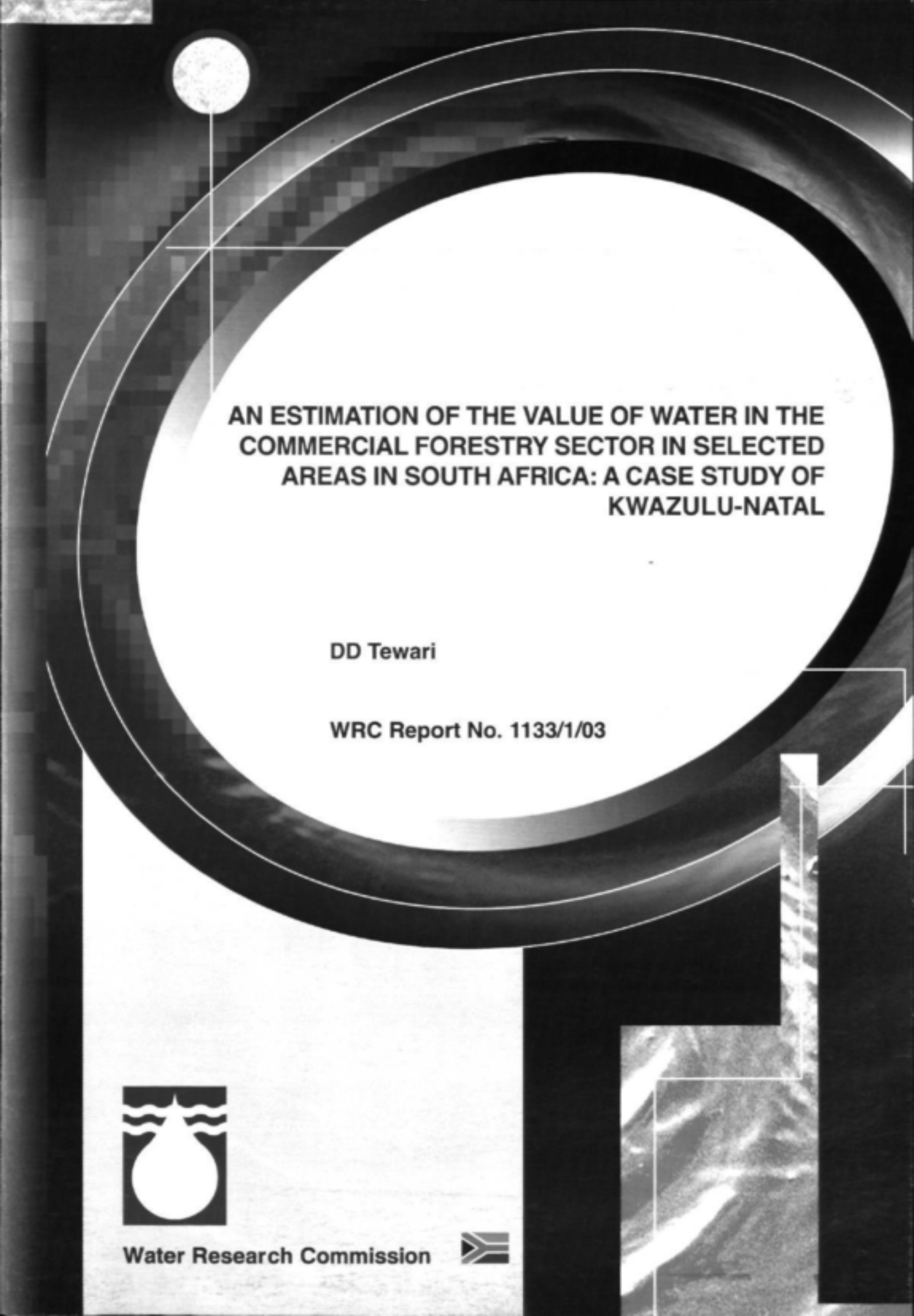

AN ESTIMATION OF THE VALUE OF WATER IN THE COMMERCIAL FORESTRY SECTOR IN SELECTED AREAS IN SOUTH AFRICA: A CASE STUDY OF KWAZULU-NATAL

DD Tewari

WRC Report No. 1133/1/03

Water Research Commission

An Estimation of the Value of Water in the Commercial Forestry Sector in Selected Areas in South Africa: A Case Study of KwaZulu-Natal

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EXECUTIVE SUMMARY

Water is the most important and limiting factor of production in the commercial forestry in South Africa. Commercial forestry uses water in two forms: evapotranspiration (ET) and streamflow reduction (SFR). The ET use refers to the total evaporative losses from forest stands which include transpiration from dry canopies, and evaporation from wet canopies and forest litter or the soil surface. The streamflow reduction use refers to the reduction in water yield from a catchment as a result of uptake of water by forest stands. Both uses--ET and SFR--are inextricably linked; a rise in ET is followed by a rise in SFR. A rule of thumb is that SFR is roughly one-tenth of the ET use. In terms of streamflow reduction, water use is estimated to be in the region of 1.4 billion cubic metres per annum--about 972.2 cubic metres per hectare per annum. This is roughly 8 percent of the total utilizable water in South Africa. The ET use will be roughly ten times of the SFR use. Water is thus an important input in the production process of commercial forestry.

Water is becoming a scarcer input over time, requiring a re-look at the water management approach. Over the years, increasing urbanization and industrialization, increased irrigated agriculture, and rising population have resulted into increased demand for water. This has brought out a change in the water management paradigm, which entails meeting water demand by using it more efficiently through re-allocation among existing and potential uses. It requires that water should be used according to economic principles and value of water should be used as a guideline in determining the most efficient use of water across industries. The new paradigm has taken roots in South Africa as well. South Africa which, being a water-stressed country, needs to use water resources more efficiently. Commercial forestry, being one of the major users of water, needs to take into account the value of water. It is an essential information for improving the efficiency in the allocation of water across different uses in the country. A review of the past research indicated that there are hardly any studies on the estimation of water values in the forestry sector in South Africa. This study will fill this void.

The term "value" in this report refers to the expected net benefits from the use of water. This does not signify a market-determined value that arises after a consensus between a willing buyer and a willing seller is reached. Theoretically speaking, the value of water, or willingness to pay for water, can be approximated from the area under its demand curve. However, this can be operationalized by various ways. One major problem in valuing water in commercial forestry is the absence of water markets as such. This required resorting to the knowledge of production economics. Two methods were chosen: (1) Residual Value (RV) Method, and the (2) Marginal Value Product (MVP) method. The residual value method is based on the premise that the residual value obtained as total revenue minus total cost, including the compensation for capital and management, is attributed to water. On the other hand, the marginal value product method is based on the assumption that water is rewarded according to its marginal productivity. Under this framework, the water values can be derived from the area under the marginal value product curve. Both approaches were used to estimate water values to selected sites of eucalyptus and pine in the eastern coast of the KwaZulu Natal Province of South Africa. The four eucalyptus sites included: Kia-Ora, Baynesfield, Tanhurst, and KwaMbonambi. The three chosen pine sites were: Richmond, Greytown, and Usutu. These two species were selected as they dominate South African forestry, especially on the east coast. Furthermore, although both species can be grown on pulpwood and sawwood regimes, only the pulpwood regime based rotations were selected for computing water values.

The typical information required for the estimation of water values was the relationship between water and yield of selected species (pine and eucalyptus). A group of experts at the Institute of Commercial Forestry and Council of Scientific and Industrial Research provided this information. The costs and price data for the study were obtained from the Forestry Economics Services (1996). The entire analysis was done in terms of constant 1996 prices (1996=100). For the seven selected sites of eucalyptus and pine, both methods—RV and MVP—were used to derive the values on ET water use. The values to SFR use were estimated using the MVP method only as the former was not applicable under the circumstances. A sensitivity analysis with respect to changing timber prices and costs was also carried out to provide insights to values under changing scenarios.

The estimated evapotranspiration (ET) water values by the Residual Value method for eucalyptus vary from 4 cents to 13 cents per cubic metre of water; 4 cents per cubic metre in low rainfall area such as Baynesfield and 13 cents per cubic metre in high rainfall area such as KwaMbonambi site. The average value comes to 8 cents per cubic metre. The ET value estimates by the Marginal Value product (MVP) method vary between 4 to 60 cents per cubic metre of water--4 cents for low-rainfall Baynesfield site and 60 cents for high rainfall KwaMbonambi site--the average being 31 cents per cubic metre. The ET value estimates by the MVP method are roughly 4 times of the estimates by the RV method. The RV method measures the residual net value attributed to water after paying for all other inputs in the production process; on the other hand, the MVP measures the value before other costs are paid off. The streamflow reduction values of water for eucalyptus vary from R 1.90 to R 4.44 per cubic metre--the average being R3.42 per cubic metre. These values are roughly 10 times of ET value estimated by MVP method and 40 times of the ET values by the RV method. Water value estimates for pine species are much lower than that estimated for eucalyptus. For example, the average ET value by RV method comes to 1.7 cents per cubic metre, and 15 cents per cubic metre by the MVP method. The average SFR value for pine is R1.79 per cubic metre. Interestingly enough, the water values for pine are well below the values for eucalyptus. The difference can be explained in terms of the growth pattern of two tree species; eucalyptus grows much faster and uses water more efficiently.

In brief, the value of water in commercial forestry depends upon the type of use--be it ET or SFR. The SFR use value is about 10 times that of ET use value. The results of this study can be used in multiple ways. Firstly, results can be used to evaluate whether tariffs charged or proposed are reasonable. For example, the calculated catchment management charge or which comes at between 0.5 and 2.5 cents per cubic metre per annum (Pegram and Palmer, 2001), is in line with the estimated values of water in this study. Secondly, water values can be used to decide on allocation of water for expansion of forestry as compared to expansion of other land uses. Here water values for other crops or other land uses are needed. Thirdly, water values can also provide guidelines for evaluating which tree species should be located where for new projects (site selection). Fourthly, the information could also be used toward evaluating which tree species should be used for expansion at which sites (species selection).

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INTRODUCTION

1.1 Problem Setting

Water is one of the essential elements for life. In the past it has been treated as a free gift of the nature. As human civilization progressed, the demand for water increased and it has now become a scarce commodity. This scarcity can be natural or man-made. The natural scarcity can emanate from aridity (low rainfall over a long period) or drought (failure of rain for a period of 1 to 7 years or so). Man-made scarcity results either from dessication of landscape that reduces accessibility of water or water stress that results from high levels of competing demand for water (Oodit and Simonis, 1992, p.8). We are concerned with man-made water scarcity, caused by ever- increasing water demand.

1.1.1 The Water Scarcity Problem

Fresh water is a basic element for the maintenance and development of human beings or life. However, over the years, this has become a scarce resource due to rising demand and ever-fixed supply. On the supply side, the amount of water that is available for human use is almost fixed due to the nature of hydrological cycle. For example, of the total water on earth, some 97 percent are in seas and oceans--this water is too salty to use for most productive uses. Only 3 percent of the total water are available as fresh water on earth's surface. And, only 1 percent of the total amount of freshwater on earth is available for human use because the largest portion of freshwater is trapped in the permanent ice and snow of the polar ice caps (Lee, 1999, pp.3-4). Furthermore, most of this water is not evenly distributed in space and time; for example, most of this falls in a particular season, some parts of earth receive more rainfall than others.

On the demand side, the continuous increase in urbanization and industrialization had led to an increased amount of water use. Water has thus become a scarce input in the modern economies. Water use has been growing at more than twice the rate of population increase during the 20th century and is still continuing to grow rapidly in many regions of the world; as a result, the theoretically available water on a per capita basis has declined by almost 40 percent since 1970 (Kuylenstierna et al., 1998). Water stress can begin as when fresh water use exceeds 10 percent of the renewable freshwater resources. The southern African countries, especially the South Africa, are using more than 40 percent of renewable freshwater (Kuylenstierna et al., 1998). In terms of per capita water use, water stress begins when annual water supplies fall below 1700 cubic metres per person per annum. Below 1000 cubic metres per annum, water supply begins to affect health, economic development, and human well-being; and, at less than 500 cubic metres per capita per annum, water availability becomes a primary constraint to life (Seckler, et al., 1998, p.1). The other indicator of water scarcity suggested by the International Water Management Institute (IWMI) is that if total withdrawals are greater than 50 percent of annual water supplies then the country is considered to be water scarce. Using both criteria of water stress for 1990 data, South Africa appears to be an extremely water-scarce country (Seckler, et al., 1998, p.26). The situation of water scarcity will become alarming as population escalates and process of urbanization and industrialization speeds up with the economic development.

1.1.2 The Changing Water Paradigm

In the past, the traditional approach to solve water scarcity problems has been in terms of increasing withdrawal or supply of water. This approach entailed new large-scale water transfers from one region to another or new construction such as damming rivers or lakes. As a result, during the 20th century, there has been an enormous expansion in the water resources infrastructure. The three major drivers to this expansion are: (1) population growth, (2) industrial development, and (3) expansion of irrigated agriculture. For example, world population increased from 1600 million in 1900 to about 6000 million in 2000, representing an increase of 275 percent. The irrigated acreage increased from 50 million hectares in 1900 to about 250 million hectares in 2000--an increase of 400 percent (Table 1.1). Similarly, the industrial production has grown substantially and agriculture now contributes a minute proportion of the gross domestic product in all the developed and in many developing countries. As a result, the withdrawal of fresh water has increased from 500 cubic kilometres per year in 1900 to more than 3500 cubic kilometres per year in 2000, representing a more than seven-fold increase (based on data from Gleick, 1998, p.7). Current estimates suggest that humans appropriate 57 percent of accessible runoff on earth and that future population growth and economic development could force humans to use more than 70 percent of accessible runoff by 2025 (Posten, et al., 1996).

Table 1.1: Change in World Freshwater Withdrawal, Population, and Irrigated Acreage between 1900-2000

Particulars	Unit	1900	2000	Percent Increase
Population	Million	1600	6000	275
Irrigated acreage	Million hectares	50	250	200
Freshwater withdrawal	Cubic kilometres/year	500	> 3500	700

Source: Constructed from Gleick (1998, p.7)

The grandiose development of water infrastructure has required enormous investment in building of dams, municipal wastewater treatment plants, canals, etc. This trend of investment is seen in most countries such as USA, India, Egypt, and others and South Africa is no exception to it. In consequence of these investments, the total water withdrawals in the world increased seven-fold during the last century (from 500 cubic kilometers per annum in 1900 to 3700 cubic kilometers per annum) but only a marginal increase in per capita withdrawal (Shiklomanov, 1998 cited in Gleick, 2000, p. 129). This means the increasing population nullified the most of the increase in water withdrawals. Over the years, particularly after the 1970s, the environmental cost of water infrastructural development came to surface and a worldwide environmental movement stalled the development of such schemes.

A change in water use planning took place in early 1990s and beyond. The major goal of this new approach was to meet water demand by making its use more efficient and put water to more productive uses, rather than increasing water withdrawals by investing in large structures. In brief, the non-structural approach to water management entails more efficient use of water by re-allocating among existing uses. The basic principles of the new paradigm are as follows (Gleick, 2000, p.131):

- Basic human needs for drinking water and sanitation services must be met.
- Basic ecosystem needs for water must be met.
- The use of non-structural alternatives to meet demands must receive higher priority.
- Economic principles must be applied more frequently and reliably to water use and management.
- New supply systems, if needed, must be flexible and maximally efficient.
- Non-governmental organizations, individuals, independent research organizations, and other affected stakeholders must be involved in water management.

In brief, the new paradigm insists on "**water use that supports the ability of human society to endure and flourish into the indefinite future, without undermining the integrity of the hydrological cycle or the ecological systems that depend on it** (Gleick, 2000, p.31)". This paradigmatic shift in water use has also affected South Africa, and more so, after the democratic transition in 1994. The new national water policy envisages water as an economic and social good and emphasizes demand management.

1.2 Water Use in Commercial Forestry in South Africa

Being a water-stressed country, water is an extremely important natural resource in South Africa. The average rainfall is around 500 mm which is 60 percent of global average. Rainfall is the highest in the eastern coastal areas and Drakensberg Mountains while the rest of the country has a rainfall below the national average. The major users of water are irrigation (52.2 percent of total), ecological use (17 percent of total), municipal and domestic use (9.3 percent of total), and forestry (7.9 percent of total) (based on data obtained from the Department of Environmental Affairs and Tourism, 1997, p. 59).

In the recent years, especially after the democratic transition, the commercial forestry sector has been criticized for its unaccounted environmental costs. The debate is in between the two groups or coalitions: firstly, the environmental advocacy coalition which advocates that commercial forestry should pay for damaging the environment, and especially for the water it uses; secondly, the commercial forestry advocacy coalition which wants to maximize profits with some concerns for environment (Tewari, 2001). The water use is the central concern of this debate since it is the most limiting factor for the growth of the plantations.

Research during the past six decades in South Africa indicates that water is the most important limiting input in the growth of alien trees such as eucalyptus, pine, and wattle. These alien trees use a lot of water through evapotranspiration (ET use). This leads to a reduction in the runoff or streamflow from the afforested site (SFR use)[1]. Both water uses--ET and SFR--are related to each other and will be discussed in later chapters. The rule of thumb is that the SFR use accounts for about 10 percent of the ET use[2]. The streamflow reduction for commercial forestry is estimated to be in the order of 1.4 billion cubic metres per annum from an area of 1.44 million hectares of plantation (that is equivalent to 972.2 cubic metres per hectare per annum); or, 8 percent of the total utilizable water (Anonymous 1998, p.7)[3].

The new water paradigm has also taken deep roots in South Africa. The new democratic government was quick to realize this and reviewed water policy; and passed a new water law, which entrusted the national government with the responsibility of water management. In other words, the national government is the public trustee of the country's water resources. The water resources of the country are hence treated as

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[1] The ET use consists of transpiration by vegetation and evaporation from soil, lakes, and water intercepted by canopy surfaces; it is also known as green water. The streamflow reduction or SFR use refers to the runoff reductions due to afforestation; this is known as blue water (Jewitt (2002, p.4)).

[2] Based on the discussion with Professor Peter Roberts, Forestry Consultant, Pietermaritzburg, 20th March, 2001. This was later validated by our results, which are discussed in chapter 5.

[3] The story of estimation of runoff reductions is complicated and is ongoing concern. For details, see Jewitt (2002).

national assets to be utilized in the best interest of all citizens in a sustainable manner to guarantee the needs of the future generations. The new paradigm, which advocates more efficient use of water, entails pricing of water or treating water as an economic good. Commercial forestry needs to respond to this situation by examining the productivity of water in raising plantations.

1.3 Need for the Study

The major importance of this study arises from two facts: firstly, South Africa is an extremely water-scarce country and secondly, a new water law in South Africa entails that water is to be used to achieve optimum, long-term environmentally sustainable social and economic benefits for the society from its use (Principle 7 of Water Law). Water is hence no more to be a free public good and every user is expected to pay for water so that the rules of efficiency can be applied. Commercial forestry is no exception to this rule and an estimation of value of water in the sector is therefore required.

The second reason for undertaking this study is to gather some objective evidence to contribute to the acrimonious debate between the supporters of commercial forestry and environmental groups[4]. An estimate of the value of water will help these two coalitions to close their gap between them and help them to better understand the reality of water use.

Thirdly, no such study has been yet conducted in South Africa. This study is expected to fill this void. It is also believed that this study is a pioneering one in assigning value to water use in commercial forestry in South Africa.

Fourthly, the study will provide some insights into water use and to the development of commercial forestry in the long run.

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[4] For details of the debate between the two advocacy coalitions, see Tewari (2001).

Fifthly, it may help the Department of Water Affairs and Forestry (DWAF) to understand water pricing issues in an objective manner, as this study provides estimates of value of water use in commercial forestry which can be compared with other water uses.

1.4 Objectives of the Study

The primary objective of the study is to estimate the value of water use in commercial forestry with special reference to KwaZulu-Natal (KZN). The more specific objectives of the study are as follows:

- To discuss and review the water supply and demand situation in South Africa, with special focus on commercial forestry.
- To develop a comprehensive review of water valuation studies and modelling techniques.
- To estimate the value of water use in pine and eucalyptus in KwaZulu-Natal province of South Africa.
- To discuss policy implications on water use in the commercial forestry.

1.5 Scope of the Study and Estimation Method

The study is primarily aimed at estimation of value of water use in Eucalyptus and pine plantations in the KwaZulu-Natal province of South Africa. Two approaches--Residual Value (RV) and the Marginal Value Product (MVP) methods--are used to put value on both evapotranspiration (ET) and streamflow reduction (SFR) water uses. Sensitivity analysis is also used to provide robust estimates of value of water. Data for this study were obtained from Forestry Economics Services (FES), Pietermaritzburg and experts from Council of Scientific and Industrial Research (CSIR) and Institute of Commercial Forestry Research (ICFR), Pietermaritzburg.

1.6 Outline of the Report

Having discussed the introduction in Chapter 1, the water supply and demand situation in South Africa with a focus on commercial forestry is reviewed in Chapter 2. The water valuation models and studies are reviewed in Chapter 3. The empirical model employed or valuation of water in commercial forestry and other modelling considerations are detailed in Chapter 4. Chapter 5 is devoted to discuss the results. Finally, summary and conclusions are presented in Chapter 6.

CHAPTER 2

WATER AVAILABILITY, USES, AND WATER USE REGULATION IN COMMERCIAL FORESTRY

This chapter explores the availability of water and its various uses in South Africa, and specifically addresses the issue of water use regulation in the commercial forestry. The discussion is arranged under six sections. The first two sections deal with the supply and disposition of water in South Africa. The section one describes water availability in South Africa; followed by a discussion on the disposition of water in section two. The third section articulates the historical events that led to the regulation of water use in the commercial forestry, known as Afforestation Permit System (APS). Functioning and effectiveness of the APS is reviewed in section four. New developments in water use regulation, which affects commercial forestry, are detailed in section five; followed by the summary in section six.

2.1 Water Availability or Supply[1]

The mean annual total rainfall in South Africa is estimated to be 497 mm, which is well below the world average of 860 mm (Department of Water Affairs and Forestry (DWAF), 1986, p. 1.3; Republic Of South Africa, Government Gazette, 2002, 46 (8): 5-6.). Furthermore, the rainfall distribution across the country is not even. The coastlines receive more rain than the interior and western portions of the country. Some 65 percent of area of the country receive less than 500 mm and other 21 percent of the area receive less than 200 mm of rainfall. In other words, about two-thirds of area are arid or semi-arid.

Contrary to rainfall, the evaporation losses are large, ranging from 1100 mm to more than 3000 mm per annum. This is in excess of rainfall, finally adding to the problem of aridity

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[1] This section is heavily based on DWAF (1986) and Basson et al. (1997). The current study predated the release of National Water Resource Strategy (NWRS) but did not influence the results of the study.

in the country. This translates into a low yield from river dams and in turn requires large storage capacity.

The available supplies of water in South Africa are more or less fixed, as climate of historical times has remained much the same (DWAF, 1986; Basson et al. 1997). The mean annual available total water supply is 56629 million cubic metres, of which 94.5 percent comes in terms of rainfall, 2.4 percent in terms of return flow, and 3.1 percent in terms of ground water abstraction (Table 2.1). Of this total available water (56629 million cubic metres per year), some 63.6 percent or 36057 million cubic metres/annum are the utilizable water. However, only 45.2 percent (16291 million cubic metres/annum) of the total utilizable water are used in the economy; the rest goes unused (based on data from DWAF (1986))[2].

Table 2.1: Available Water Supplies in South Africa, Sourcewise, 1980

Source	Quantity (million cubic metres/year)	Percent of total (%)
Mean annual runoff (MAR)	53526	94.5
Mean annual ground water abstraction	1783	3.1
Mean annual return flow	1320	2.4
Mean annual available total water supply	56629	100.0

Source: Data obtained from DWAF (1986).

However, over the years through the conscious water use planning, the return flow and ground water abstraction can increase.[3] It can be noted that the total utilizable water as a percentage of mean annual total available water is not going to increase by leaps and

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[2] The new water report " Overview of Water Resources Availability and Utilisation in South Africa" by Basson et al (1997) uses, to a great extent, the old data produced by DWAF (1986). We have therefore retained the old information wherever new information was not available.

[3] Return flow is the drainage water from a particular withdrawal that flows back into the system when it can be captured and re-used, or recycled within the system. For example, treated sewage water returns to the river where it becomes a supply of water for other downstream users.

bounds. A slight increase, less than 2 percent, is coming from the improved water re-cycling technology and increased afforestation (Table 2.2). It is obvious by now that surface runoff is the dominant source of water supply in South Africa and the precipitation is unevenly distributed. South Africa's river system also contributes to this uneven distribution of water resources. The great escarpment divides South African River system into two groups, the Plateau River and those of surrounding areas. The Orange River system is the largest one; this runs along the Witwatersrand from east to west, and drains roughly half (47.5 percent) of the area of South Africa (DWAF, 1986: p. 3.11).

