflow, as was the case with the Albany project, could not be used. The decision-making criteria for the WfW in the Pott River (Ugie) area, as calculated from the relevant costs and benefits, are shown in Table 8.10.

8.4.2 SECONDARY BENEFITS

(1) The net agricultural livestock holding benefit

The net agricultural livestock benefit of the WfW programme, which entails the removal of alien vegetation for increased grazing, is one of the most obvious non-water benefits. However, little data are available on the subject, and the fact that numerous factors need to be taken into account to determine this benefit, complicates matters further. In order to give a complete estimation of the net agricultural benefit, the gain in grazing potential for livestock, as well as the gain for other farming, such as fruit, flower harvesting (for example fynbos) and many more agricultural practices (for example mixed farming enterprises) need to be calculated. The income generated from commercial afforestation with alien tree spp. also needs to be assessed (Marais et al. 2000). However, this study limited itself to estimating the value of the net agricultural benefit derived from increasing livestock farming.

The level of infestation and degradation will not only have a big impact on the cost of clearing aliens, but also on the carrying capacity of land once clearing has been done (Campbell pers. comm. 2000). Some agricultural experts (Penny pers. comm. 2000) host the opinion that if the WfW Programme is judged from their specific viewpoint, it is not viable, due to the costs involved in clearing, including those for initial clearing, follow-up control and maintenance. In some areas it is estimated that it costs up to five times more to cut away aliens than to farm on land. In these areas prospective farmers would be better off finding a farm elsewhere in the country than trying to clear aliens for livestock farming (Penny pers. comm. 2000).

Of the six representative WfW Programme sites chosen for analysis in this study, only the Albany, Kat River and Pott River sites are currently used extensively for agriculture. The other three sites, namely Tsitsikamma, Kouga and Port Elizabeth Driftsands are not suitable for livestock farming. The Port Elizabeth Driftsands site falls within an urban area, and the Tsitsikamma and Kouga sites are covered by coastal fynbos, which is not a good grazing resource (Campbell pers. comm. 2000). Below these sites in the valleys and coastal plateau the main agricultural activities are fruit farming and mixed farming (Egan pers. comm. 2000; Hosking & du Preez 1999). In the Tsitsikamma coastal plateau, dairy farming in particular flourishes (Egan pers. comm. 2000; Hosking & du Preez 1999), but no figures were available on costs, incomes and margins above cost of this type of farming in the Department of Agriculture's Enterprise Budget.

The gain in potentially productive land was calculated by establishing the carrying capacity in the Albany, Kat River and Pott River sites. Obtaining the carrying capacity of productive agricultural land in itself proved to be difficult, as capacities can vary tremendously in the same area, due to factors such as changing slopes, soil types and soil depths. Moreover, some animals are grazers by preference, but will still eat bush - suggesting an overlap in grazing areas and carrying capacity (Zeeman pers. comm. 2001). Carrying capacity is divided into hectares per large stock unit (ha/LSU) and hectares per small stock unit (ha/SSU). A conversion can be done to interpret carrying capacity of small stock units in terms of large stock units. As a rough estimate, in sweetveld one large stock unit (e.g. cattle) will be equal to three small stock units (e.g. sheep), and in sourveld the ratio will be one to six (Maphuma pers. comm. 2000). The Department of Agriculture also has tables for more specific conversions (a specific small stock unit, e.g. sheep), such as angora sheep/LSU or kudu/LSU (Scheltema fax 2000). The figures can vary substantially, depending on which source is used. Even within the Department of Agriculture, carrying capacities differ depending on the source used. In this study, the Department of Agriculture’s Enterprise Budget statistics were used, and all carrying capacities were converted into large stock units.

The ideal would have been to calculate the carrying capacity for the areas with and without infestation, and to compare the two in order to calculate the net agricultural livestock benefit of clearing. Unfortunately, no data were available on the carrying capacity of areas with and without infestation. For this reason calculations were done assuming that the carrying capacities stay constant, and only the area available for livestock farming increases with the WfW programme.

The annual undiscounted agricultural benefits of increased grazing potential was calculated by multiplying the net profit (margin above cost) per large stock unit by the carrying capacity and the amount of hectares cleared in every area. The net profit (margin above cost) per large stock unit was estimated as the difference between total gross income (which includes total capital income minus purchases) and directly allocatable costs. Total capital income was measured as the weight of an LSU times the income per kilogram. The net agricultural livestock benefit was determined by subtracting the profit per the amount of hectares under investigation before clearing from the profit per amount of hectares under investigation after clearing. This difference constitutes the net agricultural livestock benefit.

Directly allocable costs included were marketing (cattle), transportation, medicine, lick and feed, self-produced grazing cost per cow, and the gestation examination (for beef cattle herd 7 and 30 months) (Enterprise budget 2001).

The Department of Agriculture's Enterprise Budget (2001) was used to determine the gross margin per large stock unit.

Fixed costs (such as fencing) were not included in the calculation of the Enterprise Budget. These were seen as sunk costs. The cost of sowing seeds to increase the grazing capacity of agricultural land after initial clearing was also not taken into account. The oversowing of cleared areas with grass seeds has been shown to increase grass production and retard the process of re-establishment of bush, thus retaining grazing capacity for longer (Maphuma 2000). We assumed that natural regeneration would be sufficient.

In another study (Abelson 1979) a similar approach was followed to estimate the agricultural benefits due to improved pastures. Net annual agricultural benefits were calculated as the product of the increase in output from livestock and the operating profits minus the capital costs of additional livestock. A difference between the study by Abelson (1979) and our study is that he calculated the increase in output from livestock separately and then multiplied this with operating profits. In our study, however, this was not done – the margin above cost per LSU was used. It was impossible in our study to calculate the increase in output from livestock due to the fact that we assume that more grazing land becomes available and that no changes in potential stocking rates per hectare take place. Another difference is the fact that Abelson (1979) made use of a stock composition approach, whereas in our study only large stock units (i.e. cattle) were considered.

Table 8.7 below shows the carrying capacity (ha/LSU), level of infestation and the amount of hectares cleared for the three WfW sites considered in this study.

Table 8.7: Selective information on WfW sites

Area	Carrying capacity (ha/LSU)*	Level of infestation (%)	Hectares cleared
Albany	5,5	5,1 - 10	11400
Kat River	4,6	1,1 - 5	1190
Pott River	4,25	0,1 - 1	490

* Average of the range provided by agricultural extension officers and Döhne Institute. These carrying capacities are for natural veld in good condition with no heavy encroachment of bush.

Albany:

Albany is an area covered mainly with grassveld and valley bush. Agricultural uses for this area include cattle, sheep and Angora goats. In order to determine the net agricultural benefit for clearing alien infestation in Albany, the following was done:

To get the ratio LSU/ha, one was divided by the carrying capacity (ha/LSU): 1/5,5= 0,18.

This means that 0,18 large stock units can be sustained on one hectare. In the total area cleared for Albany (11 400 hectares), this means that 2 073 large stock units can be sustained (0,18 multiplied by 11 400).

The Enterprise Budget contains a budget for beef cattle in the Queenstown area only, but it was used nonetheless, due to the fact that similar figures for Albany and the other areas were unavailable. Two budgets for a beef cattle herd were available – that for weaned calves and excess heifers sold at 7 and 30 months respectively, and that of cattle sold at 7 or 12 months, or mated at 15 months. The net agricultural livestock benefit was calculated for both these budgets, with the average of it representing the overall net agricultural benefit for cattle as a large stock unit.

Table 8.8 below depicts the steps done in order to derive the net agricultural livestock benefit for the Albany site.

Table 8.8: Calculation of the net agricultural livestock benefit in step form - Albany

Step	Description	Beef cattle (Queenstown, sell at 7, 30 months)	Beef cattle (Queenstown, sell at 7, 12 months)
1	LSU per beef cow	2,12	1,57
2	Hectares/LSU	5,5	55
3	LSU/ha	0,182	0,182
4	Carrying capacity in terms of beef cows/hectares	0,0858	0,116
5	Number of beef cows on total area under WfW programme	977,7	1320,2
6	Margin above cost	R432,49	R576,74
7	Total area profit without infestation	R422 846,1	R761 417
8	Average infestation level (%)	7,55	7,55
9	NET LIVESTOCK BENEFIT	R31 924,88	R57 486,99
10	Average net livestock benefit	R44 705,93	

In order to calculate the net agricultural livestock benefit, it is important to establish the carrying capacity of the land. The carrying capacity provides information on the number of Large Stock Units (LSU) and Small Stock Units (SSU) that can be accommodated on a hectare of land. An LSU is the equivalent of a "dry" cow of approximately 400kg. In this case, it was assumed that livestock farming on cleared areas would concentrate on cattle, and beef cattle in particular. Goats and sheep (SSU) are not a viable livestock farming option due to the fact that small animals are easy to steal. For this reason farmers are reluctant to farm with these animals in this area.

Given that an LSU is a cow weighing 400kg this means that a typical beef cattle cow weighing more than 800kg is equivalent to 2,12 times as much as an LSU (**step 1**). The ratio of LSU per cow is provided in the Department of Agriculture's Enterprise Budget for 2001.

The average carrying capacity, expressed in terms of hectares per LSU is available from the local agricultural extension officer and the Döhne Agricultural Institute. In the Albany region, the carrying capacity is 5,5ha/LSU, meaning that one LSU needs 5,5 hectares of land for sustainable grazing (**step 2**). Carrying capacity also can be expressed in terms of the amount of LSU's per hectare (LSU/ha, **step 3**). About 0,182 LSU's can be sustained on one hectare.

In order to determine the amount of beef cattle that can be sustained on the area cleared by the WfW programme, it is necessary to adjust carrying capacity to beef cows per hectare from LSU's per hectare. This is done by dividing the LSU per hectare ratio by the LSU per beef cow ratio (**outcome of step 3 divided by outcome of step 1**). In the case of beef cattle, where some of the herd are sold at 7 months and some at 30 months, one hectare can sustain 0,08 cows (**step 4**).

This relationship is crucial for estimating the livestock benefit of cleared land. If the area currently being cleared (11 400 hectares) is multiplied by the cow/hectare ratio, it gives an indication of the amount of beef cattle that can be sustained on the Albany area, with no infestation, i.e. 977,7 cows (**step 5**).

In monetary terms, this translates into a benefit of R422 846,10. This figure is obtained by multiplying the margin above cost of a beef cattle herd (net profit of a beef cow, **step 6**) as listed in the Enterprise Budget 2001 by the amount of cattle sustainable on the area (**step 7**).

In the absence of the WfW project the livestock capacity in the region is crowded out by alien infestation. The net agricultural livestock benefit of the WfW project is the difference between the total area profit without infestation and the total area profit with infestation. Calculating the total area profit with infestation was complicated by a lack of information on carrying capacity before and after infestation. In effect this difference is equivalent to the loss of income on the 7,55% of the land unusable for livestock in the Albany project site due to alien infestation (**step 8**). This amounts to R31 924,88 (**step 9**).

Similar calculations were made for a beef cattle herd, which was sold off at closer intervals, namely 7 and 12 months. These yielded a net livestock benefit of R57 486 (**step 9**). The average net livestock benefit of the WfW on the Albany site was R44 705,93 (**step 10**). The net agricultural livestock benefit calculated here is perhaps on the high side as only certain areas in the Albany region are currently being used for cattle farming. Selected areas have been earmarked for conservation. In our calculations the whole area cleared in Albany was assumed to be used for cattle livestock farming.

In the case of cattle, clearing of aliens will result in a net agricultural livestock benefit of R44 705,93. The net agricultural livestock benefit is not complete, as the benefit of having mixed livestock farming (for example cattle and Angora goats) was not calculated. This was due to the lack of figures available on percentage breakdowns of actual farming practices. It was thus assumed that if aliens were cleared in the Albany area, the increased grazing potential would be used for cattle farming only.

Kat River and Pott River

The same estimation process was applied to the two other relevant sites. The average net agricultural livestock benefit through increased grazing potential is shown in Table 8.9 below.

Table 8.9: Net agricultural livestock benefit of selected sites where WfW activities are taking place

Site	Net agricultural benefit in Rands
Kat River	2265,42
Pott River	181,15

The net agricultural livestock benefit from cattle farming in the Kat River and Pott River areas respectively, were estimated to be R2 265,42 and R181,15 respectively.

(ii) Keurbooms Estuary freshwater benefit

The WfW Programme in the upper reaches of the Keurbooms River, in the Tsitsikamma area, has a positive impact on the Keurbooms Estuary due to the fact that the Programme ensures that adequate freshwater supplies flow into the estuary, thereby helping to keep the mouth open. Adequate freshwater inflows and hence an open mouth prevents the loss of environmental services provided by the estuary (see Chapter Four).

This benefit is captured in the cost-benefit analysis through applying the contingent valuation method in deriving a price per cubic metre for the freshwater that flows into the Keurbooms Estuary. This “environmental” price for water is then used to calculate the rand benefit of increased water yield due to the actions of the WfW Programme in the Tsitsikamma area.

Two sets of decision-making criteria (NPV, IRR and BCR) are calculated for the Tsitsikamma area: one set where the willingness-to-pay value for water is used to value the primary benefit (increased water yield) and one set where the environmental value of water, calculated using the contingent valuation method, is used to value the primary benefit (see Table 8.10).

The value of freshwater derived in Chapter Seven for the Keurbooms Estuary, namely R0,046/m^3, was also applied to the Albany project.

8.5 SUMMARY RESULTS OF APPLYING THE DECISION MAKING CRITERIA

The summary results of applying the decision making criteria (NPV, BCR and IRR) to the cost benefit profiles of the selected sites of the WfW Programme in the Eastern and Southern Cape Province are presented in Table 8.10 below.

Table 8.10: Summary of results

	CBA criteria		
Project	**NPV (R)**	**IRR (%)**	**BCR**
Tsitsikamma (agricultural water value) (estuarine water value)	-31 757 404 -55 492 203	5,00 1,20	0,54 0,20
Kouga	-33 854 196	7,25	0,75
Port Elizabeth Driftsands	-14 674 240	0	0
Albany	-15 232 753	1,13	0,21
Kat River	-1 031 609	3,60	0,43
Pott River	-1 446 624	-3,14	0,03

For all the WfW projects assessed in this study (at a real social discount rate of 10,1%), the NPVs were less than zero, the BCRs were less than one and the IRRs were less than the social discount rate. When the water benefit in the Tsitsikamma case is valued at the estuarine value, the NPV is less than zero, the BCR is less than one and the IRR is less than the social discount rate.

If we redefine the project (WfW Programme) as the sum of all of the subprojects we find the cost-benefit analysis criteria negative for this summed project. For the gross regional project the NPV is -R97 996 826 and the BCR is 0,59.

8.6 SENSITIVITY ANALYSIS

It is frequently not known what the environmental repercussions will be of undertaking a specific policy or project. The framework of much environmental policy is typified by uncertainty concerning the effect and irreversibility of some effects.

The explicit difference between risk and uncertainty is that risk refers to situations where the nature of the probability distribution of future events is known, while uncertainty refers to situations where the probabilities are unknown.