Table 2.2: Estimates of Available Water Supplies in Selected Years (million cubic metres), South Africa

Source	1980	1990	2000	2010
1. Surface mean annual runoff (MAR)	53526	53526	53526	53526
2. Utilizable mean annual runoff (UMAR)	32954	32954	32954	32954
3. Mean annual ground water abstraction (MAGA)	1783	1969	2159	2386
4. Mean annual return flow (MARF)	1320	1704	2440	3274
5. Mean annual total available (MAR + return flow + ground water abstract)	56620	57199	58125	59186
6. Mean annual total utilizable water (Utilizable MAR + return flow + ground water abstract)	36057	36420	37401	38362
7. Row 6 as percentage of row 5	63.6	63.7	64.3	64.8

Source: Constructed from data obtained from DWAF (1986).

2.2 Types of Water Use/Demand

With the new paradigm of water management, the concept of water demand management has gained currency in the later part of the 20th century. The major objective of water management paradigm is to promote sustainable use of water resources which requires transferring water among alternative uses, encouraging water conservation, protecting instream flows and water quality (Johnson, 1995). In other words, water should be used in accordance with the principle of equimarginal returns. Water is demanded by a number of sectors, which compete for water with one another. This is because the available quantity of water is fixed and thus water use by one-sector affects or infringes on others. The major users of water in South Africa are agriculture, domestic uses, forestry, mining, industry, and power generation; recreation, and other protected areas.

Current estimates (at 1996 development levels) suggest that total water use in South Africa is about 20350 million cubic metres per annum: this is approximately 41 percent of the total runoff of 50150 million cubic metres per annum. Another 26 percent could be made available through construction of large dams and the remaining 33 percent represents water lost from reservoirs and conveyance systems (Basson et al, 1997, p. 51). Water use by sectors is given in Table 2.3. Agriculture is the largest user, accounting for 54 percent of the country's surface water resources, followed by environmental use (19 percent), urban use (11 percent), industry (8 percent) and forestry (8 percent). A brief description of each use type is done below.

Table 2.3: Relative Current Water Use by Sectors, South Africa

Sector	Percent of total
Agriculture	54
Environment	19
Urban	11
Industrial/Manufacturing	8
Forestry	8
Total	100

Source: Basson et al (1997) cited in Harris and Haasbrook (1998, p.19)

However, this picture is expected to change by 2030. The estimated breakdown of water use in 2030 is given as below: urban and domestic use (22.8 percent); mining and industrial use (11.1 percent); agriculture and afforestation (52.2 percent); and environmental use (3.9 percent) (computed from data obtained from Basson et. al, 1997, p. 63). The summary of current regionwise water requirements in South Africa for 1996 levels are given in Table 2.4. A brief discussion on different type of water use follows next.

Table 2.4: Summary of Current (1996) Water Requirements in South Africa

Region	Urban and Domestic (million cubic metre/annum)	Mining and Industrial (million cubic metre/annum)	Irrigation and Afforestation (million cubic metre/annum)	Environmental (million cubic metre/annum)	Total (million cubic metre/annum)
Northern	704	433	1861	375	3373
Eastern Inland	150	44	1826	300	2320
Eastern Coastal	508	589	2217	2290	5604
Southern Coastal	137	41	1350	240	1768
South Western	351	105	1570	370	2396
Karoo	65	10	2173	307	2555
Central	256	376	1347	50	2029
South Africa*	2171	1598	12344	3932	20045

* Includes Lesotho and Swaziland

Source: Basson et al (1997, p. 52)

2.2.1 Agricultural Water Use

As noted, agriculture is the largest user of water in the form of irrigation. Most irrigation water comes from large dams. In the past, irrigation schemes were built for achieving socioeconomic objectives and economic viability criteria were not accorded much importance (Backeberg et al., 1996). Water was virtually free and promoted unduly large usage. However, with the changing paradigm of water management, water use in agriculture is expected to shrink. The other important aspect of irrigation is that it imposes a net cost on society by contributing to water pollution through salinization, eutrophication, and mineralization (Uys, 1996, p. 21).[4]

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[4] Salinization is the increase in salt levels of water due to evaporation during irrigation. Eutrophication is abnormal nutrient (such as phosphates, nitrates, ammonia and potassium) enrichment of water leading to excessive growth of various plant species. Mineralization is the mineral enrichment of water by returned irrigation water and also by evaporation from the river course (Uys, 1996, p. 21)

2.2.2 Domestic or Urban Water Use

The domestic demand for water arises from its use for drinking, cooking, dishwashing, personal hygiene, gardening, sanitation and swimming pool maintenance. The domestic demand for water depends upon various variables such population density, household size, family structure, house types, gardening activity, electricity use, income, business activity, education, motor vehicle and other fixed asset ownership, water supply system type, sanitation facilities, water tariff, water quality and so on (Van Schalkwyk, 1996). This diversity can be captured by a living standard index, which ranges from 0 to 7; with 0 being the poorest and 7 being the richest. A high positive connection exists between the living standard index and water use (Van Schalkwyk, 1996). That is, the richer households tend to consume more water than others do since they engage in more water consuming activities and have more water consuming facilities. The economic conditions and whether or not water is priced determine the domestic water use. Unpriced or very low-priced water leads to wastage of water.

Domestic water demand, like irrigation, can reduce the water quality by draining the poor quality water in various ways. For example, it can happen through dissolution of oil, traffic deposits, chemical spillage and diffuse wastes in water, which is then discharged into rivers, making water less usable for downstream users. Sewage effluent is high in nutrients, which causes eutrophication and spread of disease. Inter-basin transfer can also add to water pollution.

2.2.3 Environmental Water Use

It is the second largest use of water in South Africa. This use of water is required for recreation, scenic beauty, biodiversity, and ecosystem functioning. Water use on scientific reserves and wilderness areas, natural parks and areas of cultural significance would fall under this category. However, at times, recreation such as fishing may affect the environment negatively. For example, angling can distract riparian growth and can lead to bank destabilization (Uys, 1996, p. 24).

2.2.4 Industrial Water Use

In the industrial sector, mining is intensive user of water. The effluent from mining and other industries contains toxic wastes material, including chemical rising fluids, solids, and organic washes and heavy metals. The power industry is another major user of water. The generation of power on the other hand raises water temperatures to a level that becomes harmful to biota and may cause diseases such as bilharzia and malaria (Uys, 1996, p. 24).

2.2.5 Forestry Water Use

Forestry, especially commercial one, is also an important user of water. Commercial forestry involves plantations of alien species of pine and eucalyptus. These are high water demanders. Forestry affects both the quantity and quality of the water run-off. This gets translated into reduced streamflow for downstream users. Forestry is therefore identified as a streamflow reduction (SFR Use) activity. The usage of land for forestry can reduce run-off by up to 60 percent (Uys, 1996, p. 23). Forestry also uses water through evapotranspiration (ET).

2.3 Water Use in Commercial Forestry

Water is considered to be the most important input from very beginning when plantations began in the late 19th century. There have been concerns raised about their impacts on streamflow from early period. A brief discussion follows on the water use in the commercial forestry.

2.3.1 Early Concerns about Water Use by Alien Species

Commercial forestry in South African context refers to the plantations of alien species of wattle *(Acacia mearnsii)*, pine (*Pinus patula, Pinus elliottii, Pinus taeda)*, and eucalyptus (*Eucalyptus grandis*, and many other species). The history of commercial forestry begins with the first alien plantation near Worcester in the Cape in 1876. The need for plantation of alien trees arose for two reasons. Firstly, European settlers had virtually exploited the Cape forests by 1876. The cutting of indigenous forests began in 1488 in Cape area and as time went by the more distant areas from Cape were found and cut. For example, forests of Riviersonderand, Goerge-Kysna-Tzitzikama, and Plettenberg Bay were cut during 1712 –1776, 1772, and 1786, respectively (Gasana, 1999, p. 15). The shortfall of fuelwood and timber experienced by the planners motivated them to go for plantations. Secondly, the plantations were found to be highly profitable. For example, the de Beers company (a mining company) made a net profit of 41338 pounds or 60 pounds per acre (King, 1938, p. 7). The need coupled with high profit potential made alien species very lucrative. The government also used it as an instrument to provide employment to poor whites (Van der Zel, 1989):

> The timber famine occurring during the (first world) war years, was a strong motivation for the Republic of South Africa government to establish saw timber plantations with the object of attaining self-sufficiency within 50 years. The economic depressions in the post-war period, and the unemployment coupled therewith, provided the incentive for the RSA government to embark upon large afforestation schemes to provide a living to poor whites and returned soldiers (Van der Zel, 1989).

However, high profits from alien species depended on the use of water and other high payoff inputs such as fertilizers. This realization came as early as 1915 when farmers downstream from Worcester forests in the Cape started complaining about decreased run-off from the plantations (Van der Zel, 1995). This marked the early signal for regulation of water use in the commercial forestry.

The early conflict in 1915 did not impact policy circles immediately as other concerns overshadowed the issue. The two World Wars and the rising demand for timber in the national and international markets dominated the policy scene; and government did not take farmers' concerns up as a serious one and overlooked the water problem. However, the complaints again surfaced in the 1950s and intensified during the drought of the mid-1960s. Finally, the government responded to crisis by appointing two committees to investigate afforestation and water supplies concerns. The first committee was an interdepartmental one appointed by the Minister of Forestry. This committee submitted a report on "Afforestation and Water Supplies in South Africa" in 1968 (Malherbe, 1968). The committee, named as the Committee of Investigation into Water Matters, appointed by the President of South Africa, was of diverse nature, consisting of experts from diverse fields among many other water-related issues. The Inter-Departmental Committee (IDC) recommended for the development of forestry, except in areas where water resources are limiting and threatening the development. The Water Matters Committee (WMC), whose report was published in 1970, suggested somewhat contrary to the recommendations of the IDC (Water Matters Committee, 1970). It found that, where expansion of afforestation is endangering the established irrigation or other water utilization developments, restrictions should be imposed on afforestation.

The findings and recommendations of these were eventually translated into an amendment of the Forest Act (Act No 72 of 1968) by adding specific articles on the Control of Afforestation (by means of Forest Amendment Act No 40 of 1972). The ultimate outcome was the formation of Afforestation Permit System or APS. The APS was governed by the Articles 7 and 8 of the Forest Act No 122 of 1984. These articles (cited in Van der Zel, 1995, p. 50) read as follows:

Article 7: Use of land for afforestation states that:

> (1) Without the prior written approval of the director-general no land, including land in the possession of the State (a) which has not been used previously for the establishment of commercial timber plantation; or (b) which for a period of more than five years after the removal, harvesting or destruction of a commercial timber crop, has not been so used, may be used for the planting of trees to produce timber for commercial or industrial purposes.
>
> (2) An owner who intends to establish a commercial timber plantation on any land, shall apply in the prescribed manner for the approval required in terms of subsection (1), and the director-general may in his discretion grant the approval on such conditions as he may deem fit.

Article 8: Protection of natural water resources reads:

> (1) The Minister may in respect of land which in terms of his Act is being or may be used for planting of trees to produce timber, by notice served on the owner of that land or by notice in the Gazette, prohibit the planting of trees within an area defined in the notice or the re-afforestation of such an area after the harvesting or destruction of a timber crop or prohibit any other act or direct the owner to make any other steps which in the opinion of the Minister are necessary for the protection of any water source.

> (2) An owner of land shall not permit plantation on any part of his land in respect of which a notice in terms of subsection (1) applies, after an existing timber crop has been harvested or destroyed.

The amendment to Water Act paved the way for the Afforestation Permit System, which was guided by the following principle (Bosch and Gadew, 1990, p. 43):

> If afforestation will reduce the mean annual runoff of a catchment beyond a specified minimum level, a permit (for plantation) is not granted. Otherwise planting is permitted, provided that streams, vels and other open bodies of water are not afforested.

The scientific basis of APS lies in the research done in the last 25 to 30 years or so. An extensive analysis of this may be found in Van der Zel (1995) and Dye and Bosch (2000). The major conclusion that emerges from these reviews is that alien species consume a significant amount of water and contribute to a significant decrease in the run-off from the afforested areas.

2.3.2 Magnitude of Water Use in Commercial Forestry: An Historical Overview

The concerns about the water use by alien species began to be documented since 1915 in South Africa. However, actual documentation of impacts of forests on environment and surroundings can be traced to the 1935 Empire Forestry Conference on South Africa. The conference deliberated on the effects of forests on climate, water conservation and erosion (Committee, 1935); this ushered in an era of hydrological research. The first catchment-based hydrological research station was established at Jonkershock, near Stellenbosch (Wicht, 1949). As time passed, several other hydrological research stations in other parts of the country were started. For example, a research station at Cathedral Peak along the western boundary of KwaZulu-Natal was set up in 1945. Additional research stations were set up at three locations (Mokobulaan, Witklip, and Westfalia) along the northern Drakensberg escarpment in Mpumalnanga and Northern Province.

The intensive investment in hydrological research bore fruit and South Africa became the leader in forest hydrological research (Sopper and Lull, 1957)[5].

The forest hydrological research was finally put together to provide a scientific basis of APS in 1974 (Van der Zel, 1995, p. 50). It was finally accepted that afforestation reduces run-off or streamflow. The relationship between annual run-off and reduction in annual runoff was established and was worked out by Dr D. W. Van der Zel, based on ideas and scientific publications by Nanni (1970, a and b), Midgly and Pitman (1969), Hewlett and Herbert (1961) and Hibbert (1967). This relationship was also contrasted with an extensive world survey of forest hydrological research results. Several other modifications were also made to the Van der Zel curve, the modified curve was known as Pitman curve (Pitman, 1976). The Pitman curves were once used extensively for catchment studies in South Africa (Van der Zel, 1995, p. 51). This relationship can be graphed and be seen in Van der Zel (1995, p.53). Pitman curves have been now replaced by the CSIR curves (Scott and Smith, 1997). Scott et al. (1998) provided a new estimate of water use in commercial forestry. This estimate of 1420 million cubic metre was an increase over the 1280 million cubic metre figure provided by DWAF in 1986 (Jewitt, 2002, p.2). Enormous efforts have gone into estimating the runoff reductions from commercial forestry. Two notable works are; first, the ACRU model developed by the School of Bio-Resources Engineering and Environmental Hydrology of the University of Natal (Schulze, 1995); second, the study by Gush et al. (2001). The ACRU model provides the basis and method for calculating runoff from South African land surface and many other variables such as canopy interception of rainfall by vegetation, total evaporation from the various horizons of the soil profile, and so on (See for details, Smithers and Schulze, 1995, pp. 8-9). Gush et al. derived the tables of national streamflow reductions as a result of afforestation, with the help of ACRU model.

Several additional evidences collected over the years give credence to the fact that commercial plantations reduce run-off or streamflow and that water is the limiting

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[5] Up until 1995, some R11 million were spend on hydrological research by the Department of Forestry and Water Affairs. The estimate is based on Van der Zel (1995, p. 50).

resource for their growth. Streamflow and precipitation data from seven catchment studies confirm that reductions in annual streamflow occurs to the order of 200 to 500 mm (see Table 2.5) (Dye and Bosch, 2000, p. 102). The results of reverse experiments, measuring the impacts of clearing trees on streamflow, also confirm that water usage by trees is phenomenal; for a detailed review of these studies see Dye and Bosch (2000). These kinds of experiments done in South Africa are summarized in Table 2.5 (Dye and Bosch, 2000). It is now obvious that alien species grow rapidly and water is a limiting factor for their growth. It is now agreed among the water experts in South Africa that water is a key input for the growth of alien tree species which affords them with their rapid maturity rate; interestingly enough, many studies in South Africa now confirm that water is the most important and limiting resource for the growth of alien species (Schonau and Grey, 1987; Dye and Bosch, 2000, Tewari, 2001, Box 2.1).

Table 2.5: Mean Annual Precipitation (MAP) and Mean Annual Runoff (MAR) from Seven Catchments in South Africa.

Catchment	**Westfalia D**	**Mokobulaan A**	**Mokobulaan B**	**Lambretchbos B**	**Cathedral Peak III**	**Bosboukloof**	**Biesievlei**
Province	Northen	Mpumalanga	Mpumalanga	Western Cape	KwaZulu-Natal	Western Cape	Western Cape
Area (ha)	40	26	35	65	142	210	27
Mean altitude (m)	1225	1354	1396	660	2019	543	396
MAP (mm)	1611	1135	1135	1473	1587	1296	1427
Virgin MAR (mm)	548	244	217	531	760	593	663
Run-off: rain ratio	0.34	0.21	0.19	0.36	0.48	0.46	0.46
Pre-afforestation vegetation	Scrub forest	Grassland	Grassland	Fynbos shrubland	Grassland	Fynbos shrubland	Fynbos shrubland
Plantation species	*Eucalyptus grandis*	*Eucalyptus grandis*	*Pinus patula*	*Pinus radiata*	*Pinus patula*	*Pinus radiata*	*Pinus radiata*
Afforestation extent (%)	83	100	100	84	86	57	98
References	Smith & Bosch, 1989	Van Lill et al. 1980	Van Lill et al. 1980	Van Wyk, 1987	Nanni, 1956; Bosch, 1979	Van Wyk, 1987	Van Wyk, 1987

Source: Dye and Bosch (2000, p.103).

2.4 Functioning of the Afforestation Permit System (APS)

The APS divided the South African catchments into three categories. Category one included catchments where no more afforestation was possible; the water requirements for other purposes were large enough as not to permit any more afforestation. These included: (1) catchments of the Levhuvhu and Lebata rivers, in Northern province (then Northern Transvaal); (2) catchments of the White River and Ngwempisi River in Mpumalanga (then Eastern Transvaal); (3) catchments of the Vaal River in the Free State and other areas. Category two catchments were permitted to have afforestation to the extent that it does not reduce the Mean Annual Runoff (MAR) by more than 5% from existing level of precipitation. Water needs for other sectors such as industry, power, irrigation existed and they needed to be prioritized. These catchments included: (1) catchments of Crocodile River and Komati River; the Great Usuthu River, catchment of

Box 2.1: Water Use in Commercial Forestry, South Africa

To ensure profitability, commercial companies plant water hungry alien species (principally Pine and Eucalyptus), which occupy roughly more than 80% of the total planted area. It is the substantial dependence of the alien species on both ground water and surface run-off or rain, which affords them with their rapid maturity rate. Water is the main contributing factor to the limitations of tree growth and the availability of it has been recognized as the main factor influencing the growth of commercial plantations in South Africa (Schonau and Grey, 1987). Commercial timber planting uses larger quantities of water than shorter vegetation types, such as scrub, herbs and grass (Le Roux 1990). Van der Zel (1985) indicated that for the Umvoti catchment, Pine trees would use 1080 mm of water compared to 850 mm for grassland, while Whitmore (1983) conducting a study in the Eshowe area indicated that afforestation tended to deplete substantially both the annual total water yield and the base flow in the dry season. Some estimates suggest that an establishment of 6 hectares of timber in South Africa would reduce the run-off by an equivalent amount of water required for one hectare of irrigated wheat (Le Roux 1990). Pine plantations consume more water than indigenous trees as their evaporation rate is higher, resulting in a reduced streamflow (Forsyth et al. 1997). If these trees are planted in the catchment areas on a large scale, they have a major impact on the streamflow reduction. Unfortunately owing to their high water-dependence, most plantations in South Africa were established in the escarpment areas of the country, which are also the water catchments of major rivers, particularly in the Eastern cape, KwaZulu-Natal and Mpumalanga province. As a result, the commercial forestry is classified as the major streamflow reducing activity by the Department of Water Affairs and Forestry (Warren, 1999). Besides streamflow reduction, the plantations also contribute to the lowering of the water table. Finally this maybe translated into declining timber yields as successive rotations of eucalyptus and pines which deplete the reserves of ground water (Schonau and Grey, 1987). The downstream agriculture is affected adversely as well. In KwaZulu-Natal, for instance, communities are experiencing severe water shortages as a result of such practices and rain-dependent agriculture has been further marginalized as the water table dropped. Source: Tewari (2001)

Upilozi River (Mpumalanga or then Eastern Trasvaal). (2) Umgeni and Umlazi River catchments in Natal; Tugela River catchment (Mpumalanga); (3) Buffalo River catchment (Eastern Cape). The remaining catchments were put into a category three where an arbitrary upper limit of new afforestation since 1972 using an additional 10 percent of the MAR was set (Van del Zel, 1995, p.52).

For operationalization of APS, the entire country[6] was divided into nine regions. In each region, a permit committee was formed to implement the APS. All the nine regional permit committees worked under the Central Afforestation Permits Committee. The application from a region was first commented upon by the regional committee and then forwarded to central committee in Pretoria. The central committee finally issued the permits only. Initially permits were issued only for a year but later revised and approved for a five-year period.

The APS was revised from time to time to make it amenable to the needs of society at large. For example, the category two catchments were subdivided into sub-catchments to regulate afforestation in some specific catchment. Likewise the original 20 metre open strip along riparian zones was changed to 30 metre along riparian zones and 50 metre from the edge of wetlands. Eradication of wattle and other alien trees were also given consideration while granting permits.

The APS was reviewed from time to time by academics and administration authorities and the system continued for a long time. Between 1972/73 and 1993/94, some 4300 permits were assessed, of which 3900 permits nearly for 1 million hectares were approved. Some 400 permits accounting for an area of 13700 hectares were refused (Table 2.6). The estimated net area afforested in South Africa between 1972/73 and 1992/93 for selected periods are given in Table 2.7. During this 22 year period, out of approved one million hectares (936899 ha), some 46 percent (429210 ha) area were

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[6] The independent states at that time did not opt for APS; the APS was not applicable to these areas- Venda. Lebowa. Kazanizulu. Bophuthatswana. Kangwane. Qwa-Qwa. Transkekei and Ciskei.

Table 2.6: Number of Afforestation Permits and Area Handled, 1972-1973 to 1993-1994, Selected Periods

Selected Periods	Approved Number	Approved Area (ha)	Refused Number	Refused area (ha)
1972/73 –76/77	1191	306 311	98	26 908
1977/78–81/82	304	59 551	40	12 794
1982/83-86/87	669	133 438	77	35 625
1987/88-91/92	1596	416 737	218	57 452
1992/93	86	17 770	4	1 583
93/94	27	3 042	9	2 495
Total	3873	936 849	446	136 890

Source: Constructed from Van der Zel (1995).

Table 2.7: Estimated Net Area Afforested in South Africa , 1972/73 to 1992/93

Selected periods	Newly planted (ha)	Converted out of forestry (ha)	Net gain (ha)
1972/73-76/77	24 830	4 102	20 728
1977/78-81/82	12 806	3 847	8 959
1982/83-86/87	14 087	3 456	10 631
1987/88-91/92	30 805	3 092	27 113
1992/93	1658	2 749	13 329
Total 1972/73-92/93	42 921	75 235	353 975
Annual Average	20 438	3 583	16 856

Source: Constructed from data obtained from Van del Zel (1995, p.54) planted and 8 percent of area (75235 ha) were actually taken out of forestry estate, resulting into a net gain of 3.8 percent area (Table 2.7).

From the foregoing discussion, a few salient conclusions emerge. Firstly, it is obvious that afforestation was not held back due to APS. Indeed, almost half of the approved areas were not planted with trees. However, the APS was successful in maintaining riparian zones, clearing self-sawn aliens in open areas, and keeping away from indigenous forest edges. Further, a large chunk of land, which was approved for afforestation, was not planted leaving a multitude of options for managing this land. Perhaps this land was used for biodiversity conservation, recreation, or any other purpose, thus multi-purpose forestry could be practiced.

Secondly, the APS did not hinder the economics and markets of tree-growing business. This in itself is a good thing and produced an economically efficient forest industry in the country.

Thirdly, the APS favored the large companies. Only large companies could afford the capital and infrastructure to expand plantations over the larger number of catchments and sub-catchments. Resident farmers were not usually in the position to afford the cost associated.

Fourthly, the APS permitted the quantification of water use from each quaternary catchment and could be estimated on annual basis.

Fifthly, the APS is envisaged as a forerunner of an integrated catchment management system of all land and water uses for equitable sharing of water (van der Zel, 1995, p. 57).

2.5 New Developments in Water Use Regulation

Current water use regulations in South Africa have undergone a complete change in comparison to the previous dispensation. It is hence imperative to understand the issues of water use rights in historical perspectives. Water has been a major concern to past and present governments of South Africa. The modern South African history of water use rights can be traced back to 1653 when Dutch people immigrated to Cape and colonization of South Africa began. The Dutch law treated water as a national resource and private rights to water use were not recognized. This continued up until British supremacy reigned the Cape in the early 20th century. British regime reversed the water-use rights and assigned private rights to water.