The problem of uncertainty in cost-benefit analysis may be addressed to some extent through sensitivity analysis. This type of analysis shows the variation in the measure of project worth, for example NPV, IRR and BCR, as changes are made to the values of particular variables.

A limited sensitivity analysis was carried out in this report in order to determine the effects on the abovementioned measures of project worth of varying the social discount rate and cost estimates (due to increased levels of productivity and improvements in management efficiency).

(a) The social discount rate

The analysis was conducted by assigning two different values to the social discount rate, namely 8,1% and 5,1%. The results are shown in Table 8.11 below.

Table 8.11: Sensitivity analysis results

Project	Criterion	Discount rate	
		8,1%	**5,1%**
Tsitsikamma (agricultural water value)	NPV (R) BCR	-27 712 341 0,66	-1 100 502 0,99
Tsitsikamma (estuarine water value)	NPV (R) BCR	-61 405 091 0,24	-66 842 173 0,36
Kouga	NPV (R) BCR	-15 029 416 0,91	78 304 839 1,37
Port Elizabeth Driftsands	NPV (R) BCR	-16 942 817 0	-21 491 714 0
Albany	NPV (R) BCR	-16 698 118 0,26	-17 887 841 0,38
Kat River	NPV (R) BCR	-1 003 887 0,51	-638 843 0,75
Pott River	NPV (R) BCR	-1 542 548 0,03	-1 706 982 0,04

As can be seen from Table 8.11 it makes no difference when the NPV and BCR criteria are used to decide on the Tsitsikamma project (water benefit valued at the estuarine value or water benefit valued at the agricultural value), Port Elizabeth Driftsands project, Albany project, Kat River project and Pott River project whether 8,1% or 5,1% is used. None of these projects are efficient. With the Kouga project the results shown above indicate that varying the discount rate has an effect on the outcome of the evaluation; the abovementioned project becomes desirable when a social discount rate of 5,1% is used. The NPV is positive and the BCR is greater than one. On the other hand, if a higher discount rate is used (8,1%) it is not desirable that the project should proceed because the NPV is negative and the BCR is smaller than one. For this reason it is deduced that the case for this project is a qualified one – it is based on the social discount rate not going above 5,1%.

(b) Productivity of clearing teams and management efficiency

It has been argued by Van Wilgen (pers. comm. 2002) that the increased productivity of clearing teams, due to learning by doing, will significantly reduce clearing costs. Marais (1998) maintained that the productivity of clearing teams increased substantially subsequent to the introduction of the "Piece Work System" where financial incentives to produce were are built in. According to Marais (1998) a 20% increase in productivity levels can easily be achieved. Moreover, Marais (1998) showed that an increase in productivity of 40% leads to a doubling of total NPV for clearing programmes in the inland catchments of the Western Cape.

As far as improvements in management efficiency are concerned, Marais (1998) showed that an increase of 3,1% in NPV for every 1% increase in management efficiency can be achieved. It should be noted that the majority of the clearing costs are incurred at the beginning of the project period and that the benefits accrue over the entire project period. Reductions in the cost of clearing at the beginning of the project period will have a major impact on the economic feasibility of the clearing programme over the long term.

In this study it was decided to examine what the impacts would be on the results of reducing clearing costs by 10%, 20% and 30%, as suggested by Van Wilgen (pers. comm. 2002), on the grounds that this could be achieved through increases in productivity levels of clearing teams and improvements in management efficiency. The results of this sensitivity analysis are shown in Table 8.12 below.

Table 8.12: Sensitivity analysis of the effect of improvements in productivity/management efficiency

Site	10% clearing cost reduction decision-making criteria (10,1%)		
	NPV	**IRR**	**BCR**
Tsitsikamma	-24 826 157	5,70	0,60
Kouga	-20 508 422	8,20	0,83
Port Elizabeth Driftsands	-13 206 816	0	0
Albany	-13 294 830	1,44	0,24
Kat River	-851 793	4,10	0,47
Pott River	-1 298 392	-2,99	0,02
Site	**20% clearing cost reduction decision-making criteria (10,1%)**		
	NPV	**IRR**	**BCR**
Tsitsikamma	-17 894 911	6,50	0,68
Kouga	-7 162 647	9,32	0,93
Port Elizabeth Driftsands	-11 739 392	0	0
Albany	-11 356 906	1,80	0,27
Kat River	-671 978	4,70	0,53
Pott River	-1 150 527	-2,83	0,03
Site	**30% clearing cost reduction decision-making criteria (10,1%)**		
	NPV	**IRR**	**BCR**
Tsitsikamma	-10 963 664	7,60	0,77
Kouga	6 183 126	10,90	1,07
Port Elizabeth Driftsands	-10 271 968	0	0
Albany	-9 418 982	2,24	0,31
Kat River	-492 163	5,60	0,61
Pott River	-1 002 662	-2,63	0,03

It can be seen from Table 8.12 above that increases in clearing productivity and improvements in management efficiency, which lead to clearing cost reductions, would only have a significant impact on the Kouga project. For a 30% clearing cost reduction scenario the NPV is greater than zero, the IRR exceeds the social discount rate (10,1%) and the BCR is greater than one. No marked changes can be observed for the other sites.

It should, however, be noted that the Kouga project becomes favourable with 10% and 20% clearing cost reductions if a social discount rate of 8,1% (instead of 10,%) is employed – the IRRs (8,20% and 9,32%) exceed the lower discount rate. The case for the Kouga project is a qualified one – it is based on the social discount rate not rising about 8,1% and that these clearing cost reductions, due to increases in productivity and improvements in management efficiency, are realised. According to Buckle (pers. comm. 2002) the number of person days required to clear one hectare in the Kouga project have decreased from 40 days in 1999 to 22 days in 2002. This was mainly due to learning by doing. This suggests that clearing cost reductions up to 30% can be achieved.

The same case can be made for the Tsitsikamma project. The feasibility of this project is, however, dependent on the social discount rate being 5,1% and that clearing cost reductions of 10% and more are realised.

8.7 CONCLUSION

The results of cost-benefit analyses of six WfW Programme projects in the Eastern and Southern Cape selected for this purpose were presented in this chapter. A cost-benefit profile was assembled for each project after which decision-making criteria were generated, namely NPV, IRR and BCR. A sensitivity analysis, whereby the social discount rate and clearing costs were varied, was also carried out. The cost-benefit analyses yielded qualified support for the Tsitsikamma and Kouga projects and no support for the others. The qualified support was based on a sensitivity analysis that was carried out. The sensitivity analysis entailed varying the social discount rate as well as incorporating clearing cost reductions, due to increases in productivity and improvements in management efficiency.

CHAPTER NINE: CONCLUSION AND RECOMMENDATIONS

9.1 CONCLUSION

One of the factors that may constrain growth in the South African economy in the Twenty-first century is a scarcity of fresh water (Briers & Powell 1993) if these scarce resources are not allocated and used efficiently. For this reason mountain catchments, which cover about 10% of the land surface area of South Africa, are very important and require careful management. They yield 50% of the total annual runoff of South Africa (Van der Zel 1981). Invasions by alien vegetation undermine the productive capacity of these catchment areas. The WfW Programme is a government initiative intended to clear these areas from alien vegetation in order to restore the natural water yield and to preserve the biodiversity that these catchments have historically harboured. The increased water yield due to the WfW Programme also has a positive impact on the healthy functioning of estuary systems.

Can South Africa afford the luxury of setting aside mountain catchment areas purely for water resource conservation? At the present rate of population growth it could be argued that we need to use this water for the population, agriculture and forestry. Social cost benefit analysis of the WfW Programme in the Eastern and Southern Cape Province do not support this argument, except for individual sites. Six sites were investigated: Tsitsikamma, Kouga, Port Elizabeth Driftsands, Albany, Kat River and Pott River.

For all the WfW projects assessed in this study (at a social discount rate of 10,1%) the NPVs were less than zero, the BCRs were less than one and the

IRRs were less than zero. In the case of the Tsitsikamma project, where the water benefit was valued at the estuarine price of freshwater, the NPV was less than zero, the BCR was less than one and the IRR was less than the social discount rate.

When the project is defined as the sum of all the subprojects we find the cost-benefit analysis criteria negative for the project. For the “gross” project the NPV is -R97 996 826 and the BCR is 0,59. Most of the secondary benefits identified in this investigation could not be included in the benefit profiles of the projects due to the fact that extensive further research is needed on these topics before they can be valued.

This conclusion is subject to three qualifications. The first is that more work remains to be done on the evaluation of the non-water benefits. Known non-water benefits, like fire damage reduction and preservation of biodiversity were not included in the calculations. The second qualification is that at lower discount rates, for instance 5%, the Kouga project is efficient. Our analysis has been criticised as using too high a discount rate. The third qualification is that if 30% cost savings can be achieved (and project managers believe it can), and a discount rate of 5% is employed, that both the Kouga and Tsitsikamma projects become efficient. These two projects are being run in catchments which serve areas where high consumptive demands exist.

9.2 RECOMMENDATIONS

(a) Alien control, as carried out by the WfW Programme in the six sites investigated, is unambiguously inefficient on all of them. For this reason it is suggested further work at all the sites be ceased unless there is strong reason for believing the learning by doing cost savings and unmeasured secondary benefits are overwhelming. We could not reach that conclusion ourselves.

(b) Water can be valued using a marginal cost or revealed or expressed willingness-to-pay approaches. Whichever approach is used, values should ideally be adjusted to take into account expected changes in demand and supply and differences between and within regions. This step (valuing the water) is the most important because conclusions about the efficiency of the WfW programme rest largely on deductions made in this connection.

(c) In view of the problems encountered in valuing water yielded through conservation projects it is recommended that the following four requirements be explicitly addressed in the process of setting values:

- the time horizon over which one is interested in the value needs to be defined and differences in purchasing power between different years need to be taken into account;
- the primary providers and purchasers of the water service need to be identified;
- how the market reveals water valuing information needs to be spelt out, e.g. cost recovery by government organisations or income capitalization or water right trades; and
- the effects of expected demand and supply changes on the future value of water needs to be made explicit.

(d) Encourage the WfW Programme to examine/test whether they are working in the best/right places. More effort should be directed at places that will deliver the best immediate benefits.

(e) We strongly recommend that efforts be made to estimate the non-water benefits associated with the WfW.

APPENDICES

APPENDIX A: Water yield per catchment per 20 years

Catchment	Yield per fire cycle	Fire cycle	Yield per 20 years
1 Tsitsikamma	777,1	12	1295,2 million m^3
2 Kouga	399,3	12	665,5 million m^3
3 Albany	66,2	4	331,0 million m^3
4 Port Elizabeth	73,1	12	121,8 million m^3
5 Kat River	3,4	4	17,0 million m^3
6 Pott River	2,2	4	11,0 million m^3

APPENDIX B: Streamflow per catchment in mm rainfall equivalents y^{-1}

mm/y Albany			Kat River			Kouga			Port Elizabeth			Tsitsikamma			Pott River		
Year	Grassveld	Exotic	Year	Grassveld	Exotic	Year	Fynbos	Exotic	Year	Fynbos	Exotic	Year	Fynbos	Exotic	Year	Grassveld	Exotic
0	303	160	0	335	266	0	253	253	0	227	227	0	340	340	0	327	222
1	296	152	1	327	258	1	251	249	1	224	211	1	338	331	1	319	212
2	293	147	2	324	254	2	249	246	2	222	196	2	336	322	2	316	206
3	291	144	3	322	251	3	247	239	3	220	175	3	334	314	3	314	201
4	289	142	4	321	250	4	245	232	4	218	159	4	332	297	4	313	197
4	303	160	4	335	266	5	243	226	5	216	145	5	330	283	4	327	222
5	296	152	5	327	258	6	241	220	6	214	134	6	328	271	5	319	212
6	293	147	6	324	254	7	239	214	7	212	124	7	326	261	6	316	206
7	291	144	7	322	251	8	236	207	8	210	115	8	323	251	7	314	201
8	289	142	8	321	250	9	234	201	9	208	107	9	321	241	8	313	197
8	303	160	8	335	266	10	232	195	10	206	99	10	319	233	8	327	222
9	296	152	9	327	258	11	230	188	11	204	92	11	317	224	9	319	212
10	293	147	10	324	254	12	228	181	12	201	85	12	315	216	10	316	206
11	291	144	11	322	251	12	253	253	12	227	227	12	340	340	11	314	201
12	289	142	12	321	250	13	251	249	13	224	211	13	338	331	12	313	197
						14	249	246	14	222	196	14	336	322			
						15	247	239	15	220	175	15	334	314			
						16	245	232	16	218	159	16	332	297			
						17	243	226	17	216	145	17	330	283			
						18	241	220	18	214	134	18	328	271			
						19	239	214	19	212	124	19	326	261			
						20	236	207	20	210	115	20	323	251			
						21	234	201	21	208	107	21	321	241			
						22	232	195	22	206	99	22	319	233			
						23	230	188	23	204	92	23	317	224			
						24	228	181	24	201	85	24	315	216			

Notes: (1) At fire year times there are two yield estimates – one before and one after the fire.
(2) These figures were used to derive Table 3.6.

APPENDIX C: Estimated water yield (m^3y^{-1}) per catchment

m3*10^5	Albany		Kat River			Kouga			Port Elizabeth			Tsitsikamma			Pott River		
Year	Grassveld	Exotic	Year	Grassveld	Exotic	Year	Fynbos	Exotic	Year	Fynbos	Exotic	Year	Fynbos	Exotic	Year	Grassveld	Exotic
0	346	183	0	40	32	0	4017	4017	0	197	197	0	4381	4381	0	16,0	10,9
1	337	173	1	39	31	1	3984	3961	1	195	184	1	4354	4271	1	15,6	10,4
2	334	168	2	39	30	2	3951	3905	2	193	171	2	4327	4161	2	15,5	10,1
3	331	165	3	39	30	3	3917	3795	3	192	152	3	4300	4051	3	15,4	9,9
4	330	162	4	38	30	4	3884	3686	4	190	138	4	4274	3833	4	15,3	9,7
4	346	183	4	40	32	5	3851	3585	5	188	126	5	4247	3654	4	16,0	10,9
5	337	173	5	39	31	6	3818	3487	6	186	117	6	4220	3499	5	15,6	10,4
6	334	168	6	39	30	7	3785	3389	7	184	108	7	4193	3361	6	15,5	10,1
7	331	165	7	39	30	8	3751	3290	8	183	100	8	4166	3235	7	15,4	9,9
8	330	162	8	38	30	9	3718	3190	9	181	93	9	4139	3117	8	15,3	9,7
8	346	183	8	40	32	10	3685	3086	10	179	87	10	4112	3007	8	16,0	10,9
9	337	173	9	39	31	11	3652	2980	11	177	80	11	4085	2902	9	15,6	10,4
10	334	168	10	39	30	12	3619	2868	12	175	74	12	4058	2801	10	15,5	10,1
11	331	165	11	39	30	12	4017	4017	12	197	197	12	4381	4381	11	15,4	9,9
12	330	162	12	38	30	13	3984	3961	13	195	184	13	4354	4271	12	15,3	9,7
						14	3951	3905	14	193	171	14	4327	4161			
						15	3917	3795	15	192	152	15	4300	4051			
						16	3884	3686	16	190	138	16	4274	3833			
						17	3851	3585	17	188	126	17	4247	3654			
						18	3818	3487	18	186	117	18	4220	3499			
						19	3785	3389	19	184	108	19	4193	3361			
						20	3751	3290	20	183	100	20	4166	3235			
						21	3718	3190	21	181	93	21	4139	3117			
						22	3685	3086	22	179	87	22	4112	3007			
						23	3652	2980	23	177	80	23	4085	2902			
						24	3619	2868	24	175	74	24	4058	2801			

Notes: (1) At fire year times there are two yield estimates – one before and one after the fire.
(2) These figures were used to derive Table 3.6.

APPENDIX D: Bioscience of tree water use

BioScience		**units**	
RAINFALL			
Mean annual rainfall		mm/y	**1500**
Mean annual runoff		mm (rainfall equivalent)	**742**
Winter rain		% of total	
ALIEN VEGETATION			
Average fire cycle		years	**15**
Post-fire age		years	**15**
Alien cover	**tall trees**	%	33
	medium trees	%	33
	tall shrubs	%	33
Alien biomass		g/m2	**10849**
INCREMENTAL WATER USE			
Streamflow reduction		mm (rainfall equivalent)	**258**
Biomass of	tall shrubs	g/m2	5748
	medium trees	g/m2	10666
	tall trees	g/m2	16462
Adjusted biomass of	tall shrubs	g/m2	1897
	medium trees	g/m2	3520
	tall trees	g/m2	5432

APPENDIX E: Working for Water Programme questionnaire

QUESTIONNAIRE

NAME OF WORKING FOR WATER PROJECT: ______________________________

NAME OF PROJECT MANAGER: ____

CONTACT DETAILS: __________(Cell no.) POSTAL ADDRESS:_______________
__________(Office no.) ________________________
__________ (Fax no.) ________________________

LIST OF QUESTIONS:

1 How many hectares do you plan to clear, including the amount already cleared, within the 20 year strategy?
_*Answer* __________________________________ ha.

2 What in your experience is the average *annual* rate of spread of alien invasives expressed as a percentage?
_*Answer* __________________________________ %.

3 What methods do you currently employ to eradicate alien invasives?
_*Answer*____
____

4 How many years of maintenance on average are required on each management unit after it has been cleared and followed-up for 2 years?
_*Answer*__________________________________ years.

5 List the main invaders in your area of concern:
_*Answer*____
____

6 What is the indigenous vegetation that will replace the alien invasives after they have been cleared (also state the percentage of each type for eg. 80% fynbos and 20% indigenous forest etc.)?
_*Answer*____

7 What is the mean annual precipitation (mm) in your area in which the WWP is operating? (if different per area - specify areas and millimetre averages?
_*Answer*__________________________________ mm.
__________________________________ mm.

Contact details of interviewer: Mario du Preez, ✉ 65 Lily Avenue, Sunridge Park, Port Elizabeth, 6045
☎ tel no: (041) 3601079 (h) & (041) 5042795 (w) fax no: (041) 5042574

8 Briefly describe the topography (e.g. mountainous) of the area in which the WWP is operating?
_*Answer*____

9 What are the soil type(s) found in the area in which the WWP is operating?
_*Answer*____

10 What are the major problems (e.g. water yield, erosion) resulting from alien invaders in the area in which the WWP is operating?
_*Answer*____
____

11 What percentage of the precipitation falls between April and September?
_*Answer* _________________________

12 Briefly describe your management model:
_*Answer*____
____
____
____

13 How long is the average fire cycle in your area (estimate if not known)?
_*Answer* _________________________ years.

14 When did the last fire occur in the area in which the WWP is operating?
_*Answer* 19__________.

15 Please complete the table below on infestation levels. Please note that the amount of hectares for each density class and species must be filled in

	Species:				
Density class	Pinus	Hakea	Acacia	Eucalyptus	Total
Rare (<< 0,1%)					
Occasional (< 5%)					
Scattered (5 - 25%)					
Moderate (25 - 75%)					
Dense (> 75%)					
Total area infested					
Total area planned to clear.					

THANK YOU FOR YOUR COOPERATION

Contact details of interviewer: Mario du Preez, ✉ 65 Lily Avenue, Sunridge Park, Port Elizabeth, 6045
☎ tel no: (041) 3601079 (h) & (041) 5042795 (w) fax no: (041) 5042574

APPENDIX F: Contingent valuation survey questionnaire

3

CONTINGENT VALUATION QUESTIONNAIRE ON THE ENVIRONMENTAL SERVICES PROVIDED BY THE KEURBOOMS ESTUARY

Conducted by the Department of Economics, University of Port Elizabeth, April, 2001

Instructions: Please tick the appropriate blocks. If the answer is other, please provide correct answer in the space provided alongside 'other'.

1 CATEGORY OF RESPONDENT

Category of respondent			
1.1	Fisher	1	4
1.2	Boater	2	5
1.3	Swimmer/bather	3	6
1.4	Owner with water frontage access	4	7
1.5	Other – birder, walker, house view, local appeal	5	8

2 WHAT DO YOU THINK WILL HAPPEN IF NO FRESH WATER IS ALLOWED TO FLOW INTO THE KEURBOOMS ESTUARY AND THE MOUTH CLOSES?

Person is well informed on ecology (>3 right – see below)	1	
Person is not well informed on ecology (< 3 right – see below)	2	9

Which of the following are you aware of?

If the mouth closes the following impacts could be expected:			
2.1.1	A significant shrinkage in the total area of estuary available for boating and other activities.	1	10
2.1.2	A reduction/total loss of bait for fishermen, especially prawn.	2	11
2.1.3	A reduction in fish available to be caught in the estuary and off shore, including estuary fish species (like spotted grunter and dusky cob) and migratory species (like garrick and shad).	3	12
2.1.4	An increase in smelly decaying aquatic vegetation (exposed due to lower water levels).	4	13
2.1.5	A total loss of foraging birds in the intertidal area around the estuary.	5	14
2.1.6	A less attractive estuary and mouth shoreline (mud flats where water receded)	6	15
2.1.7	Increased potential for flooding of low lying properties near the Keurbooms when dams on this river overflow (because of sand bar build up at the mouth making natural dam wall)	7	16
2.1.8	In addition, other?		18
			20

3 RATE THE FOLLOWING ACTIVITIES/ATTRIBUTES in the Keurbooms Estuary according to the importance you attach to each.

Attributes/Activities	*Major importance*	*Very important*	*Moderate importance*	*Little or no importance*		
3.1 Birdlife	4	3	2	1		21
3.2 Boating - fishing	4	3	2	1		22
3.3 Boating – sport and recreation	4	3	2	1		23
3.4 Bait availability	4	3	2	1		24
3.5 Fish availability/Angling	4	3	2	1		25
3.6 Water frontage – access	4	3	2	1		26
3.7 Water for view	4	3	2	1		27
3.8 Other (specify)	4	3	2	1		30
3.9 Other (specify)	4	3	2	1		33

4 If the Keubooms mouth were to close and you were to lose the availability of the services I have listed HOW WOULD YOU GO ABOUT SATISFYING YOUR DEMAND FOR THESE SERVICES (E.G. FISHING AND SKIING ELSEWHERE)? Please tick appropriate blocks.

4.1	Knysna Lagoon	1	34
4.2	Sedgefield	2	35
4.3	Do without	3	36
4.4	Other		38

5 HOW MUCH DO YOU PAY PER YEAR IN LEVIES for use/access to the Keurbooms in fishing, boating, bait collection and other fees?

R		
0	0	
1 – 20	1	
21 – 50	2	
51 – 100	3	
101 – 200	4	
201 – 500	5	
501 – 1 000	6	
1 000 +	7	39

Working Box

Background Information (per annum or per visit)
Boating fee (R250 p.a. and R115 for a 30 day licence motorised)
Angling fee (R35 p.a.)
Bait collection fee (R50 p.a.)
Launching fee (free)
Access to banks fee (free)
Other fees(?)

6 WHAT LEVY PER YEAR ARE YOU WILLING TO PAY to ensure adequate fresh water inflows to prevent closure of the Keurbooms mouth? (Including what you already do pay and what work income you are willing to forgo by putting time and energy into gathering support for your position?)

The levy would be collected from all users who derive benefit directly/indirectly, including those providing visitors access to the Keurbooms Estuary. This levy would enable the release of sufficient dam water or extra water generation through the Working for Water Programme in the upper reaches of the catchment, to keep the mouth of the Keurbooms open.

The willingness to pay issue arises because the 'price' of estuary services would escalate in the Plettenberg Bay area. It would rise because of reduced supply of Keurbooms Estuary services in the face of constant or increasing demand. The primary aim of this questionnaire is to shed light on what users would be prepared to pay to prevent this 'price' escalation (reduction in estuary services supply).

Please bear in mind when answering this question that the more water made available to the estuary, the greater the requirement of the local authority in Plettenberg Bay to look for more expensive supplies of water further afield and the higher will be future water bills.

R

0	0	
1 – 20	1	
21 – 50	2	
51 – 100	3	
101 – 200	4	
201 – 500	5	40
501 – 1 000	6	
1 001 – 5 000	7	
5 001 +		

7 WHAT WOULD YOU SACRIFICE IN ORDER TO MAKE THIS PAYMENT? (The money has to come from somewhere – the budget constraint). Tick the appropriate blocks.

Service income would be reallocated from		
7.1 Recreation activities	1	41
7.2 Domestic/household living	2	42
7.3 Saving	3	43
7.4 work income forgone	4	44

8 WOULD THE FRESH WATER CURRENTLY FLOWING INTO THE KEURBOOMS BE WORTH MORE from your point of view if it was reallocated to the residents of Plettenberg Bay for consumption?

Yes (worth more for consumption)	1	45
Be worth the same	2	
No (worth more flowing into estuary)	3	

9 GENDER OF RESPONDENT.

Male 1	Female 2	46

10 DISTANCE IN KILOMETRES OF RESPONDENT'S RESIDENCE FROM THE KEURBOOMS ESTUARY

Distance (kms)

0 – 1	1
1 – 3	2
3 – 5	3
5 – 10	4
10 – 15	5
15 +	6

50

11 EDUCATIONAL LEVEL OF RESPONDENT

Grade (enter highest grade passed)	
Post matric qualification	13
Diploma	14
Degree	15
Post graduate degree	16

52

12 APPROXIMATE WORTH OWNED FIXED PROPERTY (ANYWHERE IN THE WORLD) at current prices.

R

0	0
1 – 50 000	1
50 001 – 100 000	2
100 001 – 200 000	3
200 001 – 500 000	4
500 001 – 1 000 000	5
1 000 001 +	6

53

13 APPROXIMATE WORTH OF VEHICLES AND BOATS OWNED at current prices:

R

0	0
1 – 50 000	1
50 001 – 100 000	2
100 001 – 200 000	3
200 001 – 500 000	4
500 001 – 1 000 000	5
1 000 001 +	6

54

14 GROSS ANNUAL PRE-TAX INCOME OF RESPONDENT

R

0 – 60 000	1
60 001 – 120 000	2
120 001 – 250 000	3
250 001 +	4

55

Please note that this is a sensitive issue, but it makes a big difference to us and this is an anonymous survey.

Questionnaire constructed by Prof. S. G. Hosking, and Mr M. Du Preez, Dept. of Economics UPE, in consultation with Prof. T. Wooldridge, Dept. of Zoology UPE.

APPENDIX G: Ecology of the Keurbooms and Bitou Estuaries

ECOLOGY OF THE KEURBOOMS AND BITOU ESTUARIES

(by TH Wooldridge)

Executive summary

- The Keurbooms and Bitou estuaries near Plettenburg Bay share a common mouth that opens to the sea along Lookout Beach.
- The tidal inlet bisects a narrow 3,5 km longshore barrier dune. The position of the mouth is not constant and is constantly changing in position according to estuarine and nearshore hydrodynamic forces.
- Net mouth migration is southwards. Floods (particularly larger floods) scour marine-derived sediments from the lower estuary, occasionally breaching the barrier dune and creating a new mouth closer to the northern end.
- A blind lagoon forms south of the tidal inlet. This lagoon provides a rich biotic habitat in comparison to tidal areas immediately north of the mouth. The marine beach opposite the lagoon provides a major recreational facility.
- The blind arm and Lookout Beach decrease in area as the mouth migrates southwards. Thus, the functional value of both is inextricably linked to flood patterns.
- The Keurbooms-Bitou system is recognized as one of the most important estuaries along the South African coast (approximately 250 estuaries), and is ranked 16th in conservation importance. Conservation importance is calculated on the basis of weighted size, type, biogeographical zone in which it occurs, habitat types and biota present (plants, invertebrates, fish and birds).
- The future conservation status of the Keurbooms-Bitou estuaries is dependent primarily on adequate freshwater inputs. Both baseflow and flood events are important in maintaining estuarine structure and function.
- Ever-increasing human demand for freshwater in the region is a serious threat facing the estuary and further abstraction schemes could negatively alter the present functioning and status of the system.
- Huizinga & Slinger (1996) list three main physico-chemical issues pertinent to any reduction in freshwater inputs to the Keurbooms-Bitou estuaries:

- Potential closure of the estuary mouth. Although the tidal inlet has not been known to close, the mouth sometimes becomes very shallow and constricted. Mouth closure, even temporarily, would have a dramatic effect on the structure and functioning of the two estuaries.
- Increased sedimentation. Reduced estuarine scouring as a consequence of flood attenuation, would lead to progressive shallowing, especially nearer the mouth. Tidal flows would decrease leading to greater potential for mouth closure.
- Changes in hydrodynamic and water quality properties. Reduced or changes in freshwater supply would alter the hydrodynamic character of the estuaries. This would lead to changes in the persistence and distribution of salts and affect the flushing and renewal of saline water. Impacts would increase if the estuary mouth closed.

- Even a small reduction in freshwater supply in the future has the potential to lead to mouth closure, since the mouth has come close to closing on a number of occasions in the immediate past.
- From a physical point of view, estuarine processes that rely on a functional link with the marine environment include:
  - water exchange across the inlet,
  - mixing of different water masses as a result of tidal action, leading to the establishment of salinity gradients in the estuary,
  - reduce high water temperatures in the estuary, particularly in shallow marginal areas,
  - the supply, transport and distribution of autochthonous (formed in the estuary) and allochthonous (transported into the estuary from outside) organic and inorganic materials,
  - maintenance of estuarine intertidal floral and faunal zonation gradients through tidal oscillation, and
  - regulation of sediment characteristics in the estuary.

- If the mouth channel becomes constricted and choked due to less effective scour during floods (frequency and magnitude of floods reduced because of dam construction), negative non-biological impacts include:
  - reduction of the tidal prism, current velocities and nutrient inputs from the sea,

- as a result of reduced current velocities, stratification (temperature and salinity) in the water column is encouraged,
- bottom water may turn anoxic, particularly in deeper basins where more dense water becomes trapped,
- nutrients present in bottom waters are less readily available to phosynthesizers in the water column, and
- as a result of the reduced mixing ability of tidal currents, freshwater and its associated nutrient load may have a short residence time and flow directly out to sea with little benefit to the estuary.