A new revolutionary change took place in the South African history of water rights in 1994 when apartheid crumbled and democracy dawned. A National Water Act (Act 36 of 1998) was passed and this assigned the role of public trustee of country's water resources to the national government. As a result, the water resources of the country are now treated as a national asset to be utilized in the best interests of citizens in a sustainable manner to guarantee the needs of future generations. And, at the same time, the needs of individuals, including water, are guaranteed through a constitutional right to a safe, healthy environment. The Department of Water Affairs and Forestry (DWAF) is finally to play this custodian role. The new national water policies emphasize efficient, equitable, and sustainable water uses.

DWAF has identified 11 broad categories of uses of water; the streamflow reduction is one that relates to commercial forestry. Other activities such as dryland agriculture will be added to this list soon. The management of the water is guided by some 27 basic principles. The new law thus requires authorization from government for water use (Principle 19) and authorized water use is recognized in three categories: (1) the existing lawful water users; (2) the generally authorised users; and, (3) the licensed users. The existing lawful use means any lawful use of water, authorized by or under any law, which took place at any time during the period from 1 October 1996 to 31 September 1998. The streamflow reduction activity falls under this category.[7]

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[7] A streamflow reduction activity is "any activity (including the cultivation of any particular crop or other vegetation)…[that]… is likely to reduce the availability of water in a water-course to the reserve, to meet international obligations, or to other water users significantly" (NWA Section 36(2)).

The general authorization demands no license and is valid for 3 to 5 years, subject to review from time to time. The licensed use gives entitlement to water use and could be given for a period of 5 years or less. A license can be issued for a maximum of 40 years. The DWAF has decided that it would call for compulsory licenses, intially for in the stressed resources where there may be problems experienced from over-utilization and competing water uses. Both existing and generally authorized users may be required to apply for a license if water stress situation applies. Commercial forestry is thus lawful user of water and does not warrant a compulsory license at this time.

2.5.1 Water Use Licensing[8]

Since commercial afforestation has been declared as a streamflow reduction activity (SFRA), it is to be regulated by means of a SFRA Water Use Licensing System in terms of Chapter 4, Section 36 of the National Water Act (No. 36 of 1998).Water use licensing became necessary as commercial forestry consumes large amounts of water relative to veld or agriculture. Furthermore, a transfer of land use to forestry from others is irreversible for all practical purposes--this has long-run implications for water uses. The permanent change to a higher water use demands a conservative approach in water scarce country like South Africa. The need for regulation becomes more urgent as more than 60 percent of rainfall of the country falls in the three coastal provinces KwaZulu-Natal, Eastern Cape, and Mpumalanga, which are seat of commercial forestry in South Africa.

The APS, instituted in 1972, was designated to determine areas available for commercial afforestation, based on the calculation of the percentage reduction in flow regimes caused by tree planting at primary catchment scale, without considering the impacts on other water users (for example, low flows in smaller catchments) (Warren, 2000). As for APS in 1972, the clarifications of 0, 5 and 10 percent reductions in Mean Annual Runoff (MAR) from whole or part of primary catchments, guided decisions on

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[8] This is a part of the National Water Resource Strategy (NWRS) for South Africa. See Republic of South Africa (2002). The NWRS will provide a legally binding framework that will ensure protection and conservation of water resources.

determining areas to be planted (Warren, 2000). Local precipitation, which varied tremendously, was not taken into consideration. Bearing the shortcomings of APS, a new system of regulating water use was announced by the Minister of Water and Forestry, Professor Kader Asmal. The new regulation was developed in consultation with major role-players in the forestry sector and other affected parties.

The new procedure requires management of streamflow reduction activity with the help of Licence Assesment Advisory Committees (LAAC)--formerly known as Afforestation Permit Review Panels. The LAACs consist of various individual representatives from the appropriate catchment management forum, Department of Water Affairs and Forestry, Department of Environmental Affairs and Tourism, Department of Agriculture, Department of Land Affairs, Forest Owners Association and other Forestry organisation, non-governmental organisation. The duration of water-use licence is for a maximum of 40 years (Section 28 (1) (e) of the National Water Act). The licences were to be reviewed every five years within the entitlement period. The new water use licencing has thus improved upon the old APS in following respects (Warren, 1999):

- It takes into account of the environemntal and social concerns of stakeholders.
- It permits a number of stakeholders to participate in decision-making process that has led to a high level of transparency to the procedure.
- There is a shift from allocation of permits from fixed and arbitrary catchment classification to a more flexible approach.
- The controls are improved as inspection of properties where permits allocated are allowed.
- The new procedure now takes into account reductions in low flow as well as no annual flows.

2.6 Summary

Some salient conclusions emerge from this Chapter. Firstly, South Africa is a water stressed country and the problem of water scarcity will increase in the future. The new National Water Act has been promulgated at an appropriate point in time. Secondly, commercial forestry is a large user of water in South Africa; these uses are in terms of evapotranspiration (ET) and streamflow reduction (SFR). The SFR use is some 8 percent of total utilizable water in the country. The major impact of afforestation is in terms of reduction in streamflow or run-off; this means less water for downstream users. Concerns against excessive water use by alien species have persisted since early 1920s, but regulation came into effect since 1972, known as Afforestation Permit System (APS). Thirdly, the APS ha been modified and replaced by the licensed water use regulation.

CHAPTER 3

VALUING WATER: MODELS AND METHODOLOGIES

Valuing water is not an easy task as in many situations explicit markets do not exist. This chapter provides: (1) a theoretical model for valuation of water in commercial forestry sector in section one; (2) a review of modelling techniques used for estimation of water values in section two; (3) a description of the state-of-art of valuing water, based on the past studies in section three; (4) a brief review of water demand elasticities in section four; and (5) a summary in section five.

3.1 Theoretical Model for Valuing Water

As usual, the value of any commodity can be defined in terms of use and its exchange value. No doubt water is an essential element for human survival and its utility in that sense is non-priceable. However, economists in general refer to the exchange value--a value that is determined by the interaction of demand and supply forces. The value of water can be estimated like the value of an economic good. The value of an economic good can be approximated by a measure of the user's willingness to pay (WTP) for the good rather than go without it. The willingness to pay measure for a good can be approximated from a demand curve for the good in question (Figure 3.1). In Figure 3.1, DD_1 is the demand curve for water. For a given price P, the total utility gained is represented by area OQED; the expenditure or cost incurred to obtain total utility is measured by area OQEP. The net utility gained by the consumer is shown by the shaded area DPE. In other words, the value of willingness to pay may be approximated by measuring consumer surplus[1].

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[1] There are two measures of welfare changes: compensating variation (CV) equivalent variation (EV). However, under certain conditions they can be approximated by consumer's and producer's surplus (Just et al., 1982). However, Freeman (1979) has described four measures of value or welfare change: (1) compensatory variation, (2) equivalent variation, (3) compensatory surplus, and (4) equivalent surplus. Nevertheless, they all can be approximated by measuring consumer's and producer's surpluses.

However, in applying above model to commercial forestry, two major problems arise. Firstly, water is not consumed directly by final consumers unlike the case of drinking water. Secondly, no explicit market for water exists. Hence, the direct measurement of utility is not possible. Rather, water provides utility indirectly as an input into the production of commercial forestry crop. The willingness to pay for water hence depends upon the nature of timber production function in which water is one of the inputs. In this case, the willingness to pay for water is derived from the timber production function in which water is an input[2].

Figure 3.1: A Theoretical Model to Estimate the Willingness to Pay for Water as a Final Commodity

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[2] Although a tree produces not only timber but also non-timber and environmental outputs. In the case of commercial forestry, timber is the major output. Basically there are no non-timber outputs and

The willingness to pay for water will therefore depend upon the increased value of the output over and above the cost of producing extra output. This concept is referred to as producer surplus. A simple model, as shown in Figure 3.2, will illustrate that the willingness to pay measures can still be derived from the water demand curve estimated from the timber production function. A derived water demand function, timber production function, and timber output-supply curve is shown in Figure 3.2 (a), (b) and (c), respectively. Demand for timber output is assumed to be perfectly elastic (a perfectly elastic demand refers to a situation where change in output has no impact upon the price of timber; this is shown by D_T). Initially W_o units of water at a water price of r_0 are demanded in the production of Q_0 level of output, as shown in Figure 3.2 (b). A timber supply function, $Q_0 = f(P, r_0)$, intersects the perfectly elastic demand schedule, D_T, at Y, where P is the price of timber. If the price of water is lowered to r_1, water use increases to W_1 level, and the timber supply curve shifts out, the new supply curve is given by: $Q_1 = f(P, r_1)$. The net addition to producer surplus is represented by the area (XX_1Y_1Y). This is the maximum amount that commercial forestry would be willing to pay to obtain water for timber production, and any amount paid over and above this would leave them worse off. However, the theory of duality of surpluses in factor and product markets ensures that area (XX_1Y_1Y) in panel (c) equals to the area ($r_0 r_1 b_1$ b) in panel (a) (Just et al., 1982, pp. 337-356). In other words, the value of water use in commercial forestry can be estimated directly from the derived demand curve for water. The demand curve can be derived from the water and timber-yield response function. In the past, researchers have resorted to various methods to put value on water which are derived directly or indirectly from the above. These can vary from simple budgeting to mathematical programming or econometric estimation. In the next section, various modelling techniques used in valuation of water are reviewed in brief.

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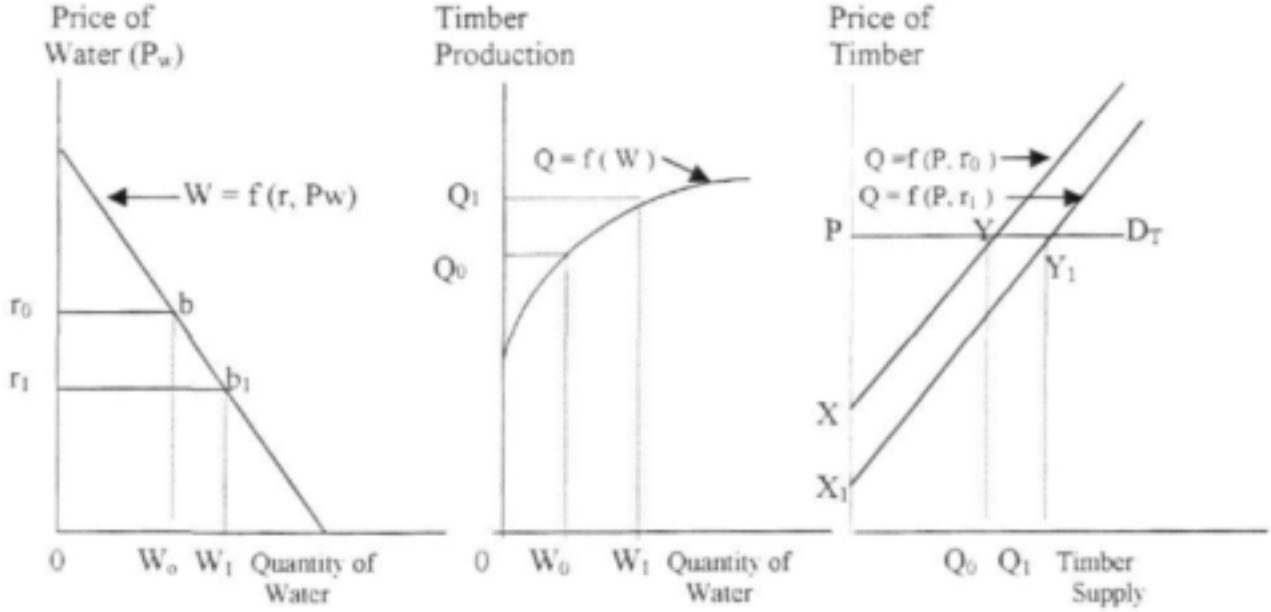
environment outputs are negative. We will however ignore all other outputs, other than timber, in computing the value of water in this study.



a) Water Demand Function b) Water Production Function c) Timber Supply

Figure 3.2: A Theoretical Model of Valuation of Water in Commercial Forestry

3.2 A Review of Modelling Techniques

Estimation of water values has induced researchers to resort to different techniques (Figure 3.3). Primarily they can be classified into two categories: (1) indirect methods, and (2) direct methods. The indirect methods aim at estimating the demand curve for water using time series or cross-sectional data. Once the water demand curve is estimated, the willingness to pay for water can be estimated by measuring the area under the demand schedule. Among the indirect methods, econometric and programming methods are commonly used. The direct methods aim at eliciting the willingness to pay value directly from the consumers. These methods include contingent valuation techniques and other hedonic price estimation methods.

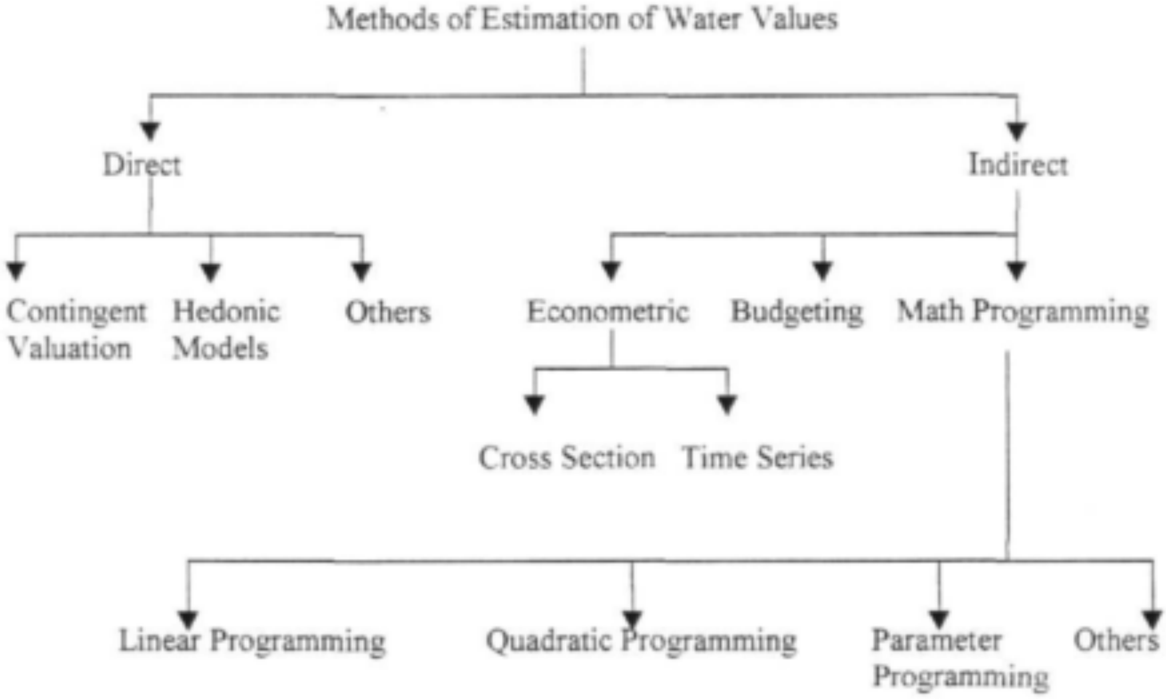


Figure 3.3: A Schematic Diagram Showing Various Methods of Estimation of Water Values

3.2.1 Econometric Method

Econometric methods basically depend on regression techniques. Under this method, water demand is specified as a function of a number of explanatory variables, including price of water, income of buyers/output in which water is used as an input, and other variables. The function can be estimated using both cross-sectional and time-series data. A number of studies that used this method are reviewed in section three of this chapter. For illustration purposes, we can take up some specific studies. For example, Capel (1971, p.4) suggested several explanatory variables that should be included in the estimation of demand function. These included: evapotranspiration, field irrigation efficiency, cost of applying water to crops, cost of complementary, and competing inputs. The other classic work is by Ruttan (1965), who estimated the value of the marginal product of irrigated land, using production functions of 16 regions in the United States. The first major limitation of this method is the massive data requirement, be it time series or cross-section ones. The second major limitation of econometric models is that they fail to capture the effects of new technologies developed outside the time span of the data.

3.2.2 Budgeting or Residual Method

The principle of budgeting approach is based on the calculation of residual value from the output after paying for all inputs except water. The residual value thus represents the value of water in the production of that particular product (timber or agricultural crops). The major limitation of this approach is that it can only be done at the small-scale level. Further, it does not permit examining the impacts of changing input parameters on the water values or substitution possibilities as a result of water price changes. Some studies that used budgeting approach are Lacewell et al. (1974), and Willitt et al. (1975).

3.2.3 Mathematical Programming Method

Mathematical programming is an alternative tool for estimation of demand for water. This is especially important when explicit water markets do not exist and demand for water is derived from the production function in which water is an input. There are several advantages of programming that make it a popular method. The first major advantage of this method is the flexibility it imparts to the model-builder: the model can be developed in linear, non-linear, single- or multi-period frameworks. The second major advantage of programming method is its capacity to accommodate the more explicit assumptions about the substitution of products and resources if adequate data set can be obtained at reasonable cost. The method permits the differentiation of sources of supply/production in the form of various activities. The activities can be also differentiated by season or by any other criterion of importance to the model builder.

The third specific advantage that arises in using programming models, especially with reference to water demand estimation, is the flexibility it provides in linearizing the non-linear yield/production response functions. Similarly the differences in resource requirements per unit of output for large-scale compared to small-scale production can be accommodated by including activities for small and large scale production operations. The fourth beneficial aspect of programming models is that they permit various sorts of variability in modelling. One can use quadratic programming, integer programming and so forth, depending upon the objective and constraints that a model builder faces. Some examples of programming models are Flinn (1969), Hartman and Whittesey (1961), Moore and Hedges (1963), Yaron (1967), Kulshreshtha and Tewari (1987).

3.2.4 Contingent Valuation Method

The contingent valuation is a direct method, which requires eliciting water values from direct questioning of water users. The CVM was proposed and first used in developed countries for valuation of public goods such as parks, clean air and so forth. However, it has now become quite a popular method to estimate willingness to pay for commodities, which do not have explicit markets, i.e., where buyers and sellers do not interact in actual sense. The technique involves direct questioning of water users to determine how they would react to certain situations. For example, we could ask the commercial forestry companies that how much they would be willing to pay for the water that they use. The answers are not clear-cut and have strategic biases. Also, note that the estimates here are not based on market or surrogate market situations, but from inferences from answers of individuals to some hypothetical situations. Having estimated the representative values from a representative set of people, the next step is to aggregate them to a total value based on the total number of individuals affected. Scura and Maimon (1993) used contingent valuation method to elicit willingness to pay for ambient surface water quality improvements in metropolitan region of Rio de Janeiro. The willingness to pay responses for boatable water quality (poorest quality) was about $4.64/household/month, amounting to $133 million for the entire population of 2.4 million of the metrocity. The swimmable level of water quality was valued at $7.90/household/month, or $228 million for the entire metro population. The similar approach was used to estimate the willingness to pay for water in rural Punjab in Pakistan (Altaf et al., 1992). Singh et al. (1993) used the contingent valuation method to examine the willingness to pay for yard taps or house connections in several rural villages in Kerala, India. A contingent valuation method survey of 1150 households was carried out, including both connected and non-connected to improved water systems. Singh et al. (1993) also derived a demand curve by varying monthly water tariff rates against the number of water connections and used this curve to estimate consumer's surpluses. This is an interesting study in the sense that water demand curve was derived from direct questioning. In South African context, a study by the Water Research Commission (WRC) was conducted to estimate the residential price elasticity of demand for water by measures of a contingent valuation approach (WRC Report No. 790/1/00).

3.2.5 Hedonic Estimation

Generally speaking hedonic pricing method is used to estimate economic values for environmental services that directly affect the market prices. The environmental quality may refer to air pollution, water pollution, or noise pollution. The economic value can be assigned to these through simple regression. This method can be amended to capture how water adds value to surrounding areas (James, 1995; Luttik, undated). Other studies include estimation of willingness to pay for improved water supplies in Onitsha town in Nigeria (Whittney, Laura and Mu 1991).

3.3 A Review of Water Valuation Studies[3]

The value of water in general depends upon its use. A high value use would enable consumers to pay a higher rate for water than otherwise. In the past, value of water has been estimated for various sectors, including residential or municipal use, irrigation, industrial use, waste assimilation use, recreation and hydropower (Gibbons, 1986). Various techniques have been used towards estimation of water values and these can be classified into three categories: (1) econometric, (2) programming, and (3) budgeting. The choice of techniques, however, depends upon the objective, availability of data, and other constraints. In the literature, a large variation exists in water values across various water uses. In the following section, water values across various sectors are reviewed and analyzed.

3.3.1 Water Values in the Residential Sector

In residential or municipal use, several studies exist, especially in the context of the United States. Several factors such as climate, population density, income and water price and other factors affect the municipal water demand. There can be seasonal or daily variation. Based on a number of demand elasticity estimates and average water quantities and the 1980 prices, Gibbons (1986) computed values for water in municipal use in three cities, Tucson in Arizona, Raleigh in North Carolina, and Toronto in Ontario. In each case, values were calculated for four different absolute reductions in consumption from the average household consumption in summer or winter. The values obviously depended on (a) water prices, (b) elasticities chosen, (c) average water consumption level, and (d) reduction in water consumption from the average consumption level. The four levels of reductions were chosen; that is, 0.7075, 1.4150, 2.830 and 5.660 cubic metre (that is equivalent to 1/4, 1/2, 1, and 2 ccf) per household per month. The variation in water values is huge; for example, the Tucson, Arizona, water value was $0.0154/cubic metre for 0.7075 cubic metre (¼ ccf) reduction from the average water consumption level, in contrast to $0.1825/cubic metre when reductions were 5.660 cubic metre (2 ccf) from the

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[3] All original $/acre-foot values are converted into $/cubic metre in this section.

average consumption level[4]. Similar patterns can be seen elsewhere (Gibson, 1986, p.18). For a 10 percent reduction from the average consumption level, the marginal water values for winter season were $0.0665, $0.0852, $0.0203/cubic metre for Tucson, Raleigh, and Toronto, respectively. In contrast, values for summer were $0.0227, $0.0170, and $0.0138/cubic metre for the same cities, respectively.

The water values are also reflected in the purchase/sale price of rights. For example, in Colorado towns on the eastern slope of the Rocky Mountains existed water markets, the price of an allotment of water right was $1900 in 1981; in annualized terms, this represented an average value of approximately $0.2433/cubic metre in 1981 prices (Gibbons, 1986, p.20). The interesting conclusion gleaned from these studies is that the marginal value of water increases as supply declines. That is, the marginal value of water approaches infinity when supply approaches zero.

3.3.2 Water Values in the Agricultural Sector

Water use in the agricultural sector is well-researched compared to other sectors. A variety of techniques--econometric, programming and budgeting--have been used to estimate water values in irrigation. A summary of various estimates of water values in agriculture from some selected studies is reported in Table 3.1. These are certainly not exhaustive, and most of them are from North America. For example, Faux and Perry (1999) used the hedonic price model to estimate the value of water in Masher county, Oregon in the US. Their estimates suggested that the value of water varied between $0.0357/cubic metre for the most productive land (class I land) and $0.0073/cubic metre for the least productive land (class V land). The study by Moore (1999) in California, based on an econometric model, found that water values vary from $0.0341 to $0.0568/cubic metre in different districts. As opposed to these high water values, Torrel et al. (1990) found the average value of water being $0.0032/cubic metre.

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[4] One acre-foot equals to 1233 cubic metre of water; 1cubic metre= 35.335 cubic feet; and 1ccf= 100 cubic feet.

Table 3.1: Some Estimates of Water Values in Irrigation, Selected Studies

Study	Location	Value Estimate ($ per cubic metre)
1. *Faux and Perry (1999)*	*Malheur County, Oregan, USA*	0.0073 (least productive land) 0.0357 (most productive land)
2. Moore (1999)	California	0.0341-0.0568
3. Torell, Gibbon and Miller (1990)	Ogallal Aquifer	0.0032
4. Lacewell, Sprott and Beattie (1974)	Texas Irish Plains	0.0122 (0.0219)[a] wheat 0.0154 (0.0260) grain sorghum 0.0462 (0.0543) corn 0.0608 (0.0770) cotton 0.0706 (0.0819) Soybean
5. Willitt, Hathorn, Robertson (1975)	Various counties in Arizona	0.0041 (barley) 0.0146 (wheat) 0.0162 (alfalfa) 0.0438 (sugarbeet)
6. Condra, Lacewell, Sprott and Adams (1975)	Texas high plains	0.0065 (0)[b] wheat 0.0316 (0.0105) grain sorghum 0.0454 (0.0114) corn 0.0560 (0.0202) cotton 0.0584 (0.0195) soybeans
7. Kebo, Martin and Mack (1973)	Roosevelt water conservancy district	0.0024-0.0154 late grain sorghum 0.0024-0.0227 early grain sorghum 0.0219-0.0284 barley 0.0243-0.0256 wheat 0.0203-0.0333 alfalfa 0.0552-0.0706 sugarbeet 0.0722-0.1346 cotton >0.1436 vegetables
8. Schumway (1973)	San Joaquin Valley, California	0.0178 barley 0.0211 alfalfa hay 0.0211 potatoes 0.0227 safflower 0.0333 dry beans 0.0300 cotton
9. Washington State University (1972)	Washington	0.0081 alfalfa 0.0251 corn 0.0422 wheat 0.0633 pears 0.0697 apples
10. Reynolds (1970)	Easton USA	0.014618 (irrigated spring pasture) 0.1273 (vegetables) 0.1955 (spring citrus)
11. Fox and Rollins (1969)	Easton USA	0.0511 cabbage 0.1500 potatoes 0.1549 snap beans
12. Russ (1969)		0.0770-0.8816 citrus

a. Figures in parentheses indicate the on-site values and outside indicate net values.

b. Figures reported in the parentheses are long-run values and those outside are short-run values.