- The estuarine biota is sensitive to physico-chemical changes in the estuary brought about by a reduction in freshwater supply. Potential impacts include:
  - Changes in the longitudinal salinity gradient lead to changes in biotic assemblages associated with specific salinity ranges along the gradient.
  - If the estuary mouth closes, decreasing salinity values can become lethal to trapped biota. Salinity values may also decline to below threshold levels necessary for reproduction and larval survival of estuarine organisms.
  - Changes in water temperature particularly in shallow, marginal areas may limit flushing of these areas during summer (a constricted tidal inlet influences tidal ebb and flow). This could lead to elevated water temperatures that become lethal for some species.
  - Mouth closure leads to changes in intertidal zonation patterns, particularly in saltmarsh areas.
  - Mouth closure disrupts the lifecycle of marine fish species that depend on estuaries as nursery areas. Conversely, the same species may become trapped in estuaries where they are unable to breed.
  - mouth closure reduces the intertidal area available to foraging birds.
  - mouth closure disrupts the lifecycle of estuarine invertebrates and fish that have a marine phase of development. In extreme cases this may lead to the local extinction of populations.
  - Mouth closure disrupts the lifecycle of catadromous species (migrate from freshwater to the sea in order to breed) as well as the immigration and emigration of species moving between estuarine and marine habitats.

Introduction

Over 500 years ago, Bartholomew Diaz gave Plettenburg Bay the name *Bahia das Alagoas* or 'Bay of the Lagoons' (Storrar 1978). The name probably referred to the extensive lagoonal system below the confluence of the Keurbooms and Bitou estuaries, an area that has retained its extraordinary landscape attraction (See Plate 1 and Fig. 1). Historically, the Bay of the Lagooons has changed names numerous times as urban settlements became established. The present name was derived after a former governor of the Cape. Today, Plettenburg Bay has a resident population of about 70 000 people, with a peak of nearly 110 000 people in the December 2000-01 holiday season (pers. com., Plettenburg Bay Health Officer). Plettenburg Bay and its environs are now well established as areas of exceptional benefit to residents and visitors alike. Besides being one of the most important estuaries along the South African coast, the Keurbooms is also extensively used for recreation.

However, ever-increasing human pressure is placing a strain on natural resources in the Plettenberg Bay region. In particular, excessive abstraction of freshwater from river catchments is a major threat facing the sustainability of the Keurbooms and Bitou (a major tributary of the Keurbooms) ecosystems. In order to function naturally, estuaries require 100% of river discharge patterns and it is essential that the consequences of any alteration in freshwater supply be assessed critically.

General review of estuarine structure and function

Estuaries are an important part of the aquatic environment, forming transitional links between rivers and the sea. Although estuaries constitute a small part of the area and an even smaller part of the volume of the total marine hydrosphere, they play a vital role in the life history and development of many marine populations. Without estuarine ecosystems, saltwater commercial and recreational fisheries would be significantly altered. In the USA, about 65% of the shellfish and fish catches depend on estuaries to complete their life cycles.

The salient feature of estuaries is the oscillating salt content of the water. A salinity gradient is established that changes according to the volume of freshwater inflow, the degree of tidal mixing and the topography of the estuary. Near the tidal head, salinity is near zero (freshwater) while at the mouth, salinity is about 35 parts per thousand or ppt (seawater). Variations in salinity are driven by factors that operate over different time scales, ranging from a few hours (tidal action), to months (seasonal changes in evaporation and rainfall) and years (wet and dry cycles). The state of the tidal inlet also exerts an influence on the salinity gradient. In South Africa, many estuaries close off periodically as a result of the accumulation of sediment in the lower estuary.

These variations in salinity contribute to the stressful nature of estuaries as an area in which to live. Although species richness is generally much lower compared to adjacent marine or freshwater habitats, a number of species are unique to estuaries and are well adapted to survive the variability of the physical environment. Despite fewer species, estuaries still rank amongst the most productive systems on earth. Estuaries are able to sustain rich populations, which may broadly be divided into those living on or in the sediment (benthic) and those associated with the water column. In the water column, organisms are grouped according to their ability to swim against water currents. Nektonic animals are strong swimmers (e.g. fish), while planktonic organisms (small drifting organisms in the water column) are more at the mercy of the currents. Despite their inability to swim against currents above a particular threshold, many species have developed behavioural patterns that aid retention in areas optimal for their survival.

Estuaries rank among the environments most affected by humans. Human intrusion has resulted in disastrous changes for some systems - having been dredged or filled and transformed into seaports, marinas, industrial parks, cities and garbage dumps. Many have been obliterated and most remaining estuaries are threatened in some way. In the USA for example, about one-third of estuaries have disappeared altogether. A major factor impacting on South African estuaries is freshwater attenuation owing to the ever-increasing demand by domestic, industrial and agricultural consumers. Local rivers and estuaries are small by world standards and specific impacts on these fragile ecosystems are sometimes considered inconsequential, although cumulative effects are often highly significant.

Classification of South African estuaries

The most widely accepted definition of estuaries in South Africa is that used by Day (1980) "a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage". However, this definition does not convey the variety of estuarine types that range from those that maintain a permanent connection with the sea to estuaries that periodically close for varying periods. Incorporated in the latter category are estuaries that are sometimes referred to as 'blind estuaries' or 'lagoons'. To facilitate a more rational approach to estuarine classification in South Africa, Whitfield (1992) described five categories of estuaries based mainly on physiographic, hydrographic and salinity characeristics. However, an estuary of one type can behave at times like a completely different type, depending on river inflow and inlet condition. In the following scheme, estuaries are described according to their dominant phase.

Permanently open estuaries (e.g. Keurbooms estuary)
These systems are permanently influenced by tidal action and exhibit typical estuarine characteristics, e.g. a moderate tidal prism and a horizontal salinity gradient. The water column may be well mixed or stratified (vertical salinity or temperature differences), with individual systems often shifting between conditions on a temporal scale. Stratification is dependent on factors such as bathymetry, tidal streaming and river flow. Permanently open estuaries usually have catchment areas >500 km^2 and sometimes greater than 10 000 km^2.

Rivers are usually perennial in their natural condition. Intertidal wetlands may also be present, vegetated with saltmarshes in more temperate regions and mangroves in tropical areas. The eelgrass *Zostera capensis* often occurs subtidally, especially in middle and lower reaches.

Salinity values usually fluctuate between 5 and 35 ppt, although hypersaline (>35 ppt) conditions sometimes develop during times of high evaporation and low or no river inflow.

Temporarily open/closed estuaries (e.g. Kabeljous estuary)
These estuaries close off from the sea for varying lengths of time owing to sandbar formation at the mouth. This occurs during times of low or no freshwater inflow, often linked to longshore sand movement in the marine nearshore. Catchment areas are usually small (<500 km^2). Hydrographic conditions are highly variable and large amounts of sediment are removed at times of river flooding. During times of mouth closure, water levels in the estuary may gradually rise until overtopping the sandbar at the mouth. Water levels drop rapidly, often exposing previously inundated areas that sustained a high biomass of plant and animal life.

River mouths (e.g. Orange river)
River processes usually dominate physical processes in the estuary, with salinity values approaching oligohaline conditions (<5 ppt) in the middle reaches. Tidal inlets often remain permanently open, although seawater penetrates only a short distance up-estuary on a flood tide. Catchment areas are usually large and their rivers generally carry a high silt load. This is in contrast to the Tsitsikamma coast where rivers are usually short, rising in Table Mountain Sandstone. Silt loads are also negligable in these systems.

Estuarine lakes (e.g. Wilderness)

Estuarine lakes mostly evolved from drowned river valleys that have separated from the sea by vegetated sand dune systems. In some cases the barrier dune has completely isolated the water body, although a relic estuarine biota sometimes survives. These systems are usually referred to as coastal lakes. Some estuarine lakes retain their marine connection, although the link may be temporary. Salinity values in the lake may vary considerably, ranging from oligohaline (salinity <5 ppt) to hypersaline (>35 ppt) depending on freshwater inflow. Consequently, biotic composition varies between extremes that may remain at extreme levels for long periods (years).

Estuarine bays (e.g. Knysna)

These estuaries may be either natural or partly artificial due to dredging activities in the mouth and harbour region. Estuarine bays have a large tidal prism and salinity values in the lower reaches usually exceed 25 ppt. Near-marine conditions can extend into the upper reaches during periods of low freshwater inflow.

The Keurbooms and Bitou estuaries

Plate 1. Aerial view of the mouth of the Keurbooms estuary. Net longshore migration of the mouth (right to left) leads to changes in the morphology of the lagoon seen on the left of the picture. Occasionally, floods cause the mouth to open in a new position along the sandbar. See Figs. 1 and 2 for further details.

The present report forms the ecological basis of a major study on the economic evaluation of the goods and services provided by the Keurbooms and Bitou estuaries. Data were derived from published information, much of it in the form of occasional reports.

Location

The estuary of the Keurbooms river opens to the bay at 34^{o} $02^{!}$ S, 23^{o} $23^{!}$ E. A major tributary, the Bitou joins the Keurbooms a short distance upstream of the mouth (Plate 1 and Fig. 1). The national road (N2) crosses the Keurbooms and Bitou rivers six and five kilometers north-east of Plettenburg Bay respectively. Bridge and embankment construction on the Keurbooms covers approximately 45% of the river width, and a large quantity of rubble still remains downstream from the bridge. Only a narrow channel 10 m wide remains navigable in this area of the estuary (Duvenage & Morant 1984). Similarly, bridge and embankment construction on the Bitou to accommodate the N2 road, diverts the flow of tidal waters to a secondary channel.

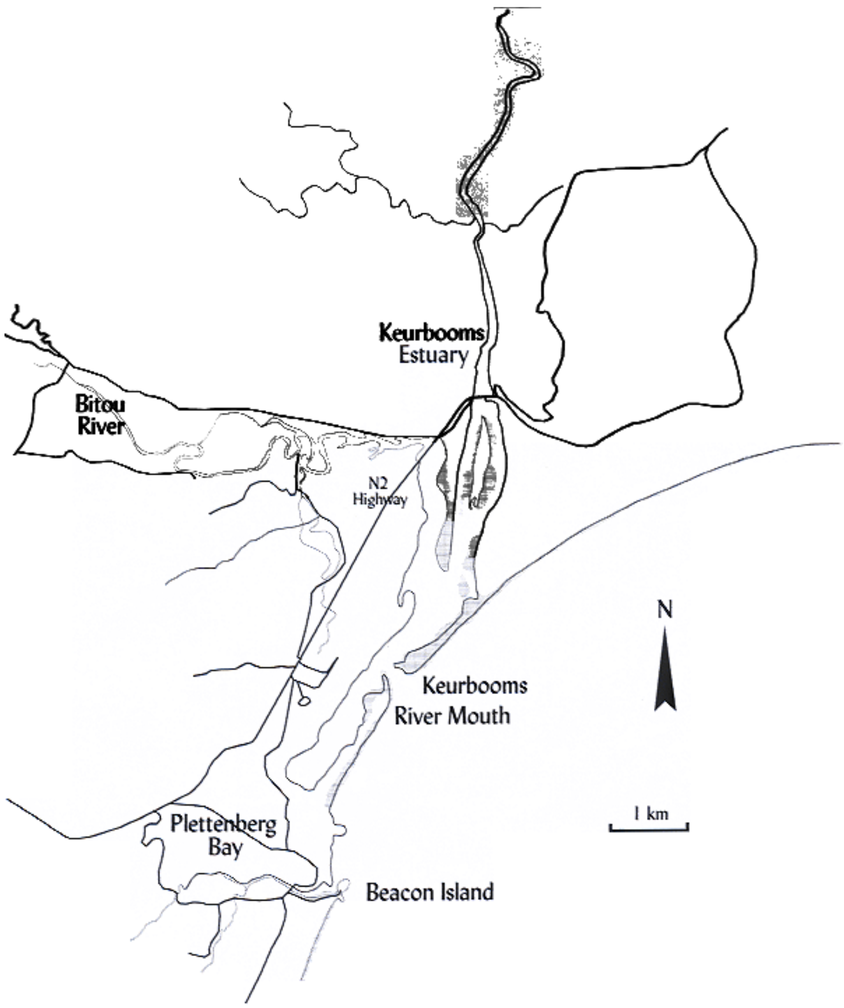


Figure 1: The Keurbooms and Bitou estuaries

ABIOTIC FEATURES

Climate

The Keurbooms and Bitou catchments receive rain almost equally in all seasons with peaks in autumn and spring (Duvenage & Morant 1984). Rainfall in the Outeniqua and Tsitsikamma mountains may exceed 1100 mm per year. On average, 8-10 rainy days can be expected per month. The rainfall pattern is mainly cyclonic and orographic.

Area of river catchments

Reddering (1981) gives the area of the catchment of the Keurbooms and the Bitou rivers as 859 km^2 and 237 km^2 respectively. The combined area of 1096 km^2 is slightly less than that given by Heydorn & Tinley (1980)(1188 km^2).

Geology

Keurbooms

The main tributaries of the Keurbooms river arise on the steep slopes of the Outeniqua, Langkloof and Tsitsikamma mountains. The river forms a deeply incised gorge in the coastal plateau while the estuarine section lies on the very narrow coastal plain. Bedrock of the river and major tributaries consists mainly of Table Mountain quartzite that resists erosion and weathering extremely well (Reddering 1996). This results in very little sediment supply to the estuary.

Bitou

The Bitou differs from the Keurbooms with respect to geological substrate in that only about half of the catchment is made up of Table Mountain quartzite. Enon Formation underlies about one third of the catchment area while some Bokkeveld slate occurs occurs in the middle reaches of the river. Sediment derived from the latter two geological units thus provides much more silt and clay compared to the Keurbooms system (Reddering 1996). Consequently, the Bitou estuary has a significant content of mud in the sediment.

River lengths

The length of the Keurbooms river from the mouth to the source at Spitskop in the Outeniqua mountains is 70 km (Duvenhage & Morant 1985). A number of tributaries join the Keurbooms river and include the Hartbees, Duivelsgat, Palmiet, Klein, Diep, Witels, Kwaai, Peters, Bos and Kykoerie rivers. The Palmiet is one of the larger tributaries (35 km long) and joins the Keurbooms river approximately 15 km from the estuary mouth. The Bitou river is 23 km long (source to the confluence with the Keurbooms).

Land ownership and catchment uses

The major part of the Keurbooms river catchment (859 km ^{2}) is made up of privately owned farms. In the upper mountain catchments, vegetation consists mostly of natural vegetation used for cattle and goat farming (Duvenage & Morant 1984). The vegetation type includes Mesic and Dry Mountain Fynbos with large areas of Wet Mountain Fynbos along the middle reaches of the river. These middle reaches also have cultivated lands and orchards along the river banks. Privately owned indigenous forests occur lower down the catchment on the southern side.

The catchment of the Klein Palmiet river (a tributary of the Palmiet) and the area from the Palmiet river up to the N2 Keurbooms bridge falls under state control. This area includes the Keurbooms River State Forest, composed of both indigenous forest and exotic plantations.

The Keurbooms River Nature Reserve (128,5 ha) extends upstream for about 6 km from the N2 bridge, mostly on the western side of the river. Banks are steep and covered with indigenous forests. Features of this reserve are hiking trails, camping sites and holiday accommodation. Angling and bait collecting are permitted within the reserve, but are subject to current control measures (method of capture, quantity and in the case of fish caught, minimum total size). Boating within the reserve is also strictly controlled, with a maximum speed of 10 km per hr imposed. However, water skiing is permitted within 2 km of the N2 bridge on the northern side and between the hours of 10:00 and 16:00.

The upper reaches of the Bitou river (catchment 257 km^2 in area) and its tributaries run through three state forests that consist mostly of indigenous vegetation. Remaining parts of the catchment are privately-owned farms that include indigenous forests and cultivated lands. The upland reaches are the best agricultural areas in the region (Duvenage & Morant 1984). Farms are relatively large producing mostly wheat, dairy products and vegetables. The Hillview area is also an important, having 3500 ha of arable land that is used mostly for mixed farming on the smaller units and dairy farming on the larger plots. In the Wittedrift area, plots are small and are not considered economically viable farming units (Duvenage & Morant 1984).

Run-off and Flow Records

The mean annual run-off for the Keurbooms and Bitou catchments is variable, depending on the reference used. The following table (Table 1) summarizes available data, mainly quoted in (Duvenage & Morant 1984).

Table 1. Summary of available information on river run-off in the Keurbooms and Bitou catchments. The discrepancy between the estimate of Midgley & Pitman 1969 and lower values for the Keurbooms is probably due to the source of the data (rainfall vs gauging plate measurements - as quoted in Duvenage & Morant (1984))

Catchment	**Annual runoff** (x 10^6 m^3 per annum)	**Reference**
Keurbooms and Bitou (combined)	160	Noble & Hemens (1978), as quoted in Duvenage & Morant (1984).
Keurbooms Bitou	127 32	Midgley & Pitman (1969), as quoted in Duvenage & Morant (1984).
Keurbooms	72,9	Reddering (1981)
Keurbooms (1960 – 1970)	64	Dept of Water Affairs. Measured 15 km from mouth, as quoted in Duvenage & Morant (1984)
Keurbooms (Oct 1970 – June1981)	71	Dept of Water Affairs. Measured 15 km from mouth, as quoted in Duvenage & Morant (1984)

In a recent study on the estuarine freshwater requirements of the Keurbooms estuary, mean annual runoff was given as102 x 10^6 m^3 (Plettenburg Bay Catchment Study, Huizinga & Slinger 1996). Mean runoff for the Bitou catchment was quoted as 32 x 10^6 m^3.

Hydrological impact of alien plant infestations

Data in this section were obtained from a report compiled by the Division of Water, Environment and Forestry Technology of the CSIR for the Department of Water Affairs and Forestry, Working for Water Programme. The project team was Scott, le Maitre, Chapman & Gelderblom (1999). The objectives of the study team were to:

- Determine the extent of invasive alien plants in the Keurbooms catchment, which species of alien plants occur there, where, and in what densities.
- Determine the current impact of alien plants on streamflow.

- Estimate the amount of additional water that would be generated by clearing existing infestations.
- Estimate, assuming infestations are not cleared, the rate of expansion and the effect this would have on future runoff in the Keurbooms catchment.

Only a summary of relevant findings is presented in this report – the reader should refer to the original document for full details. Six land-use categories are identified and the degree of invasion calculated from Table 1 in Scott, le Maitre, Chapman & Gelderblom (1999) is as follows (Table 2):

Table 2. Summary of the invaded area (%) of the six identified land use categories identified in the catchments of the Bitou and Keurbooms catchments. Note: The degree of infestation is variable within land-use categories while the ongoing invasion rate also differs according to invader species in the different categories. The state of invasion also differs along the respective river lengths.

Land-use category	**Total area (ha)**	**Invaded area (%)**
Natural forest	16194	26
Fynbos	80661	81
S & SWC Resosterveld	1820	50
Grazing	3278	20
Plantation	5940	3
Transformed (e.g. farm crops)	4542	Nil

In estimating stream flow reduction by alien plantations, plant biomass (a function of vegetation age) of specific invader species must be known. Biomass development models differ in shape, with some plant species attaining a high biomass at an early age (compared to another species).

The product of the model developed for the Keurbooms and Bitou suggest that, in the riparian zone (immediately adjacent to the river) and in upslope areas of the catchment, the condensed coverage of invader plants is about 9% and 24% respectively (in 1996). This condensed coverage will increase to 36% and 65% by 2020 if alien infestation is not controlled. Streamflow reduction will reduce from the present 567 million $m^3 a^{-1}$ to 1564 $m^3 a^{-1}$ in 2020 (176% increase in impact compared to present impact). Thus, in order to sustain water resource availability in the catchment, it is vital that adequate control measures be taken against the spread of tall, woody, alien invasive plants (Scott, le Maitre, Chapman & Gelderblom 1999).

Description of the two estuaries

The Keurbooms-Bitou estuarine complex can be divided into three main components (see Fig. 1):

- The lower 3,5 km lagoon behind a coastal barrier dune. The southern sector of the lagoon forms a blind arm, the extent of which depends on the position of the dynamic tidal inlet. At the present time (January 2000), the tidal inlet opens to the sea 0,5 km to the east of Lookout Rocks.
- The Bitou that connects with the main estuary just above the lagoon. The Bitou is 6,7 km long from its head at Wittedrift to its confluence with the Keurbooms.
- The Keurbooms estuary that extends for 7 km above the Bitou confluence to Whisky Creek at the head of tidal influence.

The permanently open tidal inlet steadily migrates southward at a rate of about 30 m per annum (Reddering 1983). This continues until a major flood breaches the spit at the northeast extremity of the barrier dune (Duvenhage & Morant 1985). During the past 125 years, the inlet migrated up to Lookout Rocks, but the possibility of this event is obviously dependent on flood frequency. Although inlet migration is generally southwards, temporary reversals in the direction can take place depending on wave climate. From an ecological point of view, reduced current velocity in the blind sector of the lagoon leads to the establishment of extensive beds of attached plants that support a rich and different animal community compared to the dynamic channel area north of the inlet. As the inlet migrates in a southward direction, the blind arm decreases in area, as does the human carrying capacity of Lookout Beach on the seaward side. Thus, the ecological importance of the blind sector of the lagoon and the extent of Lookout Beach are inextricably linked to natural flood cycles.

Spring tide range on the coast is about 1,6 m, decreasing rapidly to 1 m just inside the inlet. The substratum in the lower reaches of the estuary is marine sand transported into the estuary by tidal action and barrier overwash. This sand is mainly quartz (70%) and the remainder skeletal carbonate and some heavy minerals. Over time, a flood tidal delta develops just inside the mouth (sand is deposited after current velocity decreases inside the inlet). As the inlet migrates, deltas connect forming a continuous intertidal and subtidal sand body on the landward edge of the lagoon (Reddering 1983). Extensive sand flats develop, with tidal channels running immediately behind the barrier dune system.

The extensive shoaling of marine sand in the lower estuary causes navigational problems around low water of spring tide. Reddering & Esterhuysen (1983) estimated that 3,6 x 10^5 m^3 of sand deposited on the flood tidal deltas between 1936 and 1979. The total volume of sand calculated to have entered the estuary since 1915 probably exceeded 1000000 m^3, or an average of about 1,5 x 10^4 m^3 a^{-1}. Most sediment movement occurs during storm events.

Although the impact of major floods on the estuary are unlikely to be affected by reservoirs in the catchment, filtration of smaller floods from the natural discharge spectrum may influence removal of sediment from the lower estuary (sandy sediments). If the frequency of floods sufficient to scour sediment from the estuary is reduced, sedimentation from the marine environment will increase and this will require a flood of greater erosive capacity to remove the excess volume of sediment. Excess sediment accumulation will, in turn, negatively affect the hydraulics in the lower estuary (Reddering 1981).

Sediment deposition in the estuary derived from land drainage is not significant (Duvenage & Morant 1984). The river catchments lie in the quartzitic Table Mountain Group, a relatively small quantity of quartz almost mud-free sand is transported into the downstream estuary. The sediment yield is calculated to be 150 to 200 tons per annum (quoted in Duvenage & Morant 1984) and with a catchment area of 1096 km^2, this amounts to about 200000 tons or 100000 m^3 per year. Some of this is retained in the river system or washed to sea as suspended load. Although there did not seem to be any significant sand increase between 1946 and 1984 in the estuary, muddy sediments accumulate in the blind section of the lagoon south of the inlet.

The upper Keurbooms estuary (above the N2 Bridge) displays several sharp and narrow bends within the steeply sloping valley. Deep scour pools are a feature of this section of the estuary and six pools exceed 10 m in depth (Reddering 1996). The deepest of these exceeds 25 m water depth (below Mean Sea Level). Scour pools are formed during severe floods as water turbulence produces local vortices. Straight channel sections of the estuary are shallow and have an average depth of one to three metres.

Physico-chemical characteristics

The following data are extracted from Duvenage & Morant (1984) and represent a summary of information presented. Values are naturally variable over time and depend on the interactive effects of forcing parameters that include: distance from the tidal inlet, season, rainfall distribution, degree of vertical mixing in the water column, water exchange and vegetation cover.

pH

River water pH varies considerably, ranging between 3,9 and 8,7. High acidic values (low pH) are probably due to leached out decayed vegetation, while maximum pH values may be caused by high photosynthetic activity (minimum and maximum values were recorded in the early morning and late afternoon respectively - Duvenage & Morant 1984). The pH is higher in the estuary than in the river, with increasing values towards the mouth. This increase is probably due to the effect of seawater.

Temperature

Seasonal temperature differences range between 12^{o}C and 28^{o}C, with highest values recorded towards the head of the two estuaries in summer. Records suggest that the temperature gradient reverses in winter, decreasing upstream due to the cooling effect of inflowing river water.

Salinity

Water salinity below the bridges across the Keurbooms and Bitou estuaries varies from 13 to 30 ppt. (parts per thousand – seawater has a salinity of 35 and river water has a value of near-zero). Vertical salinity stratification is also a feature of the Keurbooms upstream of the N2 bridge. At 2 km above the Keurbooms bridge, salinity of the surface water may decrease below 10 ppt. However, salinity varies according to rainfall (inter and intra-annual variations). The Bitou tends to have higher salinity values, because of reduced freshwater inflow and evaporation. Diurnal fluctuations also occur because of tidal ebb and flow.

Biotic characteristics

Attached aquatic plants

Beds of eelgrass *Zostera capensis* occur throughout the intertidal and subtidal areas of the lagoon, as well as upstream of the bridges across the Keurbooms and Bitou estuaries Distribution and area covered (m^2) by *Z. capensis* in intertidal and subtidal zones below the N2 bridges is given in Table 3. Main channel areas where strong currents prevail are devoid of eelgrass.

Table 3. Intertidal and subtidal distribution and area covered (m^2) by *Zostera capensis* (eelgrass) living in the different substrata of the lower Keurbooms estuary. Fig. 2 provides information on the different regions listed in the second column (adapted from Zoutendyk & Bickerton 1996). I = Intertidal, S = Subtidal.

Tidal Level	Region	Sandy substrata	Sandy-mud substrata	Muddy Substrata
I	Blind arm	49600	103300	43200
I	Middle reaches	29700	-	-
I	Upper reaches	125120	381860	10000
I	Bitou	-	-	161180
S	Blind arm	19400	15000	-
S	Middle reaches	-	-	-
S	Upper reaches	-	-	-
S	Bitou	-	-	-

Salt-marsh plants are intertidal and occur predominantly around the lagoon, although distribution is patchy. Distribution and area covered by salt- marsh plants is shown in Table 4 and Fig. 2. Dominant species include *Spartina capensis* and *Sarcocornia decumbens* around the midwater level, while *Triglochin bulbosa* and *T. striata* occur up to the high tide level. Around the high tide level, species are highly tolerant of drier conditions and include *Limonium scabrum, Chenolea diffusa, Sarcocornia pillansiae* and *Sporobolus virginicus.* Patches of *Phagmites australis* and *Juncus kraussii* also occur around the lagoon. Above the N2 bridge across the Bitou estuary, agricultural practises have largely destroyed the marshes on the floodplain. However, patches of *Cotula coronopifolia, Triglochin striata, Sarcocornis perennis, Poeciolepis ficoidea, Juncus kraussii, Disphyma crassifolium and Chenolea diffusa* occur.

Table 4. Intertidal distribution and area covered (m^2) by *Spartina capensis*, *Juncus kraussii* and other salt marsh species in the lower Keurbooms estuary. Fig. 2 provides information on the different regions listed in the first column (adapted from Zoutendyk & Bickerton 1996).

Region	***Spartina Capensis***	***Juncus Kraussii***	**Other salt marsh Plants**
Blind arm	7500	-	24960
Middle reaches	3400	-	6600
Upper reaches	8400	46180	243360
Bitou	29380	17240	105400

A summary of the total intertidal non-vegetated and intertidal vegetated coverage below the N2 bridges is given in Table 5. *Zostera capensis* only covered 4,5% of subtidal areas (34400 m^2), the remainder being non-vegetated open sediments.

Table 5**.** Areas (m^2) and percentage cover of open sediment and vegetated regions in the lower Keurbooms estuary. Fig. 2 provides information on the different regions listed in the first column (adapted from Zoutendyk & Bickerton 1996).