Source: Gibbons (1986, pp. 35-39).

There are several other studies done during 1970s; for example, Lacewell, Sprott and Beatie (1974); Willett, Hathorn and Robertson (1975); Condra, Lacewell, Sprott and Adams (1975); Schumway (1973); and so on. These studies were primarily done at farm level for different crops and one can observe a lot of variation across them. Some aggregate water values in Washington and Eastern United States indicate that water contributes significantly in the production of major crops.

Glancing at the reported values in Table 3.1, one can make three important observations. Firstly, one can see a lot of variation. In the sample studies, this ranged from $0.0032/cubic metre in Ogallal aquifer to $0.8816/cubic metre in eastern United States. This can be attributed to several factors, including soil, crop type, market prices of inputs and outputs in question, among others. Secondly, the long-run values are smaller than short-run ones, as the latter ones do not take into account fixed costs of production. Thirdly, water values do not show any specific trend if we look at the studies in chronological order, though this may be a casual observation as variables compared over the years are not the same. Finally, in some cases, negative values indicate water quality externalities. For example, excessive irrigation can make soil saline and preclude crop production. Fifthly, most of the water values given in the studies are on-site or at the source values.

In the context of South Africa, the study by Olbrich and Hassan (1999) computed the Net Terminal Value (NTV) per volume of water for each crop in the Crocodile River Catchment[5]. Their results showed that the water values ranged from R0.052 to R19.04 per cubic metre of water. The highest water value was found in tropical fruits, followed by sugarcane and the majority of forestry crops. The study by Bate et al. (1999, pp.31-32) suggests a trade price of 18.75 cents/cubic metre in the Crocodile River catchment. In the lower Orange River, the mean sale price of water was found to be 22.5 cents/cubic metre (Armitage, 1999, pp.87-88). The other estimate of the water value in irrigation is from the Middle Orange River; that is estimated to be 2.08 cents per cubic metre at a real discount rate of 10 percent, compared with a shadow price of 3.5 cents per cubic metre per annum

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[5] The NTV value accounts for the time value of money.

[calculated for a typical cropping pattern of wheat, cotton, potatoes, maize near Douglas on the Orange River, (Backeberg, 1997, p.366)].

3.3.3 Water Values in the Industrial Sector

In the modern economy, industrial sector plays a major role and it is a major consumer of water as well. Industrial processes need water for various purposes such as cooling and condensation, washing raw materials, food preparation, and so on. Water costs are a small fraction of the total costs in general in the industrial sector (Gibbons, 1986, p.47). The other costs such as labour, machinery and capital are generally very large, and greatly exceed the importance of the cost of water. However, as water is becoming scarce, managers in the industrial sector are no longer ignoring water costs.

Water usage in the industry is affected by many factors, including the quality of raw materials, relative prices of other inputs in production, product quality and product prices, government regulation related to environment which impact water use in the industry (Gibbons, 1986, p.49). Gibbons (1986) notes that scanty empirical material exists on industrial demand and water values. The reasons for the lack of water values in the industrial sector is due to water being a very small proportion of the total costs. Also, there is difficulty involved in defining water price variable. Conceptually speaking, the value for water in industrial use could be derived from statistical industrial production functions, provided sufficient data is available. However, due to lack of appropriate data and other problems related to methodologies, the water value has been equated with the internal cost of water circulation. Industry should be willing to pay only up to what it would cost to produce water of adequate quality through treatment and re-use (Gibbons, 1986, p.50).

Water is a major input as a coolant in power generation. The estimates of values of water for cooling were estimated to range from $0.0049 to $0.0081/cubic metre in 1980 prices (Young and Gray, 1972). Estimates by Russell (1970) for cooling water values in electricity and petroleum refineries are respectively $0.0040 and $0.0089/cubic metre.

The water values for processed water recycling are higher, ranging from $0.0414/cubic metre in the chemical industry to around $0.3244/cubic metre for a meat-packing plant (Table 3.2).

Table 3.2: Estimates of Water Values in the Industrial Sector

Study	Industry	Value (per cubic metre)
Young and Gray (1972)	Electricity (cooling)	$0.0049-$0.0081 (1980 prices)
Russel (1970)	Electricity (cooling)	$0.0040 (1980=100)
Russel (1970)	Petroleum Refineries	$0.0089 (1980=100)
Young and Gray (1972)	Chemicals Industry	$0.0414 (1980=100)
	Paper	$0.0519 (1980=100)
	Minerals	$0.0130 (1980=100)
Kollar, Brewer, McAuley (1976)	Cotton textile	$0.1079
Kerne and Osantowski (1981)	Meat packing plant	$0.2652-$0.3698

Source: Gibbons (1986, pp. 51-56).

The sporadic estimates on water values in the industrial sector suggest a large variation across studies, apart from their methodological limitations. The estimates vary between $0.0040 to $0.3698 per cubic metre in the sample studies (Table 3.2).

3.3.4 Water Values in Recreation and Aesthetics

The water can be assigned values when it is as an input to produce recreation and aesthetic pursuit. This may include swimming, boating (in rivers and lakes), fishing and other activities such as picnicking or bird-watching along side streams (Gibbons, 1986, p.65). Over the years, with increasing urbanization and industrialization, the demand for water-based recreation has increased significantly. Although explicit market exists for such water-based recreation activities, it is difficult to assign a price to water use in such circumstances. Hence, indirect methods have been used. One way to put a value on water-based recreation is to use the price charged for water-based recreation as the minimum value. The travel cost model can also be applied. A more straightforward approach to elicit willingness to pay is the contingent valuation approach. The general consensus is that the travel cost approach works well when costs differ significantly across users and single site trips is the norm (Gibbons, 1986, p. 66). Otherwise, the consumer survey approach is preferable. Although a number of studies have been conducted after 1980s on valuing non-market goods, fewer studies exist on the estimation of water values. Some estimates of water values based on various studies are given in Table 3.3.

A cursory look at Table 3.3 reveals a lot of variation in water values, changing with the type of recreation and methods used in estimation. For example, water values for fishing decrease as one moves from low flows to high flows (Daubert, Young and Gray, 1978). Values also vary with the type of fish caught. The instream water values for recreation is high during peak seasons (Loomis and Ward, 1985). The water values discussed here simply refer to user values, and non-user values (option, existence, and bequest) are not taken into account[6]. It is also important to note that water values related to recreation depend upon the quality of water. For example, swimming requires more stringent water quality than fishing or boating. Water pollution thus affects the overall demand for water-based recreational activities.

3.3.5 Water Values in Navigation

Water has been used for transporting goods and people. The value of water for navigation depends upon the level of water in the river. If the water level is not sufficiently high as to permit navigation, then it is deemed nil. Empirical studies conducted in this regard have estimated average economic values. Different principles have been applied to approximate water values. For example, the value of water in barge transportation can be judged by looking at the opportunity cost or cost of transporting the same amount of commodities by railroad. The differential between the two costs can be attributed to water. But, this ignores the value of time. Barge transportation takes longer than by railroad.

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[6] Option values indicate what the consumer is willing to pay to use the resource at a later time. Existence values are attributed to consumer knowledge that the resource exists. The bequest values reflect a willingness to pay for saving the resource for the enjoyment of future generations. In recent years, the magnitude of these values has been estimated to be large and significant for policymaking decisions.

Table 3.3: Values of Water in Water-Based Recreation and Aesthetic Pursuits

Particulars	Industry	Value ($/ cubic metre)
Daubert, Young and Gray (1978)	Fishing	$0.0130 per low flows (0-1.42 cubic metre/second) $0 per high flow (12.73 –14.15 cubic metre/second) $0.0049 (white water recreation)
Walsh, Ericson, Arosteguy and Hansen (1978)	Colorado Mountain Streams Recreation	$0.0130 for fishing $0.0032 for Kayaking $0.0024 for rafting $0.0187 overall activities
Walsh, Aukerman and Milton (1980)	Reservoir Water Recreation	$0.0292
Loomis and Ward (1985)	Colorado instream Water Recreation	The peak values in July increased to $0.0608 per cubic metre for the first cubic metre/second.
Ward (1985)	Angling and white-water boating in Rio Chama River	$0.0219
Bush (1976)	Fish hatchery in Trinity river of California Water for Salmon spawning in Toulumne River	$0.0187 $0.0324
United States Water Recources Council (no date)	Recreational value in unit dollars per visitor a day	$0.0024 to $0.0114
Walsh, Ericson, Arosteguy and Hansen (1978)	Recreational value in unit dollars per visitor a day	$0.0114 (streamfishing) $0.0089 (kayaking) $0.0081 (rafting)
Walsh, Auckerman and Milton (1980)	Reservoir fishing	$0.0097 to $0.0187 per userday
Charbonneau and Kay (1978)	Fishing	$22/day (catfish) $31/day (trout and salmon) $45/day (pike and walleye)
Vaughan and Russel (1982)	Freshwater fishing	$0.0105-$0.0235 (cold water game fish) $0.0097-0.0210 (warm water game fish) $0.0065-0.0154 (catfish and rough fish)

Source: Gibbon (1986, pp.65-70).

In a long-run context, the return to the water can be defined as the savings of shipping by barge rather than by railroad, less the costs of the construction and operation of the waterways (Gibbons, 1986, p.79). However, in the short run, the value of water in navigation is defined as the savings of shipping by barge (instead of by rail) less the operation and maintenance costs of the waterway (Gibbons, 1986, p.80). Obviously, short-run values are higher than long-run values. This is why short-run values of water for slack-water rivers and man-made channels are very high.

Gibbons (1986) computed average per acre-foot (changed into per cubic metre) water values for selected watercourses. *Their estimates were as follows: Ohio River* (\$0.2230/cubic metre), Illinois Waterway (\$0.1938/cubic metre), Tennessee River (\$0.0422/cubic metre), Mississippi River (\$0.0049/cubic metre), Columbia/Snake River (\$0.0024/cubic metre), Missouri River (less than \$0.0008/cubic metre). The instream use of water for navigation on free-flowing rivers is fairly low-valued.

Young and Gray (1972), estimated long-run average values of water for navigation on selected waterways in the US and found a huge variation, ranging from less than \$0.0008/cubic metre for Upper Mississippi River to \$0.1833/per cubic metre for the Ohio River. In fact, in some cases, navigational water values were found to be negative.

3.3.6 Water Values in Hydropower

The basic concept in valuing water in hydropower lies in the fact that each acre-foot of water dropped over a given head (such as turbine) makes the same amount of electricity. Thus, the marginal and average productivity of water in this use is equal. The amount of electricity produced per unit of water on a specific river depends on two things: (1) number of feet of average net head on the river, (2) technology of hydropower facilities. This relationship has been standardized and can be expressed as 0.0023 kilowatt hours per cubic metre per metre of head; [Norman, et al; 1981 cited in Gibbons, (1986, p.89)]. A major problem arises in putting monetary values on the physical productivity of water because most electric utilities are heavily regulated and hence the market price and market demand is de-linked. Thus, the value of water in hydroelectric power cannot be estimated from the demand for electricity but through the alternative cost of generating electricity by some other means. Using the opportunity cost principle, three types of values have been computed: (1) short-run marginal value (base load and peak load); (2) long-run replacement capacity value; and (3) long-run average value.[7]

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[7] For a brief discussion of these, see Gibbons (1986, p.89).

The value of water for hydropower differs from river to river, depending on the number of feet of developed head (Gibbons, 1986, p.91). Some estimates of short-run marginal values for hydroelectric power generation for selected plants on selected rivers are shown in Table 3.4. The variation in values varies from less than \$0.0008 to \$0.0260/cubic metre. Gibbons (1986) also found a substantial difference between short- and long-run water values for hydroelectric power generation. The long-run values were roughly 50 percent of the short-run values (based on data from Gibbons, 1986, p.95). Some salient discussion points emanate from the foregoing discussion. Firstly, the average value of water in hydroelectric power is rising because of the rising share of hydropower in meeting peak load demand. Secondly, hydropower does not generate pollution like the fuel-based electricity; environmental advantages are therefore far higher.

3.3.7 Water Values in Waste Assimilation

When we talk of water values in general, it is implicitly assumed that water is of good quality and its supply is timeous. In point of fact the concept of water demand is associated with quantity, location and timing, and quality. Water quality is hence an important dimension while valuing the water use.

The water quality problems are ubiquitous and result from both human activity and natural causes. The hydrological connections allow pollutants to move from surface to ground water aquifers. Sources of pollutants to water pollution can be categorized into two groups: (1) point pollution, (2) non-point pollution. In the case of point pollution, the source of pollutants in the streamflow can be identified. Point-source pollutants in general comprise of liquid industrial or municipal wastes and effluent from treatment plant[8]. The nonpoint pollution does not permit to identify the source of pollutants from a definite place; for example, runoff from lands, seepage of chemicals into water table; salinity from natural resources, and acid rain.

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[8] These wastes primarily contain biochemical oxygen-demanding (BOD) materials, nitrogen, phosphorous, bacteria and viruses. The BOD depletes the oxygen from water and thus when combined with nitrogen and phosphorous results in eutrophication of downstream lakes and loss of aquatic life.

Table 3.4: Short-Run Marginal Values of Water for Hydroelectric Power Generation for Selected Plants on Selected Rivers, USA

Plant	Feet of Head	Cumulative Water Values $/cubic metre
Columbia River		
Bonneville	59	0.0007
McMary	321	0.0039
Rock Island	514	0.0062
Snake River		
Ice Harbor	419	0.0050
Little Goose	617	0.0074
Swan Falls	1348	0.0162
American Falls	2159	0.0255
Tennessee River		
Kentucky	50	0.0006
Wilson	189	0.0024
Fort Londo	484	0.0061
Colorado River		
Shoshone	170	0.0021
Parker	894	0.0107
Hoover	1555	0.0187

Source: Constructed from data obtained from Gibbons (1986, pp. 92-93)

Pollutants are thus a risk to subsequent users of waters, depending upon the level of pollution in the water. Hence, water is used to dilute the wastes so that the damage is minimized. One simple way to place value on the dilution water is to estimate the subsequent damages associated with varying water quality levels. The benefits of upgrade water quality could then be defined as the reduction in damages (Gibbons, 1986, p.59). The other approach to value water in this context would be in terms of the cost of providing the same water quality without dilution through pre-treatment of effluent. However, this is best suited to the point-source problems for which treatment costs are unknown. Using alternate cost of providing the water, Gray and Young (1974) have provided estimates of water values for numerous river basins. The value of dilution of water aggregated over the river beaches was found to be between $0.0008 and $0.0016/cubic metre (Gibbons, 1986, p.61). This suggests very low values for water when used for assimilation of biochemical oxygen-demanding (BOD) material.

3.4 A Brief Review of Water Demand Elasticities

Having reviewed the water values, the next interesting information is the water demand elasticity estimates in the literature. The estimates of water demand elasticities, however depend upon several variables including technique of estimation, type of water use, place, data period, and so on. For example, one obvious difference is between the residential and agricultural water use.

Several estimates of elasticity of demand related to the residential use are given in Table 3.5. Most estimates exist for the United States alone. Both econometric (both cross-section time series data) and mathematical programming techniques have been used. The studies based on cross-sectional data include Gottlieb (1963), Gardener-Schick (1964), Ware-North (1967), Howe and Linaweaver (1967), Turnovsky (1969), Grima (1972), and Gibbs (1978). Elasticity estimates by other studies such as Wong (1972), Young (1973), Danielson (1977), Foster and Beattie (1979), Billings and Agthe (1980) are based on time series data. Gottlieb (1963) found that the elasticity of demand for water ranges from -0.66 to -1.24, depending upon the socioeconomic profiles of residential towns surveyed. Ware-North (1967) obtained the similar estimates for Georgia--the elasticity hovering around -0.60. Other cross sectional econometric studies suggested the inelastic estimates, ranging from -0.05 to 0.93 (Table 3.5). The elasticity is also reported to be varying with season (Howe and Lineweaver 1967; Grima, 1972; Danielson, 1972). Howe and Lineweaver (1967) found that elasticity values varied between -0.23 and -1.57. For Toronto, Grima (1972) found it varied between -0.75 and -1.07. Danielson (1977), a study done for North Carolina found elasticity values to vary between -0.31 and -1.38. The interesting conclusion gleaned from these is that water demand is price-elastic in summer and price-inelastic in winter. A South African study is by Döckel (1973), who estimated a residential water demand elasticity of –0.69 for Gauteng.

Studies done in the late 1980s and 1990s revealed some interesting findings. Firstly, a study by Nieswiedomy and Malina (1989) concluded that the estimates of elasticities are dependent upon the type of estimation technique and types of models chosen.

Table 3.5: Municipal Water Demand Elasticities, Selected Studies

STUDY	METHOD	LOCATION	PERIOD	MEAN/RANGE OF ELASTICITY
Gottlieb (1963)	Econometrics, Cross-sectional	Kansas	-	-.66 to -1.24
Gardner-Schick (1964)	Econometrics, Cross-sectional	Northern Utah	-	-.77
Ware-North (1967)	Econometrics, Cross-sectional	Georgia	-	-.61 (log) to -.67 (linear)
Howe & Linaweaver (1967)	Econometrics, Cross-sectional	USA	-	Total: -.40 Winter: -.23 Summer: East, -1.57 West, -.70
Turnovsky (1969)	Econometrics, Cross-sectional	Massachusetts	-	-.05 to -.40
Wong (1972)(a)	Econometrics, Cross-sectional	Northeastern Illinois	-	-.26 to -.82
Wong (1972)(b)	Econometrics, Time-series	Chicago Suburbs	- -	-.02 -.28
Grima (1972)	Econometrics, Cross-sectional	Toronto Ontario	-	Total: -.93 Winter: -.75 Summer: -1.07
Young (1973)	Econometrics Time-series	Tucson, Arizona	1946-1965 1965-1971	-.62 -.41
Danielson (1977)	Econometrics, Time-series	Raleigh, North Carolina	-	Total: -.27 Winter: -.305 Summer: -1.38
Gibbs (1978)	Econometrics, Cross-sectional	Miami, Florida	-	Marginal price: -.51 Average price: -.62
Foster and Beattie (1979)	Econometrics, Time-series	U.S.A.	-	New England: -.43; Midwest -.30; South -.38; Plains -.58; Southwest -.36; Pacific northwest -.69
Billings and Agthe (1980)	Econometrics, Time-series	Tucson, Arizona	-	-.39 (log) to - .63 (linear)
Gibbons (1986)	Programming	Tucson, Arizona	1979	Winter: -.23 Summer: -.70
Gibbons (1986)	Programming	Raleigh, N.C.	1073	Winter: -.305 Summer: -.380
Gibbons (1986)	Programming		1967	Winter: -.75 Summer: -1.07
Dandy, Nguyen and Davies (1997)	Econometrics Time-series	Adelaid, South Australia	1978/79-1991/92	Annual: -.63to -.77 Winter: -.45 to -.29 Summer: -.69 to -.86
Hansen (1996)	Econometrics Time-series	Copenhagen, Denmark	1981-1990	-.003 to -.01
Hewitt and Hanemann (1995)	Econometric Cross-sectional	Denton, Texas	1981-1985	-1.57 to -1.63
Nieswiedomy and Molina (1989)	Econometric	Denton, Texas	1976-1985	Decreasing block rates -.68 (OLS) -.09 (IV) -.36 (2sls) Increasing Block rates 3.50 (OLS) -.86 (IV) -.55 (2sls)

Table 3.5: Municipal Water Demand Elasticities, Selected Studies (Continued)

Nauges and Thomas (2000)	Econometric	Eastern France	1988-1993	-.22 (GLS)
Chicoine et. Al. (1986)	Econometric Cross sectional	Illinois	-	-.71
Point (1993)	Econometric Cross sectional	Gironde, France	-	-.17
Billings (1982)	Econometrics Time series	Tucson, Arizona	-	-.70
Schefler and David (1985)	Econometric Cross sectional	Wisconsin	-	-.12
Renwick & Archibald (1997)	Econometrics Cross-sectional Time series	California	-	-.38
Hoglund (1997)	Econometrics Cross-sectional Time series	Sweden	-	-.20

Source: Gibbons (1986, pp.10-14).

Secondly, a recent study by Hewitt and Hanemann (1995) in Denton Texas found that price elasticity estimates could be elastic particularly when industry is regulated; the study found the estimates ranging between -1.57 and -1.63. However, other recent studies by Dandy, Nguyen and Davies (1997), based on an econometric model, found elasticity estimates ranging from -0.6 to -0.8. This means a 10 percent increase in the price would result in a reduction in demand by 8 percent. The detailed econometric study done by Nauges and Thomas (2000) in France however provided contrasting results--the price elasticity was estimated to be as low as -0.22.

Irrigation demand elasticity estimates from a number of studies are summarized in Table 3.6. The estimates of irrigation demand elasticities from different studies suggest that they vary from very inelastic to very elastic. Nieswiadomy (1985) found an estimate of -0.80 in the high plains in Texas. On the contrary, Frank (1979) found very inelastic estimates, elasticity ranging from -0.013 to -0.47. Flinn (1969) in New South Wales and Kulshreshtha and Tewari (1987) report a wide variation in elasticity estimates, ranging from zero to very elastic, depending upon primarily what price is charged for water.

A few estimates of demand elasticities in the industrial sector exist. Renzetti (1992), using cross-sectional data for 1981 for Canadian manufacturing firms estimated price elasticities, ranging from -0.15 to -0.59, depending upon the type of firm. For example, rubber producing firm have the lowest price elasticity and the paper firms has the highest price elasticity value. The estimated values for different industries were as follows:

manufacturing (-0.38), beverage (-0.39), rubber (-0.15), textile (-0.33), paper (-0.53), metal (-0.27), mineral (-0.32), and petroleum (-0.48).

There are virtually no elasticity estimates available, to the knowledge of the author, for water use in other sectors such as hydropower, waste assimilation, and forestry.

Table 3.6: Irrigation Demand Elasticities from Selected Studies

Study	Method	Location	Period	Mean/Range of Elasticity
Nieswiadomy (1985)	Econometric	High Plains Texas	1973-80	-0.80
Frank (1979)	Ridge Regression	Weston USA	-	-0.013 to 0.47
Flinn (1969)	Parametric programming	Yanco, New South Wales	-	-0.09 to -1.73
Shumway (1973)	Parametric programming	California	-	-0.48 to -2.03
Moore and Hedges (1963)	Parametric programming	Tulare County, California	-	-0.188 -0.702
Faux and Perry (1999)	Hedonic regression	Malheur County Oregan	-	-
Moore (1999)	Econometric	California Counties	1981-	-
Kulshrestha and Tewari (1987)	Variable price programming	Saskatchewan	1986	-0.0 to -7.64 -0.0 to -3.28 (Arc)

Source: Studies as cited above.

3.5 Summary

This chapter provided a theoretical framework for valuing water as a final commodity or as an intermediate input. Different methods of estimating water values as well as different estimates of water values across various sectors were thoroughly reviewed. It is interesting to note that no estimates of water values in forestry exist in South Africa and the rest of the world. This study is thus a pioneering work in estimating water values in commercial forestry, at least in South Africa.

CHAPTER 4

VALUING WATER USE IN COMMERCIAL FORESTRY: THE CONCEPTUAL FRAMEWORK

This chapter delineates the basic assumptions and models chosen for valuation of water use in commercial forestry in selected areas of South Africa. The first section outlines the basic assumptions or modelling considerations made in conducting this study. The empirical models employed in the analysis are discussed in section two. The parameters for sensitivity analysis are defined in section three. The sensitivity analysis is chosen to provide policy makers the estimates of water values in the event of changing market parameters.

4.1 *Modelling Considerations*

In order to estimate the value of water use in selected areas of commercial forestry in South Africa, a number of methodological and contextual considerations were examined. These included: the definition of value of water, selection of species, selection of sites, cost related assumptions, definitions of water use types in the commercial forestry, and finally selection of valuation techniques. These modelling considerations are discussed below.