Region	**Non-vegetated area**	**Area covered *Zostera capensis***	**Area covered *Spartina Capensis***	**Area covered Other salt marsh plants**	**Area covered Juncus Kraussii**
Blind arm	100900	196100	7500	24960	-
Middle reaches	436260	29700	3400	6600	-
Upper reaches	276160	516980	8400	243360	46180
Bitou	16740	161180	29380	105400	17240
Total area	830060	903960	48680	380320	63520
Percentage	**37,3**	**40,6**	**2,2**	**17,0**	**2,9**

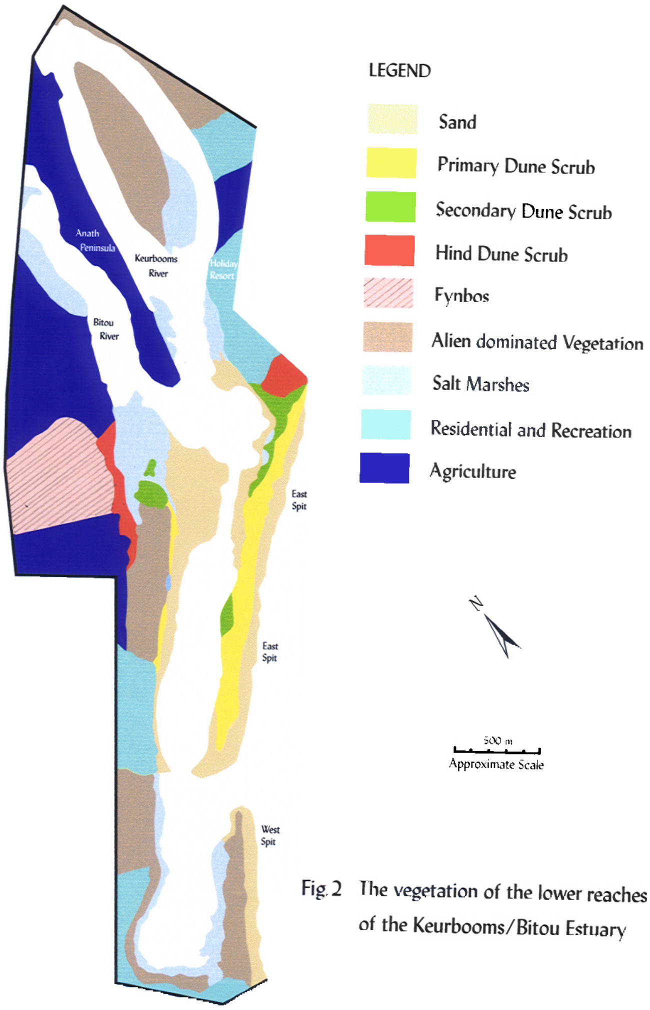


Fig. 2. Distribution of the estuarine associated vegetation in the lower Keurbooms estuary.

Along the Keurbooms, the steep river banks result in a very narrow intertidal area and saltmardsh plants are not established. However, reeds and sedges (*Phragmites australis* particularly) frequently occur in narrow patches above the N2 bridge. The area covered by reeds and sedges above the N2 bridges is about 6 ha in total.

Zooplankton

Quantitative data on the zooplankton of the Keurbooms estuary are not available, although Grindley (unpublished data) described the estuarine zooplanton as 'rich and abundant'. Thirty-nine taxa were recorded during his survey in 1969. The copepod, *Pseudodiaptomus hessei* was the numerically dominant species, being particularly abundant towards the upper reaches of the estuary. Other important taxa in the zooplankton included the copepod *Acartia natalensis* and the mysid shrimp *Gastrosaccus brevifissura*.

The distribution of *Pseudodiaptomus hessei* in the Keurbooms follows the same pattern described for other freshwater-rich estuaries in the region. In the Sundays (Wooldridge & Bailey 1982, Jerling & Wooldridge 1991) and Gamtoos estuaries (Fig. 3), populations of *Pseudodiaptomus hessei* attained maximum population densities where water salinity remains well below 28 ppt).

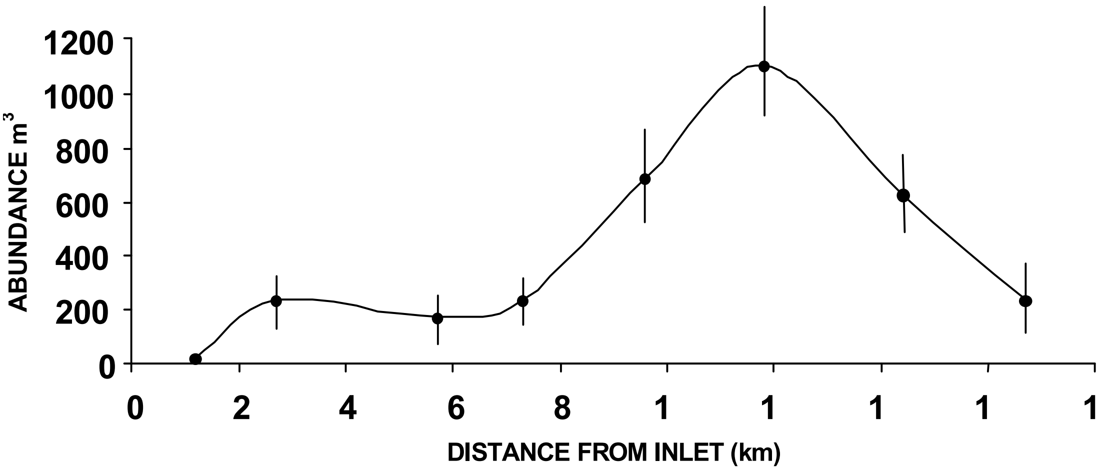


Fig. 3. Spatial distribution and abundance (+1SE) of *Pseudodiaptomus hessei* in the Gamtoos estuary. Monthly sampling over 27 months at eight stations.

When salinity remains close to that of seawater (above 28 ppt) throughout an estuary, *P. hessei* population levels are relatively low and are more homogeneously distributed in time and space. This is typical of the Kromme estuary (Fig. 4).

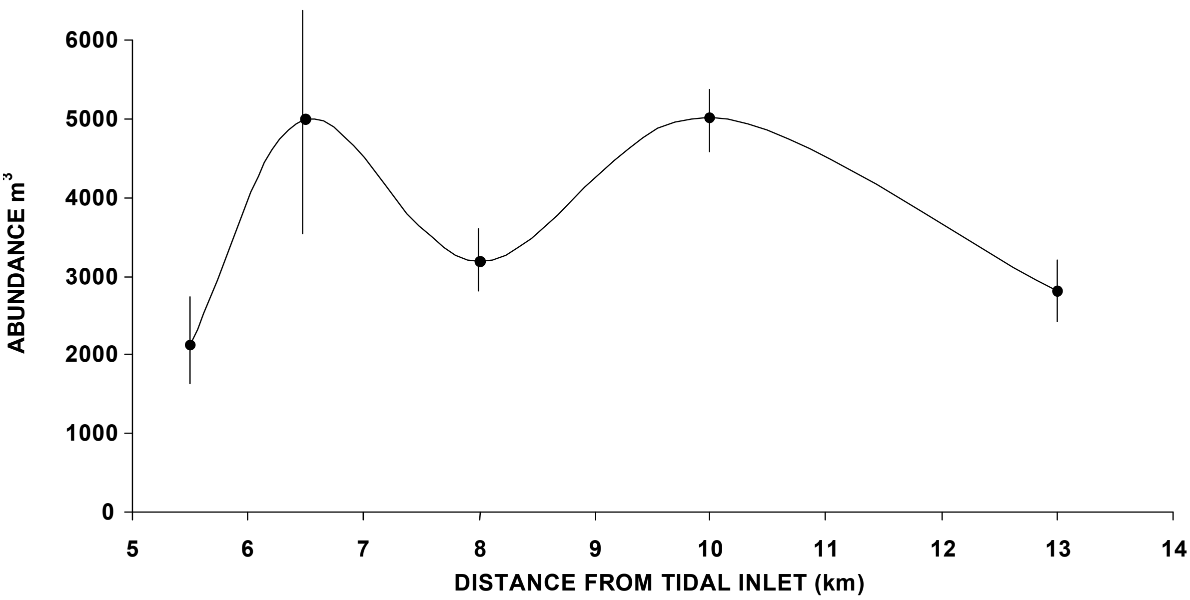


Fig. 4. Spatial distribution and abundance (+1SE) of *Pseudodiaptomus hessei* in the Kromme estuary. Monthly sampling over 36 months at five stations. Compare with data

shown in Fig. 3. The high variance is due to an increase in population density (orders of magnitude change and maintained for weeks) after a flood.

P. hessei responds positively to freshettes, and it is the first mesozooplankton species to recolonize estuaries flushed by floods (Wooldridge 1999). In *P. hessei*, temporal variations in population abundance levels do not necessarily follow seasonal cycles, but are instead linked to the timing of freshwater pulses flowing into an estuary. On occasions, increases in density are orders of magnitude higher in comparison to numbers recorded immediately before a freshwater pulse event.

Zooplankton trophic relationships

Estuarine copepods

In his review on the diets of calanoid copepods, Kleppel (1993) noted that there was overwhelming evidence to suggest that copepod diets are frequently diverse, composed of a variety of food types. Small phytoplankton and microzooplankton are also increasingly recognized as important components of copepod dietary intake (Kleppel 1993, Heip *et al*. 1995).

Diet diversity is clearly evident in feeding studies undertaken on two of the common euryhaline copepods (Jerling 1993) found in South African estuaries and also common in the Keurbooms (*Pseudodiaptomus hessei* and *Acartia longipatella*).
Phytoplankton was a major food category and this was supported by isotope ratio studies ($\square^{13}C$)(Jerling & Wooldridge 1995a).

However, in estuaries having a relatively low input of freshwater, macrophyte production dominates over phytoplankton with respect to their respective contributions to the organic carbon pool (Hilmer & Bate 1990, Allanson & Read 1995, Grange & Allanson 1995, Heymans & Baird 1995). In the Kromme estuary, reduced freshwater inflow, linked to less disturbance of the sediment, relatively stable salinity and reduced turbidity were considered to have contributed to a four-fold increase over nine years in the biomass of eelgrass *Zostera capensis* (Adams & Talbot 1992). Much of this macrophyte production probably entered the food-web as detritus, contributing to copepod diet in the estuary. However, average biomass of the dominant estuarine copepods (*Pseudodiaptomus hessei*, *Acartia longipatella* and *A. natalensis*) per unit volume of water in estuaries (Fig. 5) is directly linked to the salinity gradient along the estuary, and hence the relative amount of freshwater flowing into the estuary. The greater the salinity gradient, the greater the average copepod biomass supported. In Fig. 5, the Kromme reflected the lowest copepod biomass of six estuaries investigated (average salinity gradient <5ppt). The Gamtoos and Sundays estuaries on the other hand, had the greatest salinity gradient and supported the highest biomass of copepods.

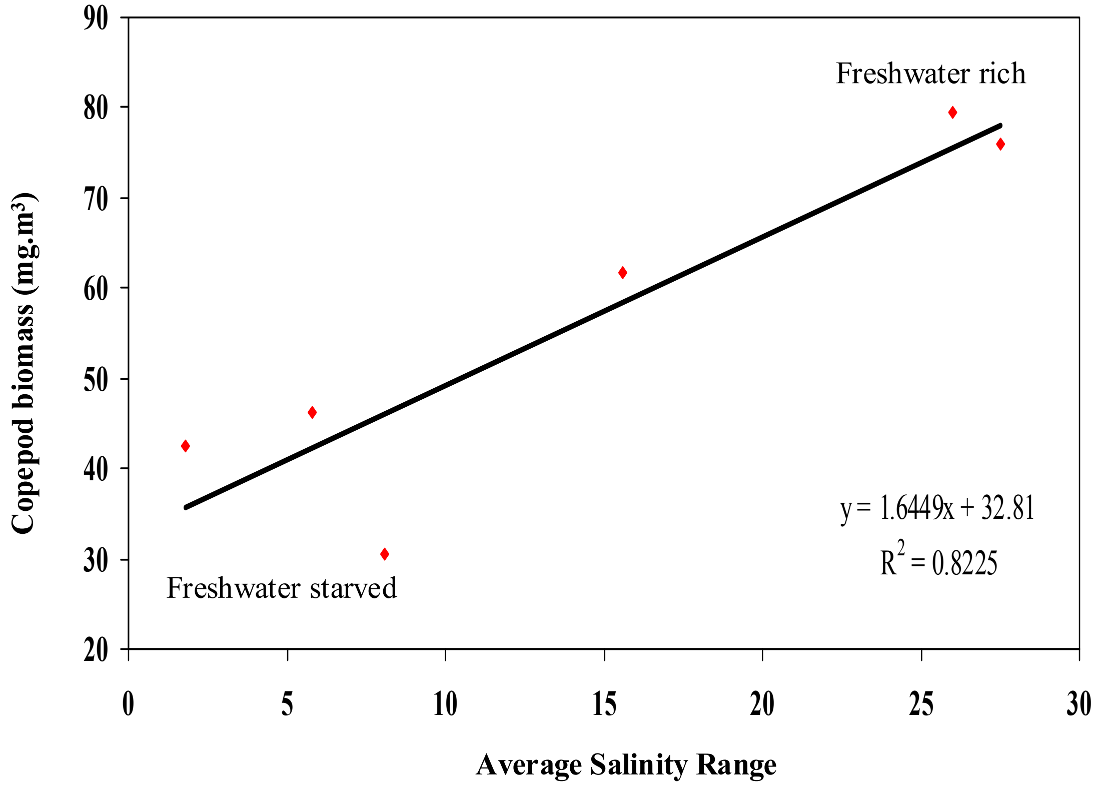


Fig. 5. Relationship between copepod biomass and axial salinity range (ppt) in six estuaries along the south-eastern Cape coast of South Africa. Each data point represents mean biomass values for estuaries having at least medium term data sets. Data represent about 1850 samples collected over a total of 20 years from the Kromme, Nahoon, Kwelera, Swartkops, Sundays and Gamtoos estuaries. Estuaries are listed in ascending order, with the Gamtoos located in the top right hand corner of the graph.

Similar correlations between copepods and chlorophyll *a* levels are documented for other South African estuaries having contrasting inputs of freshwater (Allanson & Read 1995). For example in the Great Fish estuary (freshwater rich), phytoplankton and zooplankton biomass were on average, an order of magnitude greater when compared to biomass in the freshwater starved Kariega estuary (Allanson & Read 1995). These data suggest a strong link between riverine inflow and copepod population abundance levels, probably as a result of the concommitant positive response of the microzoo- and phyto-plankton on which the copepods feed.

Mysid shrimps

Mysids are generally considered to be omnivorous (e.g., see Tattersall & Tattersall 1951, Mauchline 1980, Fenton 1996a), although herbivory (Bowers & Grossnickle 1978) or carnivory (Cooper & Goldman 1980, Johnston & Lasenby 1982, Fulton 1982) also characterise some species in specific habitats. Thus far, investigations on mysid feeding in South Africa suggest that omnivory is the principal feeding mode, with partitioning of resources within and between species. For example, the mysid *Mesopodopsis wooldridgei* feeds extensively on phyto- and microzooplankton (Jerling & Wooldridge 1995b).

Summary on zooplankton abundance and freshwater supply to estuaries

In estuaries where freshwater supply is zero or near-zero, the plankton contributes little to biotic processes. Marine dominated estuaries depend on rooted macrophytes as primary producers (e.g. Kromme and Kariega estuaries) and their faunal composition, even at higher trophic levels, is very different to that found in freshwater- rich systems. Estuaries that show phytoplankton dominance (Sundays and Fish) are uncommon in South Africa, and their conservation is essential in order to maintain estuarine diversity. Excessive freshwater abstraction is leading towards artificial changes in the functioning of many local estuaries.

Other trophic interactions

In the upper Gamtoos estuary, large numbers of sparid juvenile fish occur (mainly *Lithognathus lithognathus* and *Rhabdosargus holubi*) (Schlacher & Wooldridge 1996a). These low-salinity areas probably contribute significantly to the nursery function of estuaries. It is important to take cognisance of Whitfield's findings where densities of larvae and 0+ juveniles were significantly greater in two estuaries receiving moderate to high riverine inputs compared to a system where the axial salinity gradient was relatively uniform and closer to that of seawater (Whitfield 1994). In the Gamtoos estuary, both *L. lithognathus* and *R. holubi* strongly selected for corophioid amphipods, consuming other taxa in low numbers. The steenbras *L. lithognathus* had a narrower prey spectrum, feeding almost exclusively on the tube-dwelling amphipod, *Grandidierella lignorum* (Schlacher & Wooldridge 1996a). Grandidierellids are also present in the Keurbooms, and are likely to be very abundant in sandy areas.

Although the reed *Phragmites australis* occurs along the banks in the upper Keurbooms, the significance of its potential contribution to the estuarine foodweb is unclear. This reed prefers water of low salinity, but is also found where freshwater derived from land drainage seeps into estuarine channels (Adams & Bate 1999).

Qualitative observations in the upper Gamtoos estuary showed that the reed *Phragmites australis* is the most abundant macrophyte species forming extensive beds along the fringes of the estuarine channel. However, isotope analysis showed that only the epifaunal crab *Hymenosoma orbiculare* (□^{13}C -23,8 □ 1,5 $^{o}/_{oo}$) appeared to use benthic detrital particles to any significant extent (Schlacher & Wooldridge 1996b). Amphipods (□^{13}C -28,0 □ 0,6 $^{o}/_{oo}$) utilized some benthic detritus, but fed mainly on fine suspended particulate organic matter (□^{13}C -31,2 □ 0,5 $^{o}/_{oo}$), as did the anomuran *Callianassa kraussi* (□^{13}C -32,5 □ 0,3 $^{o}/_{oo}$). These highly negative isotope values fall within the same range as those of phytoplankton grazing copepods (□^{13}C -30,8 to -32 $^{o}/_{oo}$) in the Sundays estuary (Jerling & Wooldridge 1995b). This led to the conclusion that in the upper Gamtoos estuary, dominant macrobenthic organisms are probably mainly suspension feeders (Schlacher & Wooldridge 1996b). In this respect, published data about the exact trophic status of any of the consumer species studied above are ambiguous. *C. kraussi* is sometimes classified as a deposit feeder (e.g. Day 1981, Branch *et al*. 1994), but it is also regarded as a filter feeder (e.g. Branch & Branch 1981, Day 1981). If deposit feeding were a prevailing mode of foraging in *C. kraussi*, it does not appear to be on benthic detritus > 1 mm particle size (Schlacher & Wooldridge 1996b).

These studies on trophic relationships again suggest the prominence of phytoplankton in driving estuarine primary production in freshwater rich systems, even in estuaries that harbour large stands of macrophytes. The Keurbooms estuary falls into this category. The prominance of phytoplankton as the main primary producer is also supported by findings in the Swartkops estuary that has large areas of saltmarsh: in this estuary phytoplankton was identified as the single most productive autotroph compartment (46%) (Hilmer *et al.* 1988).

Estuarine macrozoobenthos

Hard substrata are scarce in the Bitou-Keurbooms estuarine areas, and most of the macrozoobenthos is associated with soft substrata. Included are areas associated with aquatic vegetation. However, bridges provide attachment for some species such as barnacles (*Balanus amphitrite*) and limpets (*Siphonaria oculus*)(Duvenage & Morant 1984).

A list of the 42 macroinvertebrate species is given in Table 6. Although the diversity is relatively high, seven of these species make up 95% of the biomass of the benthic community, with the sandprawn *Callianassa kraussi* and mudprawn *Upogebia qfricana* being particularly common (Zoutendyk & Bickerton 1996).

Table 6. Macroinvertebrate taxa recorded in the Keurbooms-Bitou estuary (after Zoutendyk and Bickerton 1996). S = sand, S/M = sand/mud, M = mud, S+Z = sand + *Zostera*, S/M+Z = sand/mud + *Zostera*, M+Z = mud + *Zostera*, SP = *Spartina*, SML = salt marsh low, SMM = salt marsh mid, SMH = salt marsh high, J = J*uncus*.

Species	***Substratum***
Cnidaria	
Corynactis annulata	S/M+Z
Nemertia	
Polybranchiorhynchus sp.	SP
Annelida	
Arenicola loveni *(bloodworm)*	***S, S/M, S/M+Z***
Cirriforma tentaculata	***S/M+Z***
Dasybranchus caducus	***S, S/M, S+Z, S/M+Z, M+Z***
Dendronereis arborifera	***S, S/M, S/M+Z, M+Z***
Eunice aphroditois	S, S/M, S/M+Z
Pectinaria neapolitana	***S+Z***
Crustacea	
Chthamalus dentatus	*S*
Exosphaeroma hylecoetes	S/M, S/M+Z
Pontogeloides latipes	***S, S/M***
Alpheus crassimanus	M+Z
Alpheus sp.	M+Z
Betaeus jucundus	***S/M+Z, M+Z, SP***
Callianassa kraussi	***S, S/M, S+Z, S/M+Z***
Upogebia africana (mudprawn)	S/M, S/M+Z, M+Z, SP,SML,SMM, SMH
Paratylodiplax algoensis	***S/M, S/M+Z, M+Z, SP, SML, SMM, SMH***
P. edwardsii	***S/M, S/M+Z, M+Z, SP***
Diogenes brevirostris	S, S/M, S+Z, S/M+Z, M+Z, SML

Hymenosoma orbiculare	***S+Z, S/M+Z, M+Z, SML***
Sesarma catenata	***SP, SML, SMM, SMH***
Palaemon peringueyi	water column
Mollusca	
Table 6 (continued)	
Dosinia hepatica	***S, S/M, S+Z, S/M+Z, M+Z***
Gastrana abildgaardina	***S/M+Z***
Lamya capensis	***S+Z***
Loripes clausus	***S, S/M, S+Z, S/M+Z, M+Z, SML***
Macoma littoralis	S/M+Z, M+Z, SML
Papridea papyracea	S+Z, S/M+Z
Psammotellina capensis	S, S+Z, S/M+Z
Solen capensis (pencil bait)	S, S+Z
S. cylindraceus	**M+Z**
Acera soluta	*S/M+Z*
Armia sp.	S/M+Z
Cerithidea decollata	SMH
Haminea alfredensis	S+Z, S/M+Z, M+Z
Littorina sp.	SP
Natica tecta	S, S/M, S+Z, S/M+Z, M+Z, SP
Nassarius kraussianus	***S, S/M, S+Z, S/M+Z, M+Z, SML***
Thais squamosa	**?**
Echinodermata	
Perechinus angulosus	***S/M+Z***
Patiriella exigua	***S+Z***
Tunicata	
Pyura stolonifera	S

The seven most important species that contribute more than 95% to standing stock in the different regions are shown in Table 7). The other 35 species listed in Table 6 contribute less than 1% each.

Table 7. Species contribution to standing stock (tons of carbon) of the seven dominant macrobenthic species in different regions of the Keurboos-Bitou estuary. BA = Blind arm, MR = Middle reaches, UR = Upper reaches, B = Bitou (refer to Fig. 1 and Fig. 2).

Species	***BA***	***MR***	***UR***	***B***	***Total***	***%***
Upogebia africana	,5	-	3,9	7,5	11,9	**24,9**
Callianassa kraussi	,5	.98,1	-	9,5	**19,6**	
Loripes clausus	2,8	1,4	2,6	-	6,8	**14,1**

Sesarma catenata	,3	,14.9	,5	5,8	**12,0**	
Nassarius kraussianus	1,4	,5	2,4	,8	5,1	**10,6**
Upogebia/Callianassa	1,8	-	2,9	-	4,7	**9,8**
Dasybranchus caducus	,8	,7	-	-	1,5	**3,0**
Diogenes brevirostris	,1	,6	,04	-	0,7	**1,5**

The benthic fauna is best developed between the tidal inlet and bridges across the respective estuaries. *Arenicola loveni* (bloodworm), *Callianassa kraussi* (sandprawn or pink prawn), *Upogebia africana* (mudprawn) *and Solen capensis* (pencil bait) are popular bait organisms, with each species occurring in particular areas determined by substratum characteristics. As can be seen from Table 7, sand and mudprawn make up 54% of macrofaunal biomass. Mudprawns reached a maximum density of 480 holes m^{-2} (average of about 335 holes m^{-2}, or 170 prawns m-^{2}, Duvenage & Morant 1984). Integrating data provided by these authors (their Table 5 provides average number of prawns m^{-2} for each grid square (250 x 250 m) shown in Fig. 9), the total estuarine mudprawn population is about 65 million prawns. Calculations were done for each grid square and summed to provide total density for the estuary. Similarly, the *Callianassa kraussi* (maximum density is about 360 sandprawn m^{-2} with an average of 175 prawns m^{-2}) population estimate is about 70 million prawns. Currently, recreational fishermen are permitted to collect 50 of each prawn species per day.

Sandprawn are common in sandy areas, bloodworm and pencil bait occur in muddy sand, while mudprawn dominate muddy substrata. A survey in October 1979 by Gaigher of the Department of Nature Conservation (Cape Provincial Administration and quoted in Duvenage & Morant 1984) quantified the distribution of sand and mudprawn in the lower estuary. Above the Bitou bridge only *C. kraussi* and *S. catenata* are common while the benthic fauna above the Keurbooms bridge is poor.

Bloodworm *Arenicola loven*i and pencil bait *Solen capensis* are common in sandy areas on the northern side of the lagoon, decreasing in abundance north of the confluence of the two estuaries. *Solen* reached a maximum of 40 holes m^{-2} while the maximum for *Arenicola* was 1 hole m^{-2}. Fishermen are permitted to collect 5 bloodworm and 50 pencil bait per day.

Estuarine fish

According to Whitfield (1996), the Keurbooms is dominated by marine fish species that utilize the estuary as a nursery area before returning to the sea as adults. Migration into the estuary is significantly influenced by the longitudinal salinity gradient that influences the magnitude of juvenile fish recruitment into nursery areas. Consequently, a reduction in freshwater supply to the Keurbooms-Bitou estuaries will negatively impact on the nursery value of the two systems. If the estuary mouth closes during spring and summer (period of maximum fish recruitment), the value of the nursery function of the estuary decreases by about 75%. In winter, the value decreases by about 25%.

ESTUARINE CONSERVATION ISSUES

The importance of an open tidal inlet

Precipitation in southern Africa is unevenly distributed in space and time, resulting in highly variable river discharge patterns. Severe and prolonged droughts occur that are often broken by river floods. These episodic, high discharge events perform the vital function of scouring and removing non-consolidated marine sediment that accumulates naturally in lower estuarine regions (Reddering 1988). However, the semi-arid nature of the climate in South Africa and the increasing demand for freshwater has resulted in the construction of large storage reservoirs along many of our rivers. At present, major dams have a combined storage capacity that exceeds 50% of the total mean annual runoff (Department of Water Affairs 1986). Farm dams account for a further reduction in freshwater flow along river systems.

A major consequence of river impoundments is the reduced frequency and amplitude of flood events (Reddering & Esterhuysen 1987, Whitfield & Bruton 1989). Smaller floods may even be filtered out of the discharge spectrum. Consequently, estuaries accumulate excessive volumes of sediments and inlets may become severely choked. Although opening and closing of tidal inlets is a natural occurrence, many estuaries are closing more frequently and for longer periods owing to less effective scouring of inlet channels during floods. As the frequency of river flooding decreases, shoaling also takes place over longer periods, requiring a flood of greater erosive capacity to remove the increased volume of sediment (Reddering and Esterhuysen 1987, Reddering 1988, Whitfield and Bruton 1989). Inlet constriction also results in reduced tidal exchange and this has major consequences for physical and biological processes in the estuary. Ultimately, the estuary may close off from the sea completely.

Most estuaries in southern Africa close periodically. Only 18% of South Africa's 249 estuaries (Whitfield 2000) maintain permanently open tidal inlets. Of the remaining 72%, most enter the sea by means of estuaries whose tidal inlets close periodically owing to sandbar development. Temporarily open/closed estuaries display characteristics more typical of lagoons that function differently from open systems. A reduction in freshwater supply to estuaries (e.g. reservoir retention) causes inlets to close more frequently and for longer periods, and this has the capacity to induce changes in the structure and composition of estuarine biotic communities (see following section). Although freshwater supply is now recognized as a key factor in maintaining estuarine viability, exchange across the tidal inlet is equally important.

From a physical point of view, estuarine processes that rely on a functional link with the marine environment include:

- water exchange across the inlet,
- mixing of different water masses as a result of tidal action, leading to the establishment of salinity gradients in the estuary,
- moderation of elevated estuarine water temperatures, particularly in shallow marginal areas,
- the supply, transport and distribution ofautochthonous (formed in the estuary) and allochthonous (transported into the estuary from outside) organic and inorganic materials,
- maintenance of estuarine intertidal floral and faunal zonation gradients through tidal oscillation, and
- regulation of sediment characteristics in the estuary.

Biological processes depending on estuarine-marine exchange across tidal inlets have also been identified, but the magnitude and significance of these processes are poorly known. Recent additions to the list of organisms that depend on functional links with the marine environment indicate that biotic exchange is more common than previously believed. Given the increasing frequency and duration of inlet closure, management of tidal inlets aimed at maintaining essential ecological processes must assume greater importance in the future.

Configuration of tidal inlets around the southern African coast

Climate and topographic changes around southern Africa have a marked effect on the regional characteristics of estuaries. Along the KwaZulu-Natal coast, high rainfall and the high relief of drainage basins result in seasonally regular, and at times torrential floods

(Reddering & Rust 1990). These estuaries become choked with river-borne sediment, which floods regularly flush to sea. The frequency of flood events and beach configuration effectively prevent the accumulation of large deposits of marine sediments in lower estuarine regions (Reddering & Rust 1990). Flood tidal deltas are poorly developed and this is in contrast to estuaries on the Cape south coast where rainfall is lower and floods less frequent so that tides play a more prominent role. Active sediment accumulation and removal occurs largely in lower estuarine regions where deposition of marine-derived sand may cause extensive shoaling, especially if the interval between river floods is protracted. Sand accumulation is caused by flood-tide dominance and is typical of many estuaries along the south-east coast. Excessive shoaling may cause progressive constriction of inlet channels and a reduction in tidal exchange between the estuary and the sea. If the full river discharge (especially flood discharge) is significantly or totally retained by dams, the interval between river floods is artificially extend. Under such conditions, disproportionately large flood-tidal deltas develop. Consequently, tidal exchange is further reduced (Reddering 1988).

On a sand-dominated coast, waves tend to block an estuarine tidal inlet by transporting and depositing sand across the mouth, but tidal scour removes sand from the channel (Reddering & Rust 1990). So, whether the tidal inlet is open or closed depends on the relative effects of wave and tidal action (Reddering 1988), with most estuaries in southern Africa having constricted tidal inlets (Reddering & Rust 1990). Flood-tide dominance causes sand accumulation in lower estuarine regions; some sediment is flushed out on the ebb, but the rate of sediment scour by ebb-tidal currents is much less than the rate of flood-tidal sediment input. The resulting increased constriction of lower estuarine channels causes tidal exchange to become gradually less efficient so that the tidal prism cannot effectively maintain an open tidal inlet as before (Reddering 1988). The occurrence of a flood of sufficient magnitude scours and removes these unconsolidated sediments and the cycle reverses to an unconstricted inlet.