4.1.1 Defining Value, Price, and Tariff

In the water literature, three different terms have been used to denote the charges for the water: (1) value, (2) price, (3) tariff or user charge. Sometimes these terms are used interchangeably. However, in this study, they have distinct meanings. The term "value" refers to the expected net benefits from the resource; it is hence purely conceptual definition and has no direct relation with the market. The term "price" refers to a market-determined value which arises after a consensus between a willing buyer and a willing seller is reached. The term "tariff" refers to the cost recovered by the government or water agency in order to provide service; this is also known as a user charge. It is made obvious here that term "value" is used in the strict sense as defined above. It does not indicate a price, as determined by the forces of demand and supply.

4.1.2 Selection of Tree Species

Commercial forestry in South Africa encompasses various tree species. All tree species can be classified into two categories: (1) hardwoods, and (2) softwoods. Hardwoods include eucalyptus and wattle species. Softwoods include pine and poplars. Among these species, pine and eucalyptus predominate. For example, some 91.9 percent of the total forestry acreage are under pine and eucalyptus species (Table 4.1). Of eucalyptus species, the *E. grandis* is the most important one, constituting some 73.3 percent of the total acreage[1]. Similarly, *Pinus patula* predominates among the pine species.

Table 4.1: Species Composition in Commercial Forestry in South Africa, 1997

Tree Species	Area (ha)	Percentage of total
Pines	794451	52.3
Eucalyptus	601675	39.6
Wattle	112483	7.4
Others	9999	0.7
All	1518610	100.00

Source: Compiled from data obtained from FOA (2000)

Some more than 47 percent of acreage under pine is consisted of P. patula[2]. Bearing above in mind, these two species, eucalyptus (*E. grandis*) and pines (*P. patula*) were

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[1] This estimate is based on 1997 data obtained from Forest Owners Association (2000). Other species of eucalyptus include: *E. nitens, E .macarthurii, and E. fastigata* . For historical details of various alien species in South Africa, see Sim (1927).

selected for estimating water values in commercial forestry as they are fairly representative of the mix of tree crops grown in South Africa.

It should also be noted that both tree species could be grown on sawwood and pulpwood regimes. However, for this study we have chosen only the trees on pulpwood regime. This choice was made for two reasons. Firstly, most of the trees of pine and eucalyptus that grow in KwaZulu-Natal are based on pulpwood regime. Sawwood regime is more prevalent in Mpumalanga and Limpopo provinces. Secondly, the availability of data on sawwood regime was difficult to obtain. Considering time and financial constraints, data for only pulpwood regime were obtained.

4.1.3 Selection of Sites

Having made the choice of dominant species for the value estimation, the next task is to choose the representative sites. This task was performed by a group of experts constituted by the Water Research Commission (WRC)[3]. The group included the experts from the Institute of Commercial Forestry Research (ICFR) and from Council of Scientific and Industrial Research (CSIR). The group submitted a report, suggesting some four eucalyptus and three pine sites. Most of these sites fall in KwaZulu-Natal or nearby localities, which are supposed to represent the South African forestry on the eastern coast[4]. The selected sites are given in Table 4.2 (Figure 4.1). The report submitted by the group of experts is given in Appendix A.

4.1.4 Defining Types of Water Use

The water use in commercial forestry can be defined in terms of two distinct meanings: (1) Evapotranspiration Use or ET, and (2) Stream Flow Reduction Use or SFR. The ET

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[3] The group constituted of Drs. Colin Dyer, Colin Smith, Peter Dye. The first two individuals are from ICFR and Dr. Peter Dye is from CSIR.

[4] Based on 1997/98 data, some 79.3 percent of commercial forestry acreage lie in two provinces--Mpumalanga and KwaZulu Natal.

4.1.4 Defining Types of Water Use

The water use in commercial forestry can be defined in terms of two distinct meanings: (1) Evapotranspiration Use or ET, and (2) Stream Flow Reduction Use or SFR. The ET use refers to the total evaporative loss from forest stands which includes transpiration from dry canopies, and evaporation from wet canopies and forest litter or the soil surface.

Table 4.2: Selected Sites of Eucalyptus and Pine in South Africa

Sites	Province
Eucalyptus	
1 Kia-Ora	KZN
2. Baynesfield	KZN
3. Tanhurst	KZN
4. Kwambonambi	KZN
Pine	
5.Richmond	KZN
6. Greytown	KZN
7.Usutu	Swaziland

Source: Appendix A

The SFR use refers to the reduction in water yield from a catchment as a result of uptake of water by forest stands. This is expressed in units of millimeter equivalent depth of water, and is based on a comparison of streamflows expected from catchments under forest and a baseline vegetation (commonly taken to be natural grassland vegetation in South Africa) (Dye and Smith, 2001, see Appendix A). Both water use types are very important. The ET use requires the use of water necessary for survival and growth of trees, without which the timber yield cannot be materialized. The SFR use is defined in terms of streamflow reduction and it is important for downstream users.

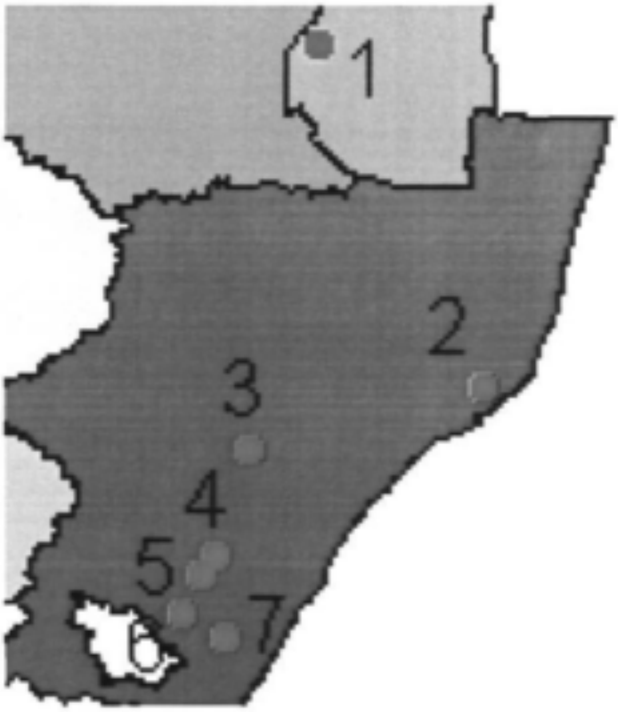

Figure 4.1: The Location of the Trial Sites Described in Table 4.1 (1- Usutu; 2 – KwaMbonambi; 3 – Greytown; 4 – Baynesfield; 5 – Richmond; 6 – Kia-Ora; 7 – Tanhurst).

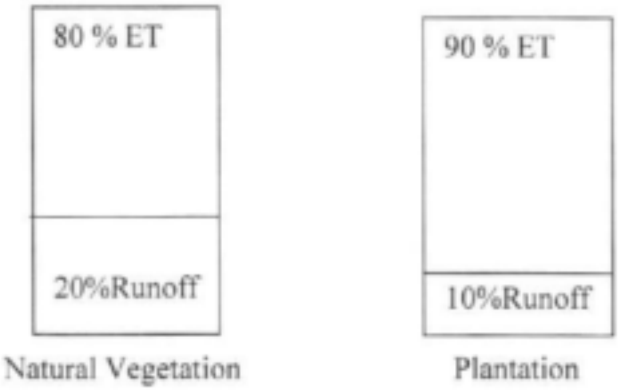

Figure 4.2: A Simplistic Relationship between Streamflow Reduction and Evapotranspiration (Source: Discussion with Prof. Peter Roberts, 2001)

The relationship between ET and SFR is complex but can be represented in a simplistic term in Figure 4.2. On an average, on natural vegetation (grassland field) some 80 percent water use is in the form of ET and rest 20 percent is run-off from the land. Once the natural vegetation is replaced by tree plantation, the distribution between ET and run-off changes. This leads to more evapotranspiration (90 percent) and less run-off (10 percent) thus resulting into 10 percent reduction in streamflow.[5] The rule of thumb is that streamflow reduction is roughly one-tenth of the evapotranspiration use; and, this holds true in the applicable range of annual rainfall of 1000 to 1200 mm (Based on discussion with Dr B. van Wilgen, CSIR, Stellenbosch).

4.1.5 Defining Cost Assumptions

The cost and price data for this study were available for the year 1996 only. Therefore, *entire water value calculations are made in terms of constant 1996 prices (1996=100).* Furthermore, the costs used in the study represent the average industry cost data for KwaZulu-Natal.

4.1.6 Choice of Water Valuation Techniques

A survey of literature in Chapter 3 indicates that different methods/techniques have been used to estimate value of water, depending upon the data availability and other constraints. In the current study, two methods were chosen: (1) Residual Value (RV) method; and (2) Marginal Value Product (MVP) method. These methods are used to estimate water values for ET and SFR water use (Figure 4.3).

4.2 Empirical Models Employed

The two empirical models are employed to estimate the values of water use. These include: (1) Residual Value (RV) method, and (2) Marginal Value Product (MVP) method.

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[5] This rule of thumb was given by Professor Peter Roberts, Pietermaritzburg, 20th March, 2001.

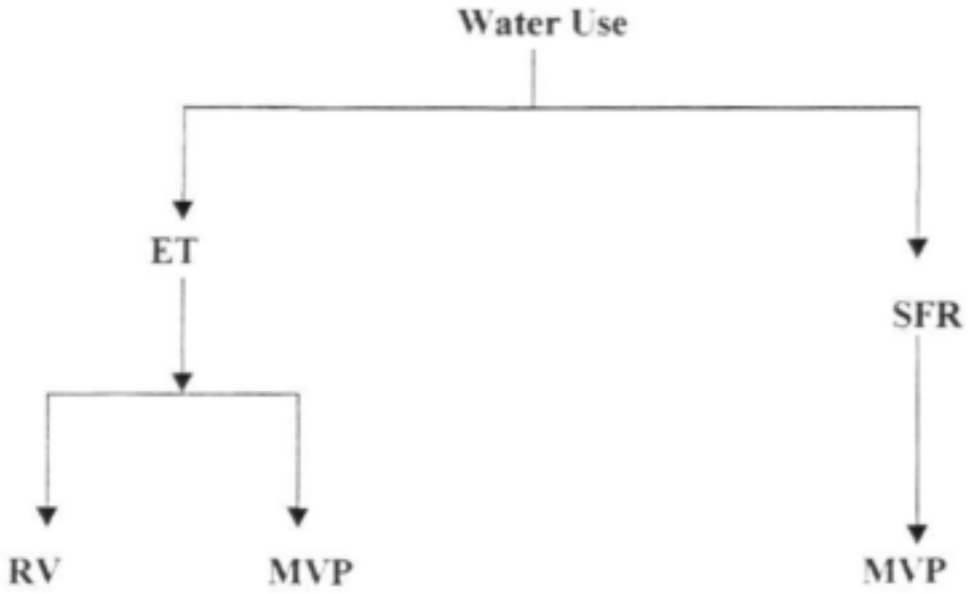

Figure 4.3: Selected Methods of Estimation of Water Value in Commercial Forestry, South Africa

4.2.1 Residual Value (RV) Method

This method is based on the premise that the residual value, obtained as total revenue minus total costs, including the compensation for other factors of production such as land, capital, and management, is attributed to water. Water as input is paid after having paid all the expenses, including both fixed and variable costs. The water values can be derived as net of total revenue and total cost curves. This means that water values will be negative below the break-even point and positive beyond it. These **average values** in a way approximate the willingness to pay for water, at the maximal level. Mathematically speaking, the value of water (V_w) can be computed as follows:

$V_w = (TR - TFC - TVC) / Q_w$

where

V_w = Value of water ,

Q_w - Quantity of water,

TR = Total revenue for a given yield level,

TVC = Fixed cost for a given yield level,

TFC = Variable cost for a given yield level.

The RV method is employed to estimate the ET water values in both eucalyptus and pine for the seven selected sites in KwaZulu-Natal.

4.2.2 Marginal Value Product (MVP) Method

From elementary microeconomic theory, the marginal value product curve of any input/factor represents the demand curve for that input/factor. The cumulative area under the MVP curve can then be approximated equal to the willingness to pay for water or total value of water. This can be done by simple integration of the MVP function/curve. In this context, the production function or water-yield response functions were obtained for all seven selected sites of eucalyptus and pine by fitting quadratic functions to the data. The estimated quadratic functions, which were used for estimation of water values, are given in Appendix B. The area under the MVP curve was estimated by integrating the function mathematically[6]. Marginal values are useful for making the investment decisions (crop or land) at the margin, whereas the average values are useful for making assessment of payment capacity (amount to be paid).

4.3 Sensitivity Analysis

Water values can change if the cost or timber price vary. To ascertain these variations in water values, the sensitivity analysis was carried out. The following changes from the base run for benchmark were computed and compared. Different scenarios examined are

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[6] Given the quadratic tree growth function: $Y = a + bX - cX^2$, we can obtain the marginal physical product (MPP) which is : $b - 2cX$. The area under the MPP is obtained by simple integration which is given by $\int (b - 2cX)\, dx = bX - cX^2$. This measures the total value of water in physical product term for X units of water used. The per unit water value is hence given by $(b - cX)$. The per unit Rand value is obtained by multiplying it with price of timber or $(b\text{-}cX)\,P$.

base run for benchmark were computed and compared. Different scenarios examined are summarized in Table 4.3. An extra scenario was included to test the impact of exclusion of land rentals on water values. For this scenario, the water values with and without land cost for some selected sites of eucalyptus and pine were estimated and compared.

Table 4.3: Scenarios Examined under Sensitivity Analysis Using the Residual Value Method

Scenario	Percent increase in cost from benchmark	Percent increase in timber price from benchmark
1	5	-
	10	-
	15	-
	20	-
2	-	5
	-	10
	-	15
	-	20
3	5	10
	10	15
	15	15
	20	20

Source: Experiments

4.4 Capitalized Values

The estimated water values by RV and MVP methods just give the static or one-time annual value of water. Assuming that the same water value is generated in perpetuity, then the capitalized value (V) can be given by a/r, where "a" is the constant future water value or income in perpetuity and "r" is the long-run interest rate (Barlowe, 1978, pp. 330-331). The capitalized values were computed for both ET and SFR water use estimated by RV and MVP methods.

4.5 Data Sources

The typical information required for the estimation of water values is the relationship between water and timber yield of selected species (pine and eucalyptus). This information was provided by a group of experts at the Institute of Commercial Forestry and Council of Scientific and Industrial Research. The costs and price data for the study were obtained from the Forestry Economics Services (1996). The entire analysis was done in terms of constant 1996 prices (1996=100).

Whether land cost should or should not be included, has been a controversial point. Economic theorists, in general, suggest that land cost should not be included. However, in this report, we have taken to other view, which recognizes land as an investment input which should be paid for. Here, water is defined as residual input. Our view is that this is more pragmatic approach in estimating the value of water in the commercial forestry.

The details of cost and timber prices used in the study are given in Appendix C. On the cost side, both fixed and variable costs were included. Fixed costs included cost of establishment, tending, land, interest on capital, management and administration cost, and others. Variable costs included costs of harvesting, loading, and transportation (for fuller details, see Appendix C). For the seven selected sites of eucalyptus and pines, both methods--RV and MVP--were used to derive the values on ET water use. The values to SFR use were estimated using the MVP method only, as the former was not applicable under the circumstances.

4.6 Summary

This Chapter covered six basic assumptions made in modelling the water valuation in commercial forestry in South Africa. Based on these assumptions, two empirical models, Residual Value and Marginal Value Product were employed for estimation. These methods approximated the net and gross average value of water, respectively. In addition, several extra scenarios were specified to examine the impact of changing price of timber, land rental, and other costs of production on water values. Furthermore, data sources and statistical techniques used in making adjustments in raw data were highlighted.

Chapter 5

Results and Discussions

The results of value analysis are presented and discussed here under three sections. The evapotranspiration (ET) water values for eucalyptus and pine, estimated by the Residual Value (RV) method, are discussed in section one. Sensitivity analysis of ET water values with respect to changing price and cost is also carried out in this section. In section two, the ET water values estimated by the Marginal Value Product (MVP) method are presented. The streamflow reduction (SFR) values are discussed in section three. A brief comparison of all water values is made in section four, followed by a summary of the chapter in section five.

5.1 Evapotranspiration (ET) Water Values by Residual Value (RV) Method for Eucalyptus and Pine

The ET water values for four eucalyptus sites are shown in Figure 5.1. A typical pattern in the water values is that they are negative in the beginning at low yield or water use level and become positive and rise as the yield or water use level rises. A similar pattern is seen in the capitalized values[1]. The range of positive ET water values for each site is given in Table 5.1. Note here that the first positive discrete value and the highest positive value are reported for all sites. The same pattern of reporting is followed in the rest of this chapter.

The ET Water values are highest in the KwaMbonambi site, ranging from R0.02 to R0.24 per cubic metre. The lowest water values are found for the Baynesfield site, ranging from R0.01 to R0.06 per cubic metre. The water value in Kia-Ora site ranges in between R0.01 and R0.10. For the Tanhurst site, the value falls in between R0.035 and R0.159

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[1] The capitalized value is actually the present value of future stream of benefits which are discounted with given interest rate (10 percent in this study).

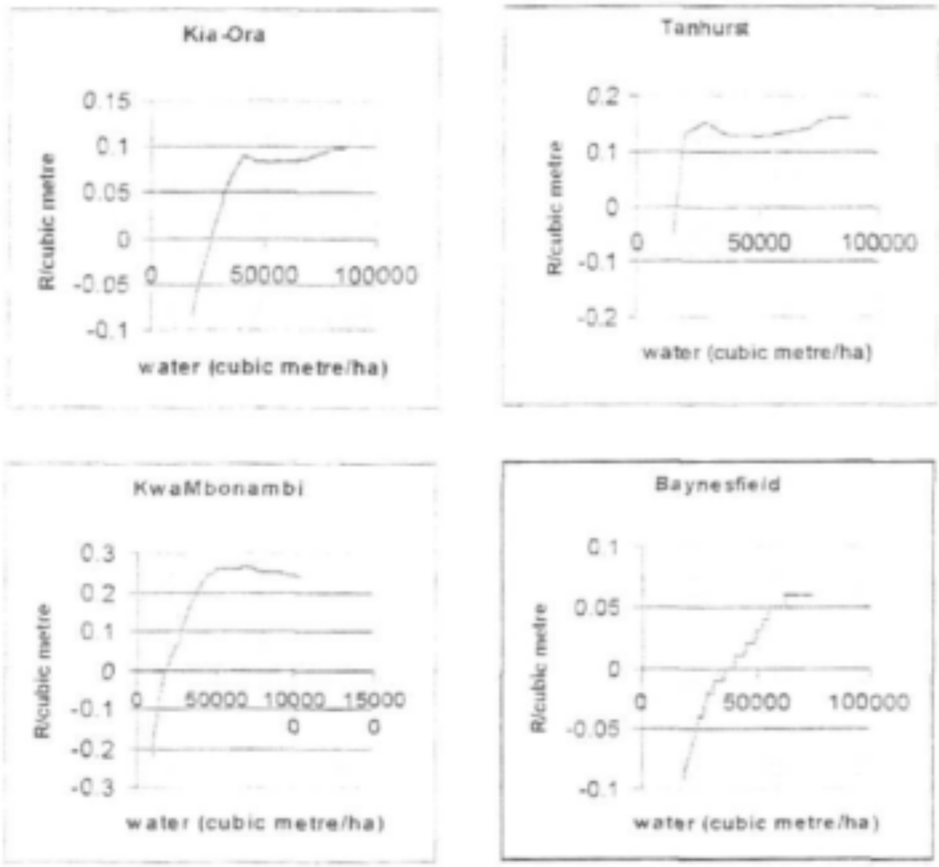

Figure 5.1: Evapotranspiration (ET) Water Values (R/cubic metre) for Four Eucalyptus Sites in KwaZulu-Natal in South Africa, Estimated by Residual Value (RV) Method

per cubic metre. The highest water values in KwaMbonambi site can be explained in the light of good weather/climate conditions for timber growth. This site is in Zululand area where higher temperature coupled with high rainfall contributes to fast growth in eucalyptus trees. By contrast, the Baynesfield is the driest site and rainfall level is low in this area, resulting into low water values falling between 1 and 6 cents per cubic metre. The mid-values of water indicate that the ET water values vary from R0.04 for the Baynesfield site to R0.013 per cubic metre for the KwaMbonambi site. However, the range of ET water value in the four sites is from R0.01 to R0.24 per cubic metre (Table 5.1).

Assuming that the continuous stream of benefits accrue in the future for an infinite time horizon, one can then estimate the capitalized value of water[2]. The capitalized ET water values for eucalyptus are shown in Figure 5.2. The capitalized value (both range and mid values) for all four sites of eucalyptus are given in Table 5.1 and are estimated using a 10 percent discount rate. The capitalized value for the KwaMbonambi site is highest as expected and ranges from R0.20 to R2.40 per cubic metre. For the Baynesfield site, the capitalized value falls in between R0.10 and R0.60 per cubic metre. For Tanhurst and Kia-Ora sites, the values fall in the range of R0.10 - 0.60 and R0.10 - 1.00 per cubic metre, respectively. The mid-capitalized-values (these are not necessarily the average values) for all sites are also reported in Table 5.1. A cursory examination of mid-values reveals that capitalized water values vary from as low as R0.40 per cubic metre on the Baynesfield to as high as R1.30 in KwaMbonambi site.

The ET water values for three pine sites are shown in Figure 5.3, followed by the capitalized values in Figure 5.4. The pine sites show a trend similar to eucalyptus. That is, water values are negative in the initial phase of growth of tree and turn positive as water use level rises. The range of positive values for each site, along with the capitalized values of the same, is given in Table 5.2. Interestingly enough, water values are very low relative to that of eucalyptus sites. The water values in all three-pine sites vary between

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[2] The capitalized value (V) with a constant future yield in perpetuity is given by a/r, where "a" is the constant future annual yield or income in perpetuity and "r" is the long –run interest rate. For details, Barlowe (1978: 330-331).

Table 5.1: Evapotranspiration (ET) Water Values for Eucalyptus Sites in KwaZulu-Natal, South Africa, Estimated by Residual Value (RV) Method

Name of Sites	Range of water values R/cubic metre/yr	Mid value R/cubic metre/yr	Range of capitalized values (at 10%) R/cubic metre	Mid capitalized value R/cubic metre
Kia –Ora	0.01-0.10	0.06	0.10-1.00	0.60
Tanhurst	0.035-0.159	0.10	0.35-1.59	1.00
KwaMbonambi	0.02-0.24	0.13	0.20-2.40	1.30
Baynesfield	0.01-0.06	0.04	0.10-0.60	0.40

Source: Estimated

Table 5.2: Evapotranspiration (ET) Water Values for Pine Sites in KwaZulu-Natal, South Africa, Estimated by Residual Value (RV) Method

Mid value	Range of water values R/cubic metre/yr	Mid value R/cubic metre/yr	Range of capitalized values(10 % discount rate) R/cubic metre	Mid capitalized value R/cubic metre
Richmond	0.001-0.025	0.013	0.01-0.25	0.13
Greytown	0.001-0.015	0.008	0.01-0.15	0.08
Usutu	0.003-0.058	0.031	0.03-0.58	0.31

Source: Estimated

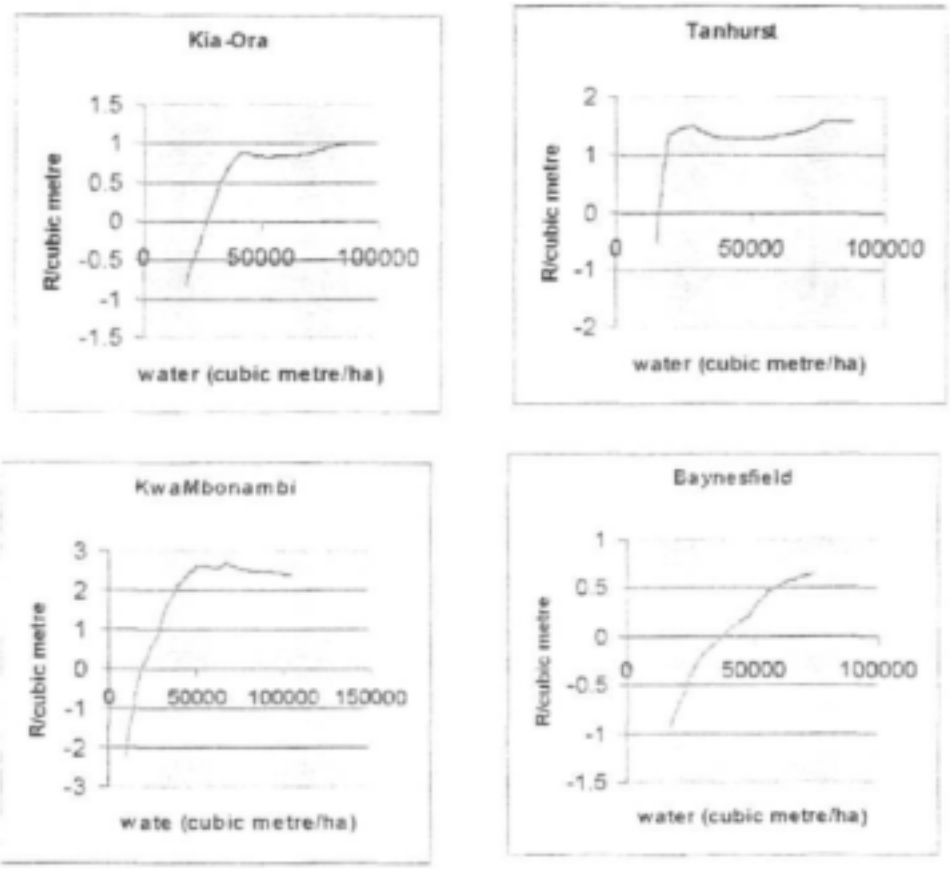

Figure 5.2: Evapotranspiration (ET) Water Capitalized Values (R/cubic metre) for Eucalyptus on Selected Sites in KwaZulu-Natal in South Africa

R0.001 and R0.058 per cubic metre--this is well below the values obtained for the eucalyptus sites. This phenomenon can be explained in terms of differential growth patterns of eucalyptus and pine species. For example, eucalyptus trees grow very fast and reach economic maturity around 10-12 years of age. On the other hand, pine trees grow more slowly and reach economic maturity much later around 25-30 years. Eucalyptus is thus more efficient user of water than pine.

A perusal of water values in eucalyptus and pine suggests that water values in eucalyptus be roughly ten times of the water values in pine. Among the pine sites, the water values are highest for the Usutu sites, ranging from R0.003 to R0.058 per cubic metre. Water values are lowest for the Greytown site, ranging from R0.001 to R0.015 per cubic metre. The values for Richmond site fall in between R0.001 and R0.025 per cubic metre. The mid values range from 0.08 cents per cubic metre for Greytown site to 3.1 cents per cubic meter for Usutu site (Table 5.2). The capitalized values for these sites are also given in Table 5.2. These are the lowest (R0.01 to R0.15) for the Greytown site, and the highest for Usutu site (R0.03 to 0.58). The mid capitalized value ranges from R0.08 to R0.31 per cubic metre (Table 5.2).

From the foregoing analysis of water values, we can take note of some salient points. Firstly, eucalyptus trees produce relatively higher economic benefits compared to the pine trees from the given level of water use. Eucalyptus trees are hence more efficient users of water. Secondly, water values also vary with the site. For example, a high rainfall site such as KwaMbonambi shows relatively far higher values compared to the driest site Baynesfield; the KwaMbonambi water values are roughly three times of the Baynesfield values. Thirdly, the capitalized values at 10 percent discount rate are between R0.40 and 1.30 for eucalyptus and between R0.08 and 0.31 for pine. This reconfirms the relative economic profitability of the eucalyptus species.

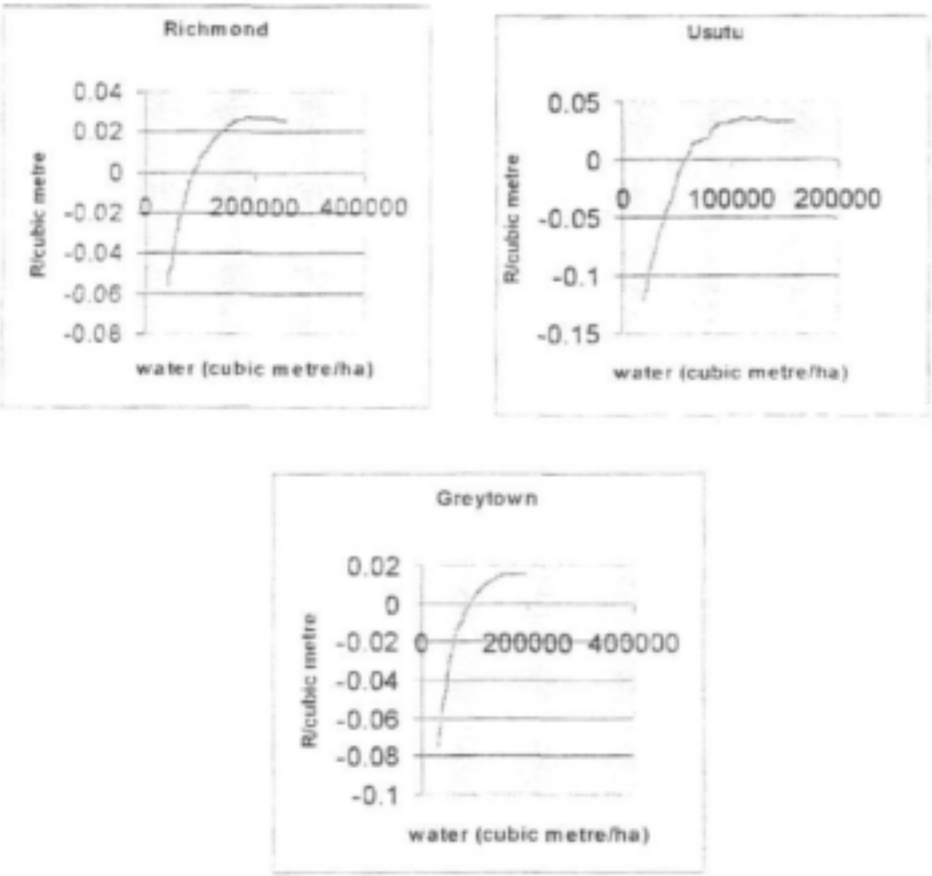

Figure 5.3: Evapotranspiration (ET) Water Values (R/cubic metre) for Pine on Selected Sites in KwaZulu-Natal in South Africa, Estimated by Residual Value (RV) Method

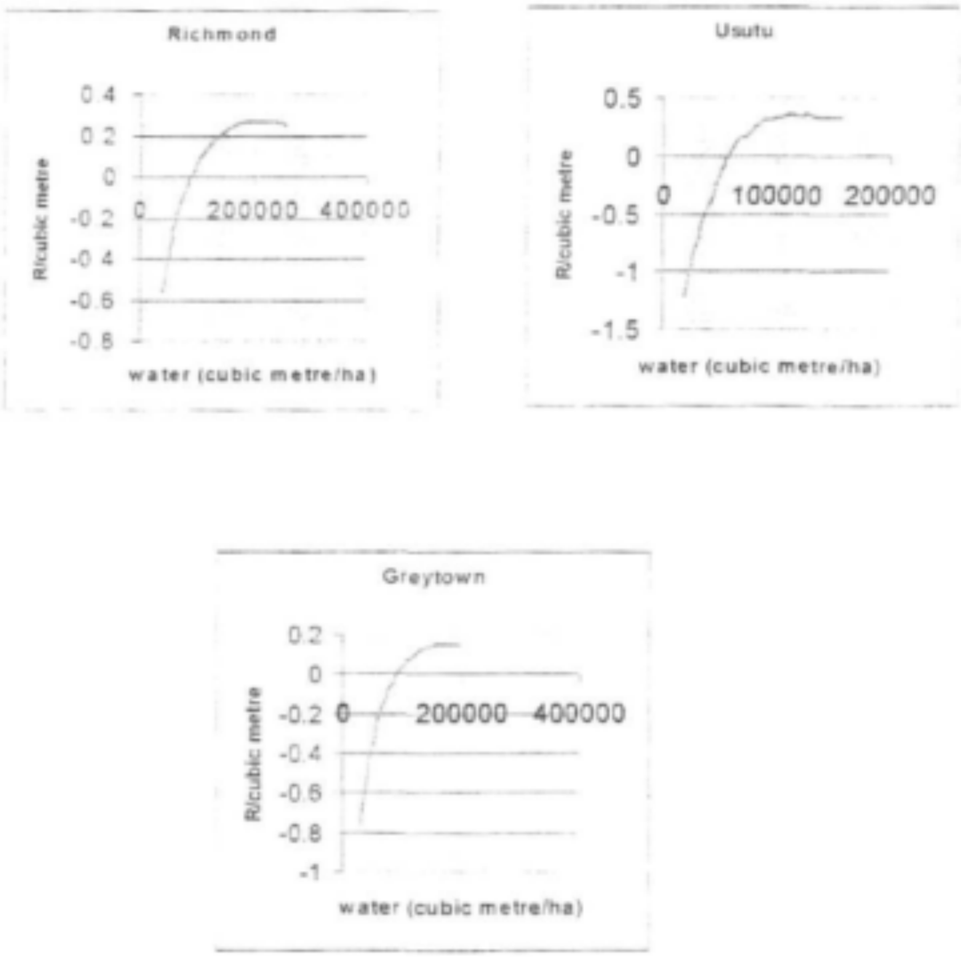

Figure 5.4: Evapotranspiration (ET) Water Capitalized Values (R/cubic metre) for Pine on Selected Sites in KwaZulu-Natal in South Africa

5.1.1 Sensitivity Analysis

The ET water values as discussed above are subject to change should the prices of timber or cost of production rise or fall. Increasing inflation may cause rising cost of production of timber, which ultimately would impact on water values. Similarly, fluctuating prices of timber in the national and international markets can also influence water values. To capture these variations, the sensitivity analysis was carried out and some probable scenarios were simulated. These included: (1) 5, 10, 15, and 20 percent increase in the cost from the benchmark level; (2) 5, 10, 15, 20 percent increase in the price of timber from the benchmark level; and (3) combinations of price and cost increases such as 5 percent increase in cost plus 10 percent increase in prices, and so on (See details of scenarios postulated in Chapter 4). A fourth scenario is simulated to see the impacts of exclusion of land costs on the water values.

The impacts of cost increases under four scenarios on the ET water values of eucalyptus and pine are given in Figures 5.5 and 5.6, respectively. A perusal of Figure 5.5 reveals that ET water values decline as cost is increased from 5 to 20 percent from the benchmark level. The magnitude of decrease is enhanced with the rise in the cost of production. For example, a 5 percent increase in the cost will reduce the maximal ET water value in Kia-Ora site from R0.10 to R0.09 per cubic metre. A 20 percent increase in the cost will bring down the maximal water value to R0.07 per cubic metre. Similarly for the KwaMbonabi site the maximal water values decline from R0.24 at the benchmark level to R0.20 per cubic metre (Figure 5.5). A similar pattern of water values is seen among the pine sites (Figure 5.6).

The price increase scenarios for eucalyptus and pine are shown in Figures 5.7 and 5.8, respectively. The combination scenarios (simultaneous change in price and cost) were also carried out. Results are found to be mixed as a price increase has a tendency to increase the water values, while a cost increase dampens it. The resultant impact depends upon the magnitude of changes in prices and costs. The major result that emanates from the sensitivity analysis is that fluctuation in prices and cost impact on the water values.

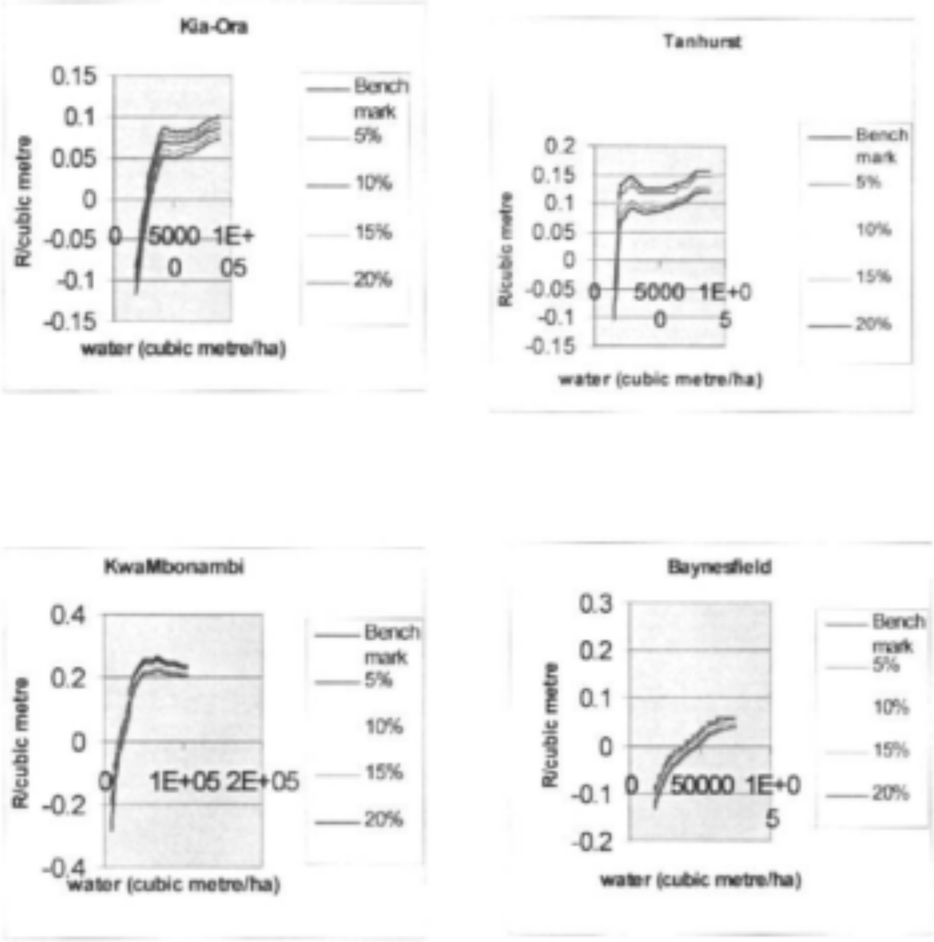

Figure 5.5: Impact of Cost Increases on the Evapotranspiration (ET) Water Values (R/cubic metre) for Selected Sites of Eucalyptus in KwaZulu-Natal in South Africa

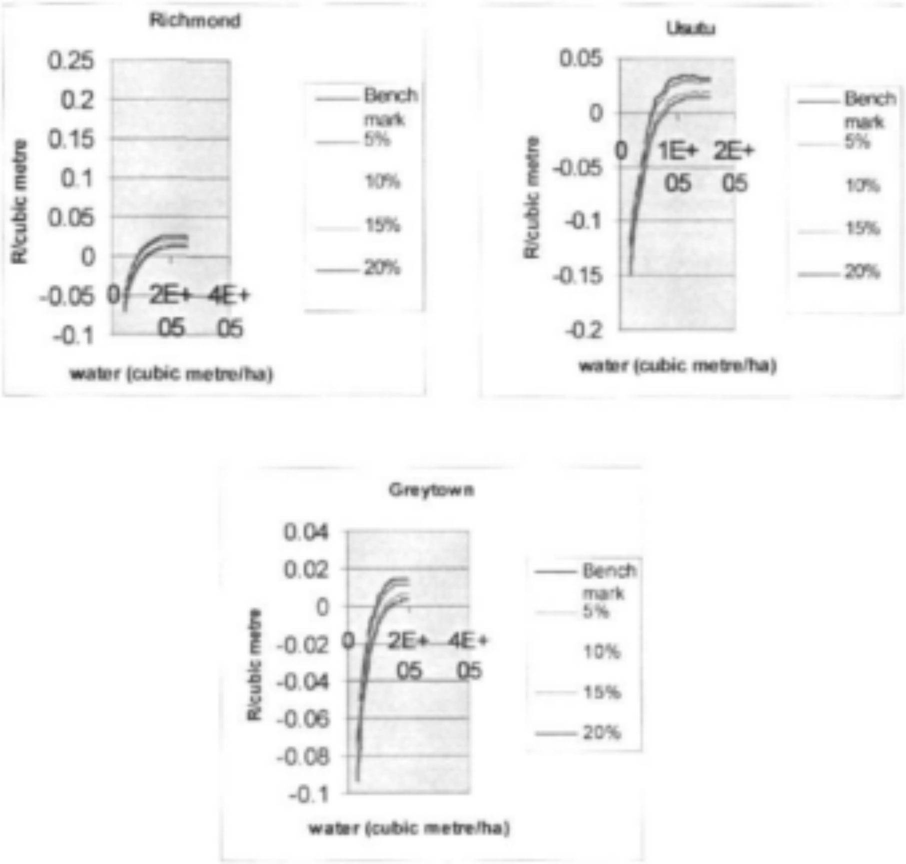

Figure 5.6: Impact of Cost Increases on the Evapotranspiration (ET) Water Values (R/cubic metre) for Selected Sites of Pine in KwaZulu-Natal in South Africa

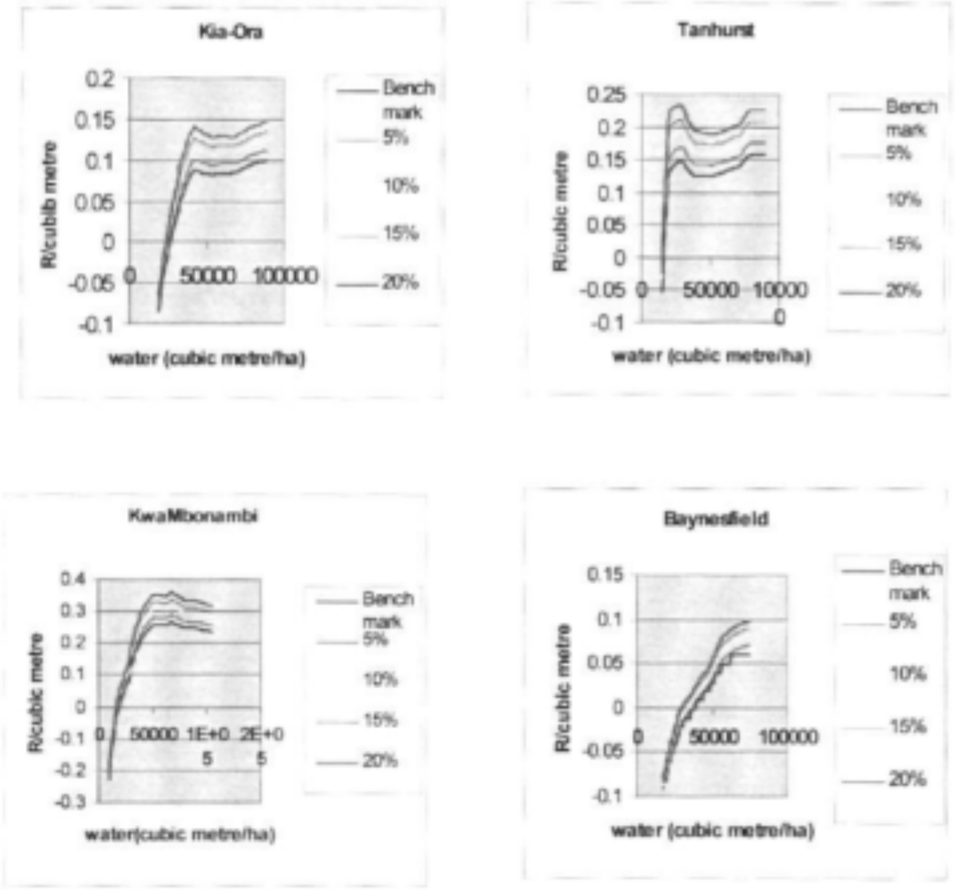

Figure 5.7: Impact of Price Increases on the Evapotranpiration (ET) Water Values (R/cubic metre) for Selected Sites of Eucalyptus in KwaZulu-Natal in South Africa

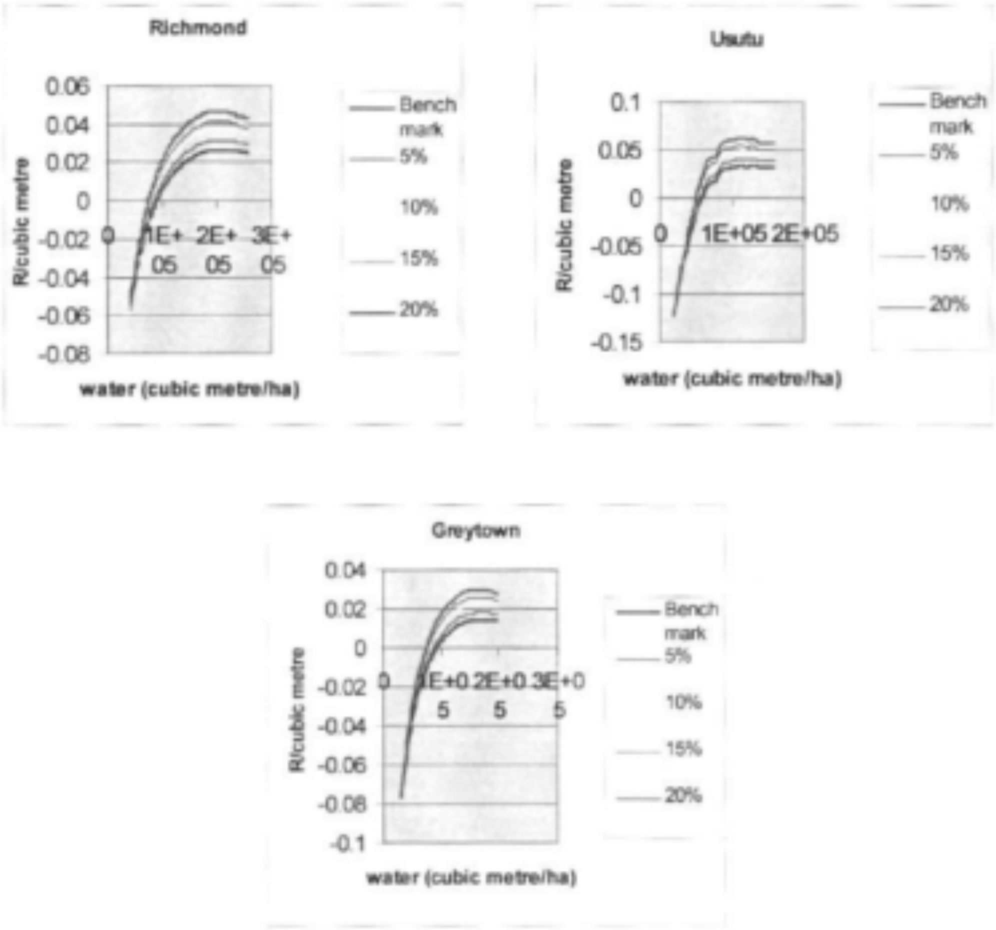

Figure 5.8: Impact of Price Increases on the Evapotranpiration (ET) Water Values (R/cubic metre) for Selected Sites of Pine in KwaZulu-Natal in South Africa

The impression that is formed from this analysis is that water values will be affected in the proportionate manner given the current data set.

The fourth scenario was simulated for two sites: Kia-Ora of Eucalyptus and Richmond of Pine. For these sites, water values were computed with and without land costs using the RV method. The differential in water values computed with and without land costs is computed; this amounts to an increase in the water values by 1 to 3 percent from the benchmark water values (benchmark water values were those which were computed including land cost). Over all, the inclusion of land costs in computing water values does not make a big difference. For details of calculations, see Appendix D.

5.2 Evapotranspiration (ET) Water Values by Marginal Value Product (MVP) Method for Eucalyptus and Pine

The ET values for both tree species were also computed using the MVP method. The range of ET water values estimated by the MVP method for all four sites of eucalyptus are given in Table 5.3. The water values are the highest for the KwaMbonambi site, ranging from R0.48 to R0.72 per cubic metre, with a mid value of R0.60 per cubic metre (Table 5.3). For the Tanhurst site, water values range between R0.23 and R0.27 per cubic metre, with a mid value of R0.25 per cubic metre. The Kia-Ora site has the second highest mid-value of R0.34 per cubic metre while the Baynesfield has the lowest value of R0.04 per cubic meter (Table 5.3). Looking at the capitalized values, we find the similar pattern except that they are higher as they reflect present value of future streams of benefits. The capitalized mid-values for all sites range from R0.41 per cubic metre for Baynesfield to R6.05 per cubic metre for the KwaMbonambi site (Table 5.3).

The ET water values by MVP method for all pine sites are reported in Table 5.4. The water values for all pine sites range between R0.09 to R0.26 per cubic metre (Table 5.4). The highest value (R0.16-0.26/cubic metre) is estimated for the Usutu site and the

Table 5.3: Evapotranspiration (ET) Water Values by the Marginal Value Product (MVP) Method for Eucalyptus Sites in KwaZulu-Natal, South Africa

Name of Sites	Range of water values R/cubic metre/yr	Mid value R/cubic metre/yr	Range of capitalized value R/cubic metre	Mid capitalized value R/cubic metre
Kia-Ora	0.28-0.39	0.34	2.83-3.91	3.37
Tanhurst	0.23-0.27	0.25	2.39-2.72	2.56
KwaMbonambi	0.48-0.72	0.60	4.89-7.20	6.05
Baynesfield	0.009-0.07	0.04	0.09-0.72	0.41
Average	0.25-0.36	0.31	2.55-3.64	3.10

Source: Estimation

Table 5.4: Evapotranspiration (ET) Water Values by the Marginal Value Product (MVP) Method for Pine Sites in KwaZulu-Natal, South Africa

Name of Sites	Range of water values R/cubic metre/yr	Mid value R/cubic metre/yr	Range of capitalized values R/cubic metre	Mid capitalized value R/cubic metre
Richmond	0.12-0.17	0.15	1.22-1.79	1.51
Greytown	0.09-0.13	0.11	0.95-1.39	1.17
Usutu	0.16-0.26	0.21	1.66-2.57	2.12
Average	0.12-0.19	0.16	1.28-1.92	1.60

Source: Estimation

lowest one (R0.09 to 0.13/cubic metre) is for Greytown site. A similar pattern is seen among the capitalized values. The capitalized mid-values for all sites range from R1.17 per cubic metre for Greytown to R2.12 per cubic metre for Usutu site. As before, water values for eucalyptus are much higher than that for the pine; this can be attributed to the differential growth patterns of eucalyptus and pine trees.

5.2.1 A Comparison of the Evapotranspiration (ET) Water Values Estimated by Residual Value (RV) and Marginal Value Product (MVP) Methods

A comparison of ET values obtained by the Residual Value and Marginal Value Product Methods is shown in Table 5.5. The ET water values estimated by MVP method are roughly 1 to 13 times of that estimated by the Residual Value Method. In the case of eucalyptus sites, the ET values by the MVP method are roughly 1 to 5 times higher, whereas in the case of pine sites, this is roughly 5 to 13 times higher (Table 5.5). The similar pattern is seen in the capitalized values (Table 5.5). The variation in ET water values across two types of estimation methods (RV and MVP) can be attributed to the method itself. The mathematical interpretation of the two methods is shown in Appendix E. The RV measures the residual net value attributed to water after paying for all other inputs in the production process; on the other hand, the MVP measures the value before other costs are paid off.

5.3 Streamflow Reduction (SFR) Water Values for Eucalyptus and Pine

The range for SFR values for eucalyptus sites are given in Table 5.6. As before, the SFR values are the highest for KwaMbonambi site, ranging in between R2.76 and R5.09 per cubic metre (Table 5.6). For Tanhurst site, the value ranges between R1.73 and R2.06 per cubic metre; while for the Kia-Ora site, it falls between R3.99 and R4.89 per cubic metre. The mid value estimates for all sites range from R1.90 to R4.44 per cubic metre.

The capitalized values are computed and their range is also given in the Table 5.6. The capitalized mid-values vary between R18.96 and R44.41 per cubic metre and are roughly 10 times of the simple SFR values.

Table 5.5: A Comparison of the Evapotranspiration (ET) Values (Mid-Value Estimates) by Residual Value (RV) and Marginal Value Product (MVP)Methods

ET Values				Capitalized ET values		
Name of Sites	ET value by RV method R/cubic metre/yr (1)	ET value by MVP method R/cubic metre/yr (2)	Ratio of (2) to (1)	Residual value method (R/cubic metre) (3)	Marginal value product method (R/cubic metre) (4)	Ratio of (4) to (3)
Eucalyptus						
Kia-Ora	0.06	0.34	5.7	0.60	3.37	4.6
Tanhurst	0.10	0.25	2.5	1.00	2.56	2.6
Kwambonambi	0.13	0.60	4.6	1.30	6.05	3.7
Baynesfield	0.04	0.04	1.0	0.40	0.41	1.0
Pine						
Richmond	0.013	0.15	11.5	0.13	1.51	10.6
Greytown	0.008	0.11	13.8	0.08	1.17	13.6
Usutu	0.031	0.21	6.8	0.31	2.12	1.8

Source: Estimation

The SFR values for pine sites are given in Table 5.7. For example, the SFR values for Richmond site fall between R1.03 and R1.51 per cubic metre, for Greytown it is between R1.78 and R2.61 per cubic metre; for Usutu the SFR values fall between R1.39 and R2.39 per cubic metre. The mid-value estimates are R1.27, 2.20, and R1.89 per cubic metre, respectively for Richmond, Greytown, and Usutu sites. The capitalization values show the similar pattern and are roughly ten times of the simple values. The capitalized mid-values range from R12.76 to R22.00 per cubic metre (Table 5.7).

Table 5.6: Streamflow Reduction (SFR) Values for Eucalyptus Sites in KwaZulu-Natal, South Africa

Name of Site	Range of values R/cubic metre/yr	Mid values R/cubic metre/yr	Range of capitalized (10% discount rate) values R/cubic metre	Mid capitalized value R/cubic metre
Kia-Ora	3.99 - 4.89	4.44	39.91 - 48.93	44.41
Tanhurst	1.73 - 2.06	1.90	17.31 - 20.65	18.96
KwaMbonambi	2.76 - 5.09	3.92	27.68 - 50.98	39.33
Baynesfield	--	--	--	--
Average	2.82 - 4.01	3.42	28.3 - 40.2	34.2

Source: Estimated

Table 5.7: Streamflow Reduction (SFR) Values for Pine Sites in KwaZulu-Natal, South Africa

Name of Sites	Range of values R/cubic metre/yr	Mid values R/cubic metre/yr	Range of capitalized (10 % discount rate) values R/cubic metre	Mid capitalized value R/cubic metre
Richmond	1.03 - 1.51	1.27	10.34 - 15.18	12.76
Greytown	1.78 - 2.61	2.20	17.89 - 26.11	22.00
Usutu	1.39 - 2.39	1.89	13.97 - 23.97	18.95
Average	1.4 - 2.17	1.79	14.07 - 21.74	17.9

Source: Estimated

5.4 A Brief Comparison of All Water Values

A comparison of water values across different methods of estimation and across different water use types is presented in Table 5.8. The estimated ET water values for eucalyptus by the MVP method vary from 4 cents to 34 cents per cubic metre, the average being 31 cents per cubic metre. On the other hand, the value estimates by the Residual Value method vary from 4 cents to 13 cents per cubic metre, average being 8 cents per cubic metre.

Table 5.8: A Comparison of Different Types of Water Values Estimated in the Current Study

	Annual Values			Capitalized values		
Name of Sites	ET value by RV method R/cubic metre/yr	ET value by MVP method R/cubic metre/yr	SFR value by MVP method R/cubic metre/yr	ET value by RV method R/cubic metre	ET value by MVP method R/cubic metre	SFR value by MVP method R/cubic metre
Eucalyptus						
Kia-Ora	0.06	0.34	4.44	0.66	3.37	44.41
Tanhurst	0.10	0.25	1.90	1.00	2.56	18.98
Kwambonambi	0.13	0.60	3.92	1.30	6.05	39.33
Baynesfield	0.04	0.04	--	0.40	0.41	--
Average	0.08	0.31	3.42	0.83	3.10	34.24
Pine						
Richmond	0.013	0.15	1.27	0.13	1.51	12.76
Greytown	0.008	0.11	2.20	0.08	1.17	22.00
Usutu	0.031	0.21	1.89	0.31	2.12	18.98
Average	0.017	0.15	1.79	0.17	1.6	17.90

Source: Estimated

Roughly speaking, the ET water values by the MVP method are two to four times of the values estimated by the RV method. The difference between the two can be attributed to the method itself as discussed earlier in this chapter. We can take marginal values as upper bounds and residual average values as lower bounds. The SFR values for eucalyptus vary between R1.90 and R4.44 per cubic metre, the average being R3.42 per cubic metre. This is roughly 10 times of the ET values estimated by the MVP method, and 40 times the ET values estimated by the RV method. The capitalized values for eucalyptus are also given in Table 5.8. Note that these represent the long-run values of water at 10 percent interest rate. The average capitalized value of ET water use comes to R0.83 and R3.10 per cubic metre respectively by the RV and MVP methods. The SFR value is R34.24 per cubic metre (Table 5.8).

The ET water values for pine by the RV method vary from 1.3 cents to 3.1 cents per cubic metre, the average being 1.7 cent per cubic metre. The ET water values by the MVP method range between 11 cents to 21 cents per cubic metre, the average being 15 cents per cubic metre. The ET water values by the MVP methods are roughly 9 times of the values estimated by the RV method. The SFR values range from R1.27 to R2.20 per cubic metre, the average being R1.79 per cubic metre. This is roughly 12 times of the ET value by MVP method and 100 times of the ET value by the RV method. The capitalization values for pine at 10 percent interest are also compared. The average ET water capitalized value by RV and MVP method is respectively R0.17 and R1.60 per cubic metre. The average SFR water capitalized value is R17.90 per cubic metre.

5.5 Summary

The results indicate a few general conclusions. Firstly, the SFR values are far higher than ET values. A rough guide line is that SFR values are approximately ten or more than ten times of the ET values; this holds true generally in the applicable range of annual rainfall of 1000 to 1200 mm (Based on discussion with Dr B. van Wilgen, CSIR, Stellenbosh). The similar results hold true for capitalized values estimated for ET and SFR use. Secondly, the water values for pine are way below the values estimated for eucalyptus.

For example, the average ET value for pine, estimated by MVP method, is about 15 cents per cubic metre as opposed to 31 cents per cubic metre for eucalyptus. This differential can be attributed to rapid growth of eucalyptus compared to slow growth of pine. Eucalyptus appears to be a more efficient user of water than pine. Furthermore, water values estimated in this study are site specific and indicate the efficiency of water use more than the scarcity of water per se. Thirdly, the value of water can vary with the prices of timber or its cost of production. The policy implications of these results are manifold and are discussed in Chapter 6.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Introduction and Objectives

With the passage of time, water has become a very scarce input. Rising world population, increasing industrial development, and increasing area under irrigated agriculture have brought about this change. For example, the world population increased from 1600 million in 1900 to about 6000 million in 2000--an increase of 275 percent within a century. In the same period, the irrigated acreage increased from 50 million hectares in 1900 to 250 million hectares in 2000--an increase of 400 percent; the fresh water withdrawal increased from 500 cubic kilometres per annum to more than 3500 cubic kilometres per annum--an increase of 700 percent over a period of hundred years or 7 percent per annum. Water is thus becoming a scarcer input throughout the world; South Africa is no exception to this. The per capita consumption of water in South Africa is now below 750 cubic metres per annum, which is way below the critical limit (1000 cubic metres per capita per person); this is finally expected to affect economic development and human health negatively.

The traditional approach to solve water scarcity problems has been in terms of increasing withdrawal or supply of water. This approach entailed new large-scale water transfers from one region to another or building dams on the rivers or lakes. However, the environmental costs of large-scale water infrastructure development came to the attention of policymakers in 1970s and thereafter. A world-wide movement stalled the development of such schemes. A change in water use planning took place in early 1990s and beyond. The major goal of this new approach was to meet water demand by making its use more efficient and put water to more productive uses, rather than increasing water withdrawals by investing in large structures. The non-structural approach to water management emphasizes more efficient use of water by re-allocating among existing uses. The new paradigm insists on "water use that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of hydrological cycle or ecological systems that depend on it (Gleick, 2000, p. 31). One important recommendation that emanates from this paradigm is that water should be used in accordance with the principle of equi-marginal return. The knowledge of water values thus becomes an important information for efficient management of water resource across various sectors. This paradigmatic shift has also occurred in South Africa, especially after the democratic transition in 1994. The new water law envisages water as an economic and social good and emphasizes water demand management. This principle is now being applied to all sectors of the economy, including the commercial forestry.

The research in the past six decades in South Africa indicates that water is the most important limiting input in the growth of alien trees such as eucalyptus, pine, and wattle. These trees use a lot of water through evapotranspiration (ET). This leads to reduction in the run-off or stream flow (SFR) from the afforested site. Both water uses-- ET and SFR--are intricately inter-related to each other; a rise in ET leads to a rise in SFR. Water use by commercial forestry through SFR use constitutes some 8 percent of total volume of utilizable water in South Africa. The SFR use is estimated to be around 1.4 billion cubic meters per annum--about 972.2 cubic meter/ha/yr. The ET use is expected to be almost ten times of the SFR use. Water is thus important and scarce input in the production process of commercial forestry.

The new water law requires that water should be used to achieve optimum, long-term environmentally sustainable social and economic benefit for the society from its use (Principle 7 of water law). Water is hence no more a free public good and every user is expected to pay for it so that rules of efficiency can be applied upon. The major objective of this study was to estimate the value of water use in commercial forestry with special reference to KwaZulu-Natal (KZN), besides other minor objectives such as discussion of water value modelling techniques, discussion of water use regulation policy, and so on.

6.2 Method of Analysis, Assumptions, and Data Sources

Theoretically speaking, the value of water or willingness to pay can be approximated from the area under the water demand curve. In practice, this can be operationalized in various ways, depending upon the data availability and other constraints. The major problem in valuing water use in commercial forestry was the absence of water markets as the rainfall is the free gift of nature. This necessitated resorting on to the knowledge of production economics. In this context, two methods were chosen: (1) Residual value (RV) method, and (2) Marginal Value Product (MVP) method.

The RV method is based on the premise that water is paid after all other inputs (both fixed and variable) in the production process of commercial forestry are paid off. The value of water is thus computed by subtracting total costs from total revenue and then dividing the residual value or profit by the quantity of water used. This is likened to the net value of water. On the other hand, the MVP method estimates the area under the MVP curve of water. The MVP curve can be obtained from the total product curve by obtaining the first partial derivative with respect to water use. For this purpose, a quadratic function was fitted through the water-timber yield data. The estimated function was used to generate the MVP functions. The area under the MVP curve was estimated through integration technique of calculus. Both methods--RV and MVP--were applied to derive ET water values; while the SFR values were estimated with the MVP method only.

In order to estimate the value of water use in selected areas of commercial forestry in South Africa, a number of assumptions were also made. Firstly, water values are estimated for eucalyptus and pine only as these two species make up some 91.9 percent of total forestry acreage in South Africa. Furthermore, among the various eucalyptus species, *E. grandis* is the most common one, constituting 73.3 percent of the total acreage under eucalyptus. Similarly, *Pinus patula* predominates among the pine species. Bearing these facts in mind, these two species, eucalypyus (*E. Grandis*) and pine (*P. patula*) were selected for estimating water values in commercial forestry, as they are fairly representative of the mix of the crop grown in the commercial forestry. Futhermore, only the production of both species based on pulpwood regime was chosen for estimating the water values. Secondly, the water values for the selected species were estimated for some selected representative sites, chosen by a team of forestry experts in the country. The team included scientists from the Institute of Commercial Forestry Research (ICFR) and from the council of Scientific and Industrial Research (CSIR). Most of these selected sites fall in KwaZulu-Natal or nearby localities and are considered to be representative of commercial forestry on the eastern coast. Thirdly, two types of water uses were defined: (1) evapotranspiration use or ET; and, (2) streamflow reduction use or SFR. The ET use refers to the total evaporative loss from forest stand, which includes transpiration from dry canopies, and evaporation from wet canopies or forest litter or the soil surface. On the other hand, the SFR use refers to the reduction in water yield from a catchment as a result of uptake of water by forest stands. This is based on a comparison of stream flows expected from catchment under forest and baseline vegetation (commonly taken to be the natural grassland vegetation in South Africa). Fourthly, the cost data for the study are for the year 1996. All computations of water values are thus in the 1996 prices. Furthermore, the price and cost estimates used in the study represent averages for KwaZulu-Natal.

Two important sets of data were required for this study: (1) water-timber yield relationship, and (2) cost and price data. The expert team provided the data on relationship between water use (ET or SFR) and timber yield. Water Research Commission (WRC) constituted the team of experts and team recommended four sites of eucalyptus and three sites of pine-- a total of seven sites. These sites included: (1) Kia-Ora; (2) Tanhurst; (3) KwaMbonambi; (4) Baynesfield; (5) Richmond; (6) Usutu; (7) Greytown. The cost and timber price data were obtained from the Forestry Economics Services (FES). For the seven selected sites of eucalyptus and pine, both methods-- RV and MVP-- were used to derive the values on ET water use. The values to SFR use were estimated using the MVP method only, as RV was not applicable and not relevant for the estimation of SFR. The detailed methodology of these methods is discussed in Chapter 4 of this study.

6.3 Estimated Water Values and Policy Implications

The estimated water values in commercial forestry in KwaZulu-Natal vary with the type of water use and the method of estimation. The estimated ET water values by the Residual Value method for eucalyptus sites vary from 4 cents to 13 cents per cubic metre; 4 cents per cubic metre in low rainfall area such Baynesfield site and 13 cents per cubic metre in high rainfall area such as KwaMbonambi site. The average value comes to 8 cents per cubic metre.

The ET value estimates for eucalyptus sites by the Marginal Value Product method vary from 4 to 60 cents per cubic metre; 4 cents for a low rainfall site Baynesfield and 60 cents for high rainfall site KwaMbonambi; the average value comes to 31 cents per cubic metre. It is interesting to note that ET values by Marginal Value Product method are roughly 4 times of that estimated by the Residual Value method. This difference can be attributed to the method itself; the Marginal Value Product method estimates the value before all costs toward inputs are paid off, whereas the RV method estimates the water values after paying for all other inputs (except water).

The streamflow reduction or SFR values for eucalyptus sites vary from R1.90 to R4.44 per cubic metre--the average being R3.42 per cubic metre. These are roughly 10 times of the ET values estimated by the Marginal Value Product method and 40 times of the ET values estimated by the Residual Value method.

Another interesting result is that water values (ET or SFR) for pine is much smaller than the values estimated for eucalyptus. For example, the average ET value for pine by the RV method comes to 1.7 cents per cubic metre and 15 cents per cubic metre by the MVP method. The average SFR value comes to R1.79 per cubic metre. The low water values for pine can be explained in terms of their slow and long maturity period as opposed to eucalyptus.

The results of this study can be used in multiple ways. Firstly, results can be used to evaluate whether tariffs charged/ proposed are reasonable. For example, the calculated catchment management charge, which comes at between 0.5 and 2.5 cents per cubic metre per annum (Pegram and Palme, 2001), is in line with the estimated values of water in this study. Secondly, water values can be used decide on allocation of water for expansion of forestry as compared to expansion of other land uses. Here, we need water values for other crops or other land uses. Thirdly, water values can also provide guide to evaluating which tree species should be located where for new projects (site selection). Fourthly, the information could also be used toward evaluating which tree species should be used for expansion at which sites (species selection).

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APPENDICES

APPENDIX A

The Relation between Timber Yield and Water Use for *Eucalyptus grandis* and *Pinus patula*

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22 June 2001

INTRODUCTION

The purpose of this report is to provide quantitative information on the relation between the timber yield and water use of *Eucalyptus grandis* and *Pinus patula*, respectively the most widely planted hardwood and softwood species in South Africa. This information is required as a basis for assessing the economics of water use by forests (WRC project 1133).

The relationship between yield and water use is relatively stable for many annual crops, where the pattern of plant development can be predicted with a high degree of certainty. By comparison, much recent work has shown that the relation may be highly variable in trees, where the pattern of growth, and particularly the allocation of assimilated carbon to above and below ground sinks, is significantly influenced by the level of stress experienced by the trees. The greater the stress, the more assimilated carbon is allocated to roots (Landsberg and Gower, 1997). Consequently, trees do not exhibit a constant water use efficiency where measured yields apply to above-ground growth, especially where the trees experience significant drought stress. It is important to recognize this variability in analyses of the economics of water use by forest plantations. The strategy here is to describe the range of water use efficiency encountered on forestry sites representing a wide range of growth potential. If efficiency of water use can be shown to be usefully correlated to site growth potential, this will provide a practical framework for analysing the variation in water use efficiency (WUE) on a broad spatial scale. We believe it is important that such analyses of WUE are based on data spanning a whole forest rotation, since WUE may vary greatly from year to year in response to varying rainfall (Dye, 2000).

There are various ways of expressing the relationship between timber yield and water use. Forest yields are traditionally expressed in terms of volume (cubic metres of harvestable wood per hectare). However, since this relationship is required to analyse the economics of timber grown predominantly for pulpwood (which is measured in units of mass), we assumed that mass is the more appropriate measure in this study. Where growth data were expressed in volume units, these were converted to dry mass by assuming a wood density of 500 kg per cubic metre of wood for *Eucalyptus grandis* (Coetzee, 1998) and 380 for *Pinus patula* (Morris, 1992; Zwolinski *et al.*, 1997).

The steering committee for this project recommended that water use be expressed in two ways:

- For the purpose of direct comparison to alternative crops, as actual evapotranspiration, i.e. the total evaporative loss from forest stands. This includes transpiration from dry canopies, and evaporation from wet canopies and forest litter or the soil surface.

- For the purpose of assessing forest impacts on catchment water yields, as streamflow reduction. This is expressed in units of mm equivalent depth of water, and is based on a comparison of streamflows expected from catchments under forest and a baseline vegetation (commonly taken to be natural grassland in South Africa).

RELATING FOREST YIELDS TO ACTUAL EVAPOTRANSPIRATION

Suitable data for these analyses were sought from research trials, where annual growth and rainfall measurements are most likely to be available. Four ICFR *Eucalyptus grandis* espacement trials situated in different localities in KwaZulu-Natal (KwaMbonambi, Tanhurst, Kia-Ora and Baynesfield; Figure 1; Table 1) were judged to be highly suitable for this analysis, covering the range of site index and MAP commonly encountered in KwaZulu-Natal. Several other advantages to using the data from these trials were recognised:

- Effective weed control took place at all sites. This hastened the development of a closed forest canopy at these sites, and ensured that the trees did not have to compete with understorey plants for soil water.

- The trials were situated on relatively flat uniform ground, where lateral flow of water as overland flow or sub-surface movement was minimized. These conditions favour the assumption made in the analyses that annual evapotranspiration at these sites is very similar to recorded annual rainfall. As *Eucalyptus* trees are known to be very deep rooted, the possibility exists that these trees may gain access to deep reserves of accumulated soil water where the permeable subsoils are deep. This was judged to be a possibility at the kwaMbonambi and Tanhurst sites, where some evidence of soil water carryover from the previous year has been demonstrated (Dye, 2000) or is suggested by Figure 2. However, in this analysis of whole-rotation growth trends and cumulative ET, this source of error declines in significance.

- The range of MAP at the sites (822 to 1102 mm) is well below the maximum potential annual water use by forests (1500 to 1600 mm). It is unlikely therefore

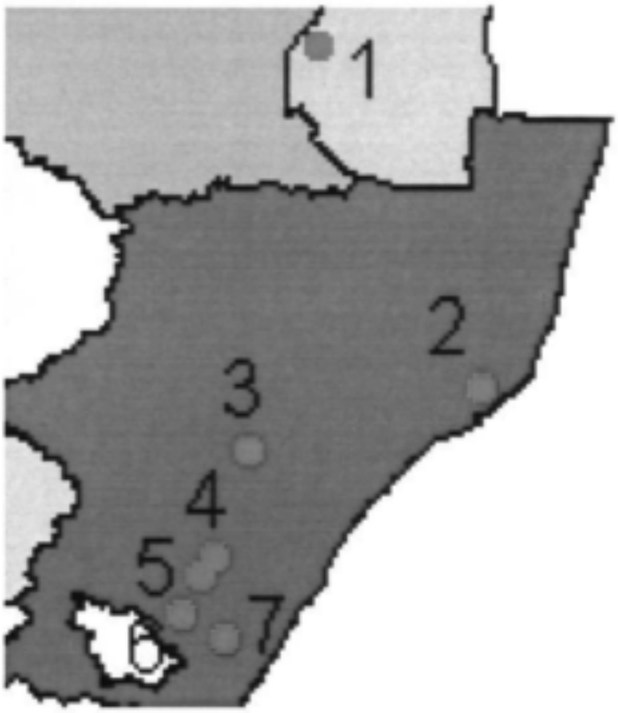

Figure 1. The location of the trial sites described in Table 1. (1- Usutu; 2 – KwaMbonambi; 3 – Greytown; 4 – Baynesfield; 5 – Richmond; 6 – Kia-Ora; 7 – Tanhurst).

that significant amounts of annual rainfall remain unutilised within the rooting zone.

- A typical pulpwood management regime was applied to all the trial plots. Complexities arising from periodic thinning were therefore avoided.

Annual surveys of the diameter and heights of trees at each trial site were converted to estimates of harvestable volume (Coetzee and Naicker, 1998). We selected mean annual volume growth data recorded from three replicate plots planted at an initial espacement of 1667 stems per hectare. Volumes were converted to mass, assuming a wood density of 500 kg dry mass per cubic metre of timber (Coetzee, 1998).

Table 1. Site information pertaining to the *Eucalyptus* and pine sites

Trial	Coordinates Lat/Long	Altitude (m)	MAT (°C)	MAP (mm)	Peak MAI ($m^3 ha^{-1}$)	Site Index (age may vary)	Soil form
Kwambo	28° 38' 09" 32° 05' 08"	50	21.6	1102	55	25-26 (5 years)	Fernwood
Tanhurst	30° 17' 42" 30° 26' 08"	610	18.1	962	35	20-21 (5 years)	Inanda
Kia-Ora	30° 06' 32" 30° 08' 40"	780	17.4	822	22	15-16 (5 years)	Hutton
Baynesfield	29° 45' 04" 30° 21' 10"	841	17.9	834	15	13-14 (5 years)	Hutton
Usutu	26° 25' 31° 00'	1440	16.6	1124	23.4	19.2 (15 years)	Inanda
Greytown area	-	1300	15.8	1025	20	22.8 (20 years)	Inanda/Kranskop
Richmond area	-	1300	15.8	786	12	18.8 (20 years)	Glenrosa

MAT = mean annual temperature
MAP = mean annual precipitation
MAI = mean annual volume increment
Site index = the mean height (m) of the 20% of trees with the largest diameters at the stated tree age.

Figure 2 illustrates the plots of cumulative growth against cumulative evapotranspiration (considered equal to annual rainfall recorded in nearby gauges). There is an obvious correlation between site growth potential (expressed as mean annual volume increment) and the efficiency of water use, with lowest efficiency evident on the poorest sites. The pattern of growth at the most favourable site (KwaMbonambi) appears to be largely unchecked by droughts, and displays a typical slow decline towards the end of the rotation. The effects of rainfall variability are far more apparent in the Tanhurst, Kia-Ora and Baynesfield data. At Kia-Ora, a drought in the fifth year of measurement caused the efficiency of water use to drop significantly, due to very poor growth in this year. Recovery took place over several subsequent years. Interestingly, a severe drought at Tanhurst in the third year of measurement had the opposite effect,

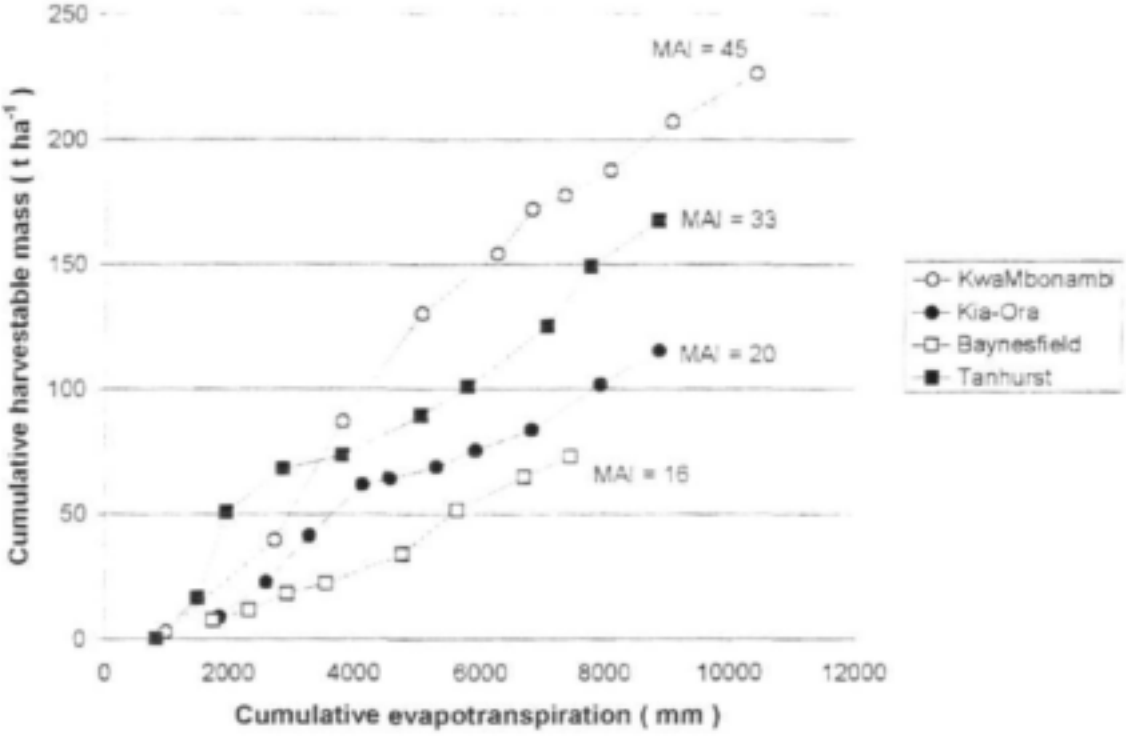

Figure 2. The relation between cumulative evapotranspiration and cumulative harvestable mass of timber at the four *Eucalyptus* sites.

with a large growth increment being recorded in a year of low rainfall. One possible hypothesis is that the deepening root systems of these young trees accessed reserves of deep soil water accumulated in prior years. This phenomenon has been observed before (Dye *et al*, 1997).

Locating suitable data for stands of *Pinus patula* proved more difficult. One data set describing an espacement trial site in Usutu forest was available (Morris, 1995a; Morris, 1995b). A rainfall record from Nerston Police station was used in this analysis. It covers all but the last half-year of the 15 year growth record. Mean monthly rainfall totals were used to patch missing data. Mean annual precipitation (MAP) at the trial site was estimated to be 1124 mm (Rob Guy, Pers. Comm.), compared to 1008 mm recorded for

Nerston (Midgley, *et al.*, 1994). Consequently the Nerston annual rainfall figures were scaled up by a factor of 1.115. In the absence of further annual data sets for this species, we made use of yield tables for *P. patula* pulpwood rotations reported by Kassier and Kotze (2000). These authors list annual growth rates typical of trees planted at an initial density of 1200 trees per hectare, for a low, medium and high growth potential site. The low and medium sites represent the range of growth potential commonly encountered in KwaZulu-Natal, and were used in the analysis. As in the *Eucalyptus* analyses, volumes were converted to mass. A classification of land types in KwaZulu-Natal (Pallett and Mitchell, 1993) was used to select sites where the two *P. patula* growth potentials are typically found. Representative sites were deemed to be Greytown (low site index, MAI = 10-12, MAP = 786 mm, Land type 334) and Richmond (high site index, MAI = 16-20, MAP = 1025 mm, Land type 325). MAP for these sites (Table 1) was used to estimate cumulative ET. Figure 3 shows a plot of cumulative ET versus cumulative mass of harvestable timber. Once again, efficiency of water use is positively correlated to the growth potential of the site. Two further data points have been added to Figure 3. Zwolinski *et al.* (1997) report final yields and MAP for a range of *P. patula* sites in the vicinity of Maclear and Ugie in the North East Cape. Two sites (identified as sites 1 and 7 in their report) confirm the correlation between site growth potential and efficiency of water use shown by the annual data sets. The trend lines suggest less scatter in the early years of the rotation than in the *Eucalyptus* data, probably reflecting the slower canopy development in pines, as well as the tendency for *Eucalyptus* trees to be planted in marginal forestry sites. The trends in Figure 3 also suggest a more marked difference in water use efficiency later in the rotation, perhaps as growth becomes increasingly restricted at the poorer site by lower MAP.

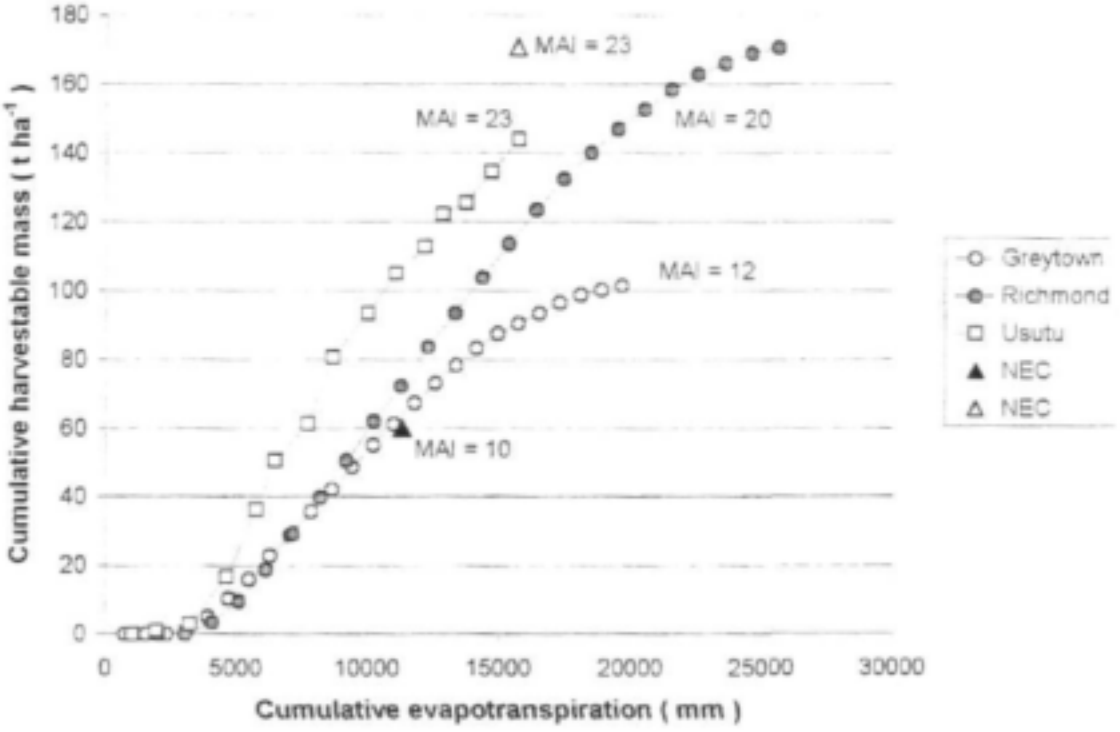

Figure 3. The relation between cumulative evapotranspiration and cumulative harvestable mass of timber at five representative *Pinus patula* sites.

ROTATION-AVERAGE EFFICIENCY OF WATER USE

A convenient measure of the efficiency of water use at all the sites is the quotient of the end-of-rotation harvestable dry mass and the cumulative mass of water lost through evapotranspiration. One mm of water over a hectare equates to a mass of 10 tonnes. In Table 2 we convert the rotation-long cumulative ET from units of mm to tonnes, and express efficiency of water use as tonnes of rotation-end harvestable wood per tonne of water evapotranspired.

Comparisons of water use efficiency among crops may also be made on the basis of crop yield and transpiration. This approach excludes the loss of water evaporated from the surfaces of wet leaves and forest litter. Some experimental data on the interception of rainfall by canopies of *Eucalyptus grandis* and *Pinus patula* (Dye and Versfeld, 1991; Dye and Versfeld, 1992) indicated a canopy interception loss (gross rainfall minus throughfall and stemflow) of approximately 4% and 13% respectively. Interception losses by the litter layer are less well understood: a loss of 4 % is believed to be realistic (Dye and Mostert, 1994) for the sites included in this study. Table 3 summarises the efficiency of water use at the sites, where water use is now defined as the quantity of water transpired by the trees.

Table 2. A summary of growth, water use (**ET**) and efficiency of water use recorded at the *Eucalyptus* and pine sites.

Site	End of rotation harvestable wood (t ha^{-1})	End of rotation cumulative ET (mm)	End of rotation cumulative ET (t ha^{-1})	Tonnes of harvestable wood per tonne of water used (ET)
Kwambonambi	226	10431	104310	$2.17 * 10^{-3}$
Tanhurst	168	8851	88510	$1.9 * 10^{-3}$
Kia-Ora	115	8882	88820	$1.29 * 10^{-3}$
Baynesfield	73	7444	74440	$9.81 * 10^{-4}$
Usutu	144	15723	157230	$9.16 * 10^{-4}$
Richmond	171	25625	256250	$6.67 * 10^{-4}$
Greytown	101	19650	196500	$5.14 * 10^{-4}$

Table 3. A summary of growth, water use (**transpiration**) and efficiency of water use recorded at the *Eucalyptus* and pine sites.

Site	End of rotation harvestable wood (t ha^{-1})	End of rotation cumulative transpiration (mm)	End of rotation cumulative transpiration (t ha^{-1})	Tonnes of harvestable wood per tonne of water transpired
Kwambonambi	226	9597	95970	$2.35 * 10^{-3}$
Tanhurst	168	8143	81430	$2.06 * 10^{-3}$
Kia-Ora	115	8171	81710	$1.41 * 10^{-3}$
Baynesfield	73	6848	68480	$1.07 * 10^{-3}$
Usutu	144	13050	130500	$1.10 * 10^{-3}$
Richmond	171	21289	212890	$8.03 * 10^{-4}$
Greytown	101	16325	163250	$6.19 * 10^{-4}$

RELATING FOREST YIELDS TO STREAMFLOW REDUCTION

The previous section reports data that are suitable for direct comparison to other crops. It is important, however, to also express timber yields in terms of the likely reduction in streamflow caused by the presence of the forest plantation. This catchment-scale measure of forest hydrological impact is useful in planning land use and water allocation in catchments where water supply is insufficient to meet demand.

This analysis requires quantifying the streamflow reduction caused by replacing baseline vegetation in a catchment with forest plantations. Indigenous grassland is considered to be the most appropriate baseline vegetation for most of the higher rainfall regions of KwaZulu-Natal. We make the assumption that the difference in annual evapotranspiration between grassland and forest plantation closely approximates the change in catchment water yield, after a period of hydrological equilibration following the land use conversion. Evapotranspiration and streamflow account for nearly all of the loss of water from catchments; change in one result in a reciprocal change in the other. This assumes that catchment leakage, as well as annual changes in soil water storage, is negligible.

In estimating the evaporative loss of water from afforested catchments, it is no longer possible to assume that all rainfall recorded at a site is ultimately lost as evapotranspiration. Areas of saturated or near-saturated riparian soil have little soil water storage capacity and readily shed water to the stream, especially after significant rainfall. These zones are fed by laterally moving soil water, especially from steep slopes and shallow soils. Catchments show great variation in their physical attributes, and their hydrological characteristics are similarly varied.

The strategy followed here is to use available catchment data to estimate the change in ET, and therefore streamflow reduction, that would occur at each of the forestry sites. Table 4 lists recorded MAP and mean annual runoff (MAR) reported by Schulze (1979) and Smithers and Schulze (1994), for a selection of catchments of varying size in the Natal Drakensberg and adjacent highlands. The vegetation in these catchments is predominantly or wholly grassland. Figure 4 shows that annual ET from these grassland catchments is variable, but nevertheless defines a distinct trend, ranging between 600 and 800 mm, and increasing with increasing MAP. Also shown in this Figure is a curve published by Nänni (1970) relating annual runoff from KwaZulu-Natal upland grassland to annual rainfall. Correspondence is reasonably good. The lower section of the Nänni curve was based on a similar curve described by Midgley and Pitman (1969). Schulze (1979) compared this Midgley and Pitman curve to a wide range of Drakensberg catchment data, and showed that it underestimated streamflow in

Table 4. A summary of mean annual precipitation (MAP), mean annual runoff (MAR) and estimated mean annual ET for catchments in the Natal Drakensberg and adjacent areas (Schulze, 1979; Smithers and Schulze, 1994).

Weir	Catchment area (km^2)	MAP (mm)	MAR (mm)	Estimated annual ET (mm)	Years of record used
V1M01	4176	991	226	765	26
V1M02	1689	1036	388	648	14
V1M09	196	697	105	592	17
CP1	0.49	1381	561	829	25
CP3	1.39	1515	663	863	24
CP4	0.95	1376	733	744	27
CP6	0.68	1219	523	696	22
CP7	0.45	1305	535	770	20
CP9	0.65	1216	535	681	20
CP10	0.73	1293	595	787	20
V2M02	937	986	378	608	25
T5M03	140	1084	382	702	19
T5M04	545	1126	433	693	25
T5M07	3586	1010	263	747	13
T3M02	2101	895	154	741	18
T3M04	1029	733	102	631	21
V1H015	1.03	915	114	801	15
V1H019	14.64	798	87	711	15
V1H028	0.41	848	141	707	15
V7H003	0.43	858	203	655	15

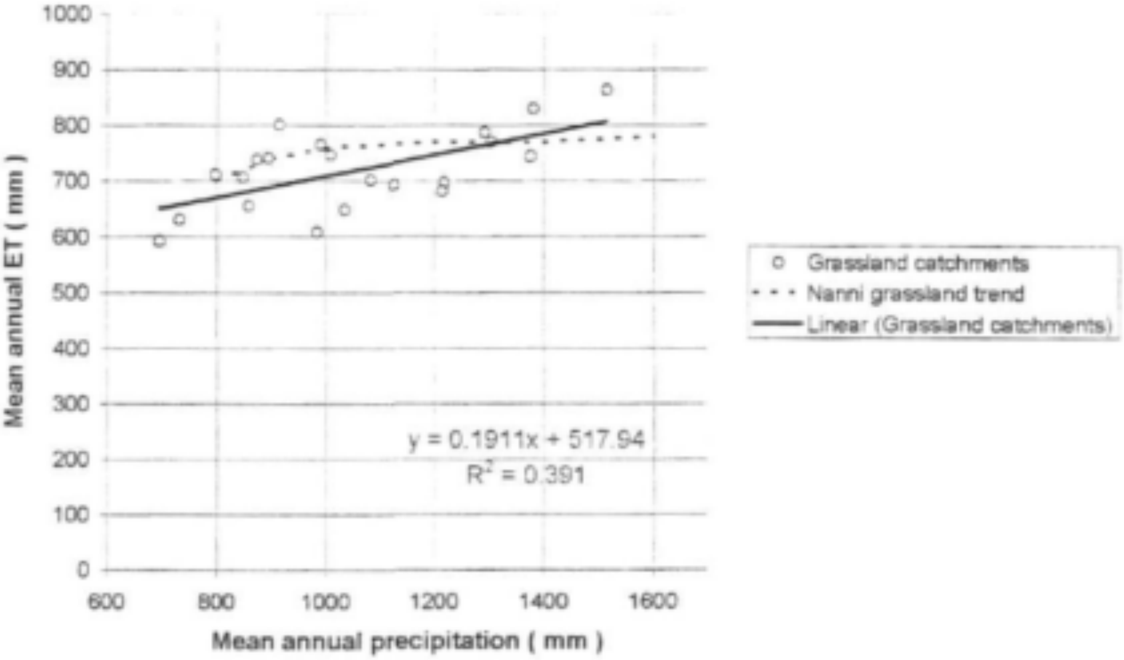

Figure 4. The relation between estimated mean annual ET and MAP for a selection of predominantly grassland catchments in the Drakensberg and adjacent uplands areas.

the lower range of MAP. Consequently, the trend based on the data in table 4 is regarded as the more accurate one.

Deriving a comparable trend for afforested catchments is much more difficult, since the hydrological influence of forest plantations varies significantly during the course of a rotation. Effects on streamflow are minimal in the period shortly after planting, when the tree canopies are still small and leaf area index (LAI) is low. Both LAI and ET increase to a peak as the trees mature, but may decline towards the end of the rotation as the trees enter a period of physiological decline. The consequences of these changes in forest structure and physiology are clearly seen in streamflow time series data recorded in research catchments (Scott *et al.*, 2000).

Nänni (1970) published a nomogram in which he illustrated three curves depicting the annual decrease in runoff from catchments afforested with *Pinus patula* in the Cathedral Peak area. The curves apply to three plantation situations: mature trees (curve A), trees grown over a 40 year rotation (curve B), and trees grown over a 15-year rotation (curve C). Streamflow reductions are least for the 15-year rotation, since the initial period of small canopy size and low ET is a relatively large fraction of the total rotation period. This same period is a smaller fraction of a 40-year rotation, hence the overall higher ET and greater streamflow reduction by long-rotation plantations. Greatest streamflow reduction is shown by mature trees over shorter periods corresponding to maximum leaf area development and physiological activity. These three lines are shown in Figure 5. Their validity is supported by the fact that they encompass a global forest ET trend calculated from a very wide range of forest catchments by Zhang (1999).

For the purpose of this report, streamflow reductions by *Pinus patula* are calculated as the difference in ET between the grassland baseline and the Nänni curve C applicable to 15-year rotations for this species. The majority of plantings in the regions of the sample sites in this analysis are managed for pulpwood and are therefore grown for the shorter rotation period.

Data from several *Eucalyptus* catchments in South Africa and Australia are also shown in Figure 5. Estimated ET in the Mokobulaan catchment is especially high, but is believed to be due to significant leakage of ground water past the weir. The remaining data points suggest that the global forestry trend is likely to be an adequate, but perhaps slightly underestimated reflection of the average ET from *Eucalyptus* catchments.

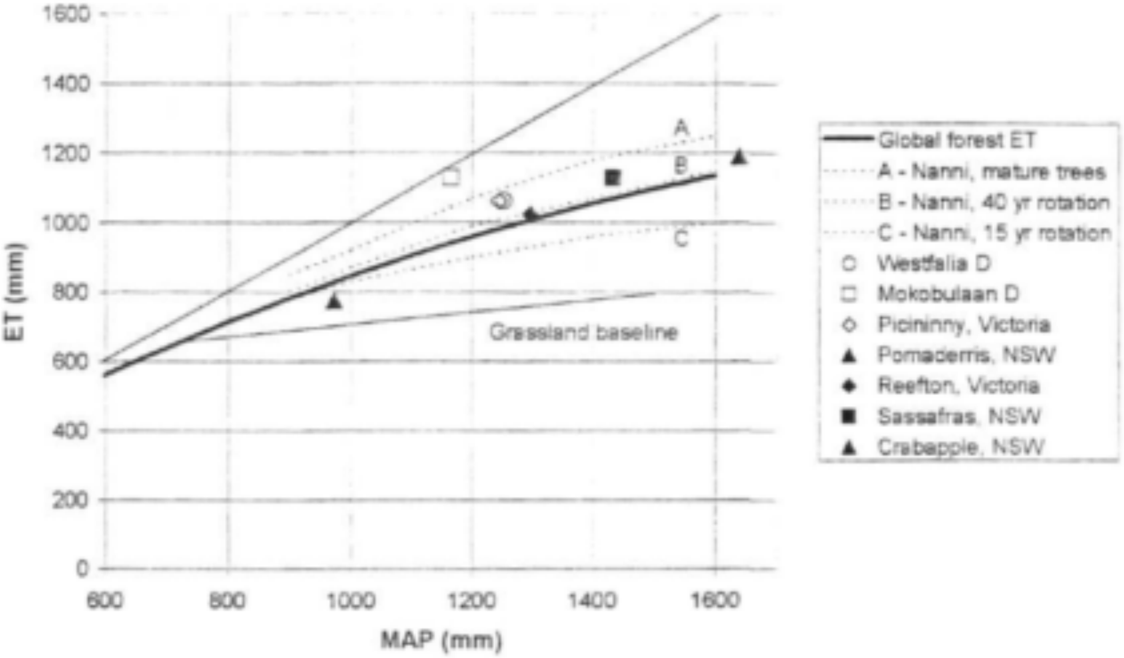

Figure 5. Trends in grassland and afforested catchment ET defined by the grassland catchments listed in Table 4. and the Nänni (1970) nomogram applicable to *Pinus patula*. Selected *Eucalyptus* catchment data are also shown.

The grassland and forest trend lines are used to estimate the difference in annual ET between afforested catchments and grassland catchments on the basis of the mean annual rainfall associated with each trial site or land type category used in the earlier analysis. These estimates are summarised in Table 5.

Table 5. Estimated grassland and forest evapotranspiration, and streamflow reduction, at each site.

Species	Location	MAP (mm)	Grassland ET (mm yr^{-1})	Rotation-average forest ET (mm yr^{-1})	Streamflow reduction (mm yr^{-1})
Eucalyptus grandis	KwaMbonambi	1102	729	904	175
	Tanhurst	962	702	820	118
	Kia-Ora	822	675	726	51
	Baynesfield	834	677	735	58
Pinus patula	Usutu	1124	733	860	127
	Richmond	1025	714	835	121
	Greytown	786	668	710	42

PATTERNS OF STREAMFLOW REDUCTION OVER A FORESTRY ROTATION

Year-by-year streamflow reductions following a change from grassland or fynbos vegetation to plantation forests have been recorded and analysed in a variety of hydrological research catchments (Scott *et al.*, 2000). General streamflow reduction curves linking streamflow reduction to plantation age, and applying to optimal and sub-optimal growth of *E. grandis* and *P. patula*, have been published (Scott and Smith, 1997). There is some uncertainty, however, as to whether these curves would apply in catchments under continuous forestry production, where successive rotations occur without significant fallow period in between. This is the case in the vast majority of forestry sites in South Africa. There is evidence from the Mokobulaan catchments that four or more years of soil water recharge following clearfelling may be required before a grassland hydrological equilibrium is achieved (Scott and Lesch, 1997). If adequate recharge is curtailed by the quick development of the next rotation of trees, the streamflow reduction would show less variability than inferred by the trends characteristic of catchments under a first rotation.

We believe that it is more appropriate in this study for the calculation of streamflow reduction to be based on a comparison of "equilibrium" grassland and "equilibrium" forest situations, thereby avoiding having to make assumptions about the short-term dynamics of the catchment