On the west coast of southern Africa, low rainfall conditions lead to the development of 'stunted estuaries' as a consequence of low average river discharge and infrequent floods (Reddering & Rust 1990). Exceptions are the Orange and Olifants, which have the two largest river catchment areas on the subcontinent. The Berg is the only other major river system on the west coast, having a catchment area of <10% of that of the Olifants.

The importance of water exchange across estuary mouths

Water circulation and mixing processes in estuaries are complex, and have not been extensively studied in southern Africa. Investigations by Largier (1986) and Slinger & Largier (1990) in the Palmiet estuary, and MacKay & Schumann (1990) in the Sundays estuary show that tidal currents are the main forcing function in vertical mixing. Under conditions of weak or no tidal exchange, salinity and temperature stratification is encouraged. Salinity stratification further depends on the freshwater discharge into the estuary, which under extreme cases, may flow directly out to sea over a relatively stable, more dense underlying water body. Stagnant bottom layers may become anoxic (oxygen depleted) with the transfer of nutrients to surface waters being repressed. Conversely, nutrients present in the freshwater layer may be transported directly out to sea with relatively little advantage for estuarine primary production. Inlet constriction may therefore influence water exchange and nutrient availability in estuaries in a number of ways:

- by reducing the tidal prism and nutrient input from the sea,
- as a result of reduced current velocities, stratification (temperature and salinity) in the water column is encouraged,
- bottom water may turn anoxic, particularly in deeper basins where more dense water becomes trapped,
- nutrients present in bottom waters are less readily available to phosynthesizers in the water column, and
- as a result of the reduced mixing ability of tidal currents, freshwater and its associated nutrient load may have a short residence time and flow directly out to sea with little benefit to the estuary.

Clearly, natural fluctuations in tidal inlet morphology and freshwater flow patterns result in some estuaries shifting from well-mixed through to highly stratified systems over time, particularly in narrow, deeper estuaries. Spring-neap tidal cycles also induce a shift in the structure of the water column (MacKay & Schumann 1990), and the greatest seaward export of freshwater may occur at neap tides (Griffin & LeBlond 1990). This underlines the importance of an unblocked tidal inlet to maximize the mixing process through tidal flow. Although constriction of tidal inlets is a natural process, prolonged accumulation of marine-derived sediment as a result of man's activities will shift and maintain some estuaries as stratified systems for longer periods. Although freshwater may be seen to be flowing into an estuary, maximum benefits to the estuary are lost.

The biota of estuaries

In general, estuaries are environments inhabited by far fewer species compared to other marine ecosystems, but they rank among the most productive environments on earth. This is only possible if estuaries maintain functional links with both rivers and the sea. Three broad categories of the estuarine flora and fauna are recognized:

- A **marine component** is the largest in terms of the number of species and includes two subgroups. Stenohaline marine animals are typical marine forms that either are unable to tolerate, or barely able to tolerate salinity changes. This component is restricted to the tidal inlet region where salinity remains close to that of seawater. These animals are ususally found in the adjacent marine environment. Euryhaline marine animals can tolerate varying degrees of salinity reduction below 30 ppt and can penetrate some distance up-estuary. Many can tolerate salinity values down to about 15 ppt, with a few hardy species tolerating levels down to 3 ppt.

- A **brackish water or true estuarine component** comprises those species that are found in the middle reaches of estuaries where salinity varies between 5 ppt and 20 ppt. This category includes endemic species.

- A third component is **derived from freshwater**, with species usually restricted to areas where salinity does not exceed 5 ppt in the upper reaches.

There is also a migratory component that includes species that pass through an estuary on their way to breeding grounds, either in fresh or salt water. Examples include freshwater eels that breed at sea or fish, such as salmon that move from the marine environment to spawn in rivers.

Biotic exchange across estuary mouths

In southern Africa, biotic exchange across estuary mouths is best known for the ichthyofauna, but many invertebrate groups also undergo such movements. An important aspect emerging in many studies is the presence of both estuarine and marine phases in the lifecycle of species. Such lifestyles support the need for greater consideration of biotic exchange processes when considering future estuarine management strategies, given the response of tidal inlets to changing freshwater supply patterns to estuaries. An important aspect to be considered is the **timing** of the exchange process. Faunal groups are therefore considered separately and include immigration and emigration (where data are available) within respective categories.

The ichthyofauna

Most species of fish recorded in estuaries do not spawn in these environments. The most common life history pattern is spawning in the marine environment followed by immigration of larvae or early juvenile stages into estuaries. After remaining in estuaries for varying periods of time, fish emigrate back to the marine environment prior to, or after attaining sexual maturity. Whitfield (1994) identified five major categories of fishes that utilize southern African estuaries (south of 26^{o}S):

I. Estuarine species that breed in estuaries.
II. Euryhaline marine species that usually breed at sea and whose juveniles show varying degrees of estuarine dependence.
III. Marine species that occur in estuaries in small numbers but are not dependent on these systems.
IV. Euryhaline freshwater species, whose penetration into estuaries is determined primarily by salinity tolerance. Some species may breed in both freshwater and estuarine systems.
V. Obligate catadromous species (must spawn at sea to complete their life cycle).

Category I comprises about 40 species (28% of the 142 estuarine-associated fish taxa). Included in this group are species that are totally dependent on estuaries (e.g., the roundherring, *Gilchristella aestuaria*). Larvae of a number of gobiids (*Caffrogobius* spp., *Psammogobius knysnaensis*) and the blenny, *Omobranchus woodi* in Category I undergo a marine phase of development (Whitfield 1989). Successful larval efflux and subsequent postlarval return of these resident estuarine spawners is therefore dependent on synchronization of the open phase of the tidal inlet with the breeding season.

Species totally dependent on estuaries (sub-divisions of Categories I and II) number about 37 or 26% of all the estuarine-associated species recorded. Included are important angling species such as the spotted grunter *Pomadasys commersonnii*. Catadromous species (present in freshwater as adults, but migrating to sea to spawn) migrate through estuaries to complete their life cycles. Species in this group include the eels (Bruton *et al*. 1987) and the freshwater mullet, *Myxus capensis* (Bok 1979).

Although a number of factors determine fish species richness and abundance in estuaries, the open or closed condition of the tidal inlet is probably the main determinant (Whitfield & Kok1992). Closure of the inlet effectively blocks further recruitment and prevents emigration of sub-adults or adults back to sea. Bennett (1989) calculated that in the Bot estuary, marine migrants comprised 1% of the total number of fish present after three years of inlet closure. In the nearby and permanently open Palmiet estuary, 53% of the numbers of fish recorded were marine migrants. Expressed in terms of species number, marine migrants constituted 36% and 73% in the two estuaries respectively. In systems such as the Bot estuary, prolonged closure and dilution of lagoonal waters can lead to osmoregulatory stress and mass mortality of entrapped marine fish species (Bennett 1985). Mass mortalities of fish of marine origin have also been reported in the St Lucia system and in Lake Nhlange at Kosi Bay (Blaber & Whitfield 1976), and were probably due to low salinity water similar to levels recorded in the Bot (<3,5 ppt).

Whitfield and Kok (1992) investigated recruitment of juvenile marine fishes into the Knysna and Swartvlei estuarine systems. A summary of the number of fish species recruiting into these systems indicated that whereas juveniles were present throughout the year, maximum numbers entered during midsummer (November - January). These authors emphasized that artificial winter breaching of the Swartvlei mouth may lead to reduced availability of estuarine nursery areas during summer when the inlet would not be able to scour effectively (loss of the head of water needed for the summer breaching) and lead to the subsequent premature closing of the mouth.

Penaeid prawns

Most species of shallow-water penaeid prawns spawn in the open sea, followed by postlarval migration to inshore and estuarine waters (Staples & Vance 1985). After several months of rapid growth and development in these nursery areas, prawns again migrate offshore where maturation and spawning take place.

In South Africa, penaeid prawns constitute a valuable crustacean resource trawled mainly on the Tugela Bank and St Lucia Bank (Forbes & Benfield 1985, De Freitas 1989). The resource consists of five main species: the white prawn *Penaeus indicus*, the tiger prawn

P. *monodon*, the zebra prawn *P*. *semisulcatus*, the bamboo prawn *P. japonicus* and the brownprawn *Metapenaeus monoceros*. These species have a life cycle that includes an estuarine phase of development. Kwazulu-Natal estuaries are particularly important for penaeids on the southern African coast, especially the St Lucia Lake system and Richards Bay (Forbes & Benfield 1985).

In the St Lucia system (Forbes & Benfield 1986), recruitment is dominated by *Penaeus japonicus* with peaks in autumn (May - June) and spring (September - October). Postlarval recruitment does not follow the same seasonal pattern for all species listed above. Individual species recruiting into the estuary also show large inter-annual variations in abundance.

Carid shrimps

The caridean shrimp *Palaemon peringueyi* is distributed throughout the Indo-Pacific region. In southern Africa, breeding occurs in marine coastal waters, followed by onshore movement of Stage 6 and post-larvae into tidal pools or estuarine *Zostera capensis* beds. Juveniles spend 9 to 12 months in *Zostera* beds, before returning to the marine environment as subadults (Emmerson 1986). In an extensive study of three eastern Cape estuaries, shrimp abundance peaked from November to March (Emmerson 1986). Estuarine recruitment of *P. peringueyi* takes place on both diurnal and nocturnal flood tides, but highest numbers migrate after dark (Wooldridge 1991). In comparison, emigration of subadults back to the marine environment occurs only at night on the ebb tide.

Although not dependent on estuaries to complete its life cycle, large numbers of *Palaemon peringueyi* migrate into these environments where they potentially play an important role in the estuarine foodweb. In the Krom estuary, *P*. *peringueyi* is the most important contributor to macroinvertebrate production, followed by the saltmarsh crab *Sesarma catenata* and the mudprawn, *Upogebia africana* (Winter & Baird 1988).

Anomuran mudprawns

The mudprawn *Upogebia africana* is common in estuarine muddy substrata where it often dominates the intertidal macrobenthos, particularly at lower tidal levels along channel margins. In the Swartkops estuary, it accounts for >80% of total macrofaunal biomass on the mudflats (Hanekom, Baird & Erasmus 1988). The importance of this species in foodwebs of open eastern Cape estuaries is now well established (Marais 1984, Martin &

Baird 1987, Baird 1988). By contrast, it is absent from estuaries that have closed off from the sea (Wooldridge 2000)

Upogebia africana has a marine phase of development during its life cycle (Wooldridge 2000). Stage 1 larvae do not metamorphose through subsequent larval stages if trapped in estuaries and this accounts for the absence of the species in closed systems. After a period of development at sea, postlarvae recruit back into estuaries.

The continued existance of *Upogebia africana* in temporary closed estuaries is dependent on the relationship between open and closed phases of the tidal inlet. If the tendency in South African estuaries is towards prolonged closure of tidal inlets (freshwater abstraction), estuarine populations will at best fluctuate more markedly over time. During periods of low population densities and providing the inlet remains open, a low level of recruitment may lead to a protracted period of recovery. Recovery rates will also depend on the time interval the mouth remains open to the sea, which over the longer term, may cumulatively be insufficient to avert eventual extinction of estuarine populations.

Brachyura

The saltmarsh crabs *Sesarma catenata* and *Paratylodiplax* (formerly *Cleistostoma*) *edwardsii* are often dominant epibenthic organisms in *Spartina maritima* regions of estuarine saltmarshes (Els 1982, Pereyra Lago 1986, Winter & Baird 1988). Pereyra Lago (1993) has demonstrated a pattern of tidal exchange for *Sesarma catenata* larvae, with highest abundance of zoea 1 larvae on nocturnal ebb tides. Distinct peaks in abundance were observed in November and February-March. Recruitment of megalopae to the estuary occurred mainly on flood tides from January to March. Clear patterns of larval exchange have also been observed in *Paratylodiplax edwardsii* (Skelton 1993), with larval release and megalopal return following a similar pattern to that described for *Upogebia africana*. It is not yet known whether a marine phase of development is obligatory for these two brachyuran species.

The two saltmarsh crab species probably play an important role in nutrient recycling on estuarine saltmarshes. If a marine phase is obligatory for these species, extended periods of inlet closure will result in no recruitment to estuarine populations as described for the mudprawn. Potentially, this has negative implications for nutrient recycling on the saltmarshes.

Other changes of a biological nature also occur as a consequence of a reduction in freshwater supply to estuaries. These are broadly summarized as follows:

- Changes in the axial salinity gradient (freshwater reduction) lead to changes in biotic assemblages associated with specific salinity ranges along the gradient.
- If the estuary mouth closes, decreasing salinity values can be lethal to trapped biota. Salinity values may also decline to below threshold levels necessary for reproduction and larval survival of estuarine organisms. The sandprawn *Callianassa kraussi* for example, tolerates reductions in salinity down to <2 ppt, but successful development from egg to the post-larval stage requires a salinity >20 ppt (Forbes 1977).
- Changes in water temperature, particularly in shallow marginal areas may limited flushing of these areas during summer (a constricted tidal inlet influences tidal ebb and flow) and lead to elevated water water temperatures lethal for some species (survival time of *Upogebia africana* decreases rapidly at temperatures above 29^{o}C under experimental conditions, Hill 1971).
- Mouth closure leads to changes in intertidal zonation patterns, particularly in saltmarsh areas.
- Mouth closure disrupts the lifecycle of marine species that depend on estuaries as nursery areas. Conversely, the same species may become trapped in estuaries where they are unable to breed.
- Mouth closure reduces the intertidal area available to foraging birds.

Thus, estuaries are highly dependent on maintaining functional links with both marine and freshwater environments and they cannot be considered as isolated ecosystems.

Present conservation status of the Keurbooms estuary

Huizinga & Slinger (1996) list three main physico-chemical issues pertinent to any reduction in freshwater inputs to the Keurbooms-Bitou estuaries:

- Potential closure of the estuary mouth. Although the tidal inlet has not been known to close, the mouth sometimes becomes very shallow and constricted. Mouth closure, even temporarily, would have a dramatic effect on the structure and functioning of the two estuaries.

- Increased sedimentation. Reduced estuarine scouring as a consequence of flood attenuation, would lead to progressive shallowing, especially nearer the mouth. Tidal flows would decrease leading to greater potential for mouth closure.
- Changes in hydrodynamic and water quality properties. Reduced or changes in freshwater supply would alter the hydrodynamic character of the estuaries. This would lead to changes in the persistence and distribution of salts and affect the flushing and renewal of saline water. Effects would be enhanced if the estuary mouth were to close.
- Clearly, any further reduction in freshwater supply to the Keurbooms system has the potential to lead to mouth closure. Should this happen, the conservation status of the estuary will change dramatically. Turpie (1999) provides a preliminary list of the 50 most important estuaries in South Africa from a conservation perspective. The Keurbooms ranks 16th in conservation importance. Conservation importance is calculated on the basis of weighted size, type, biogeographical zone in which it occurs, habitat types and biota present (plants, invertebrates, fish and birds).

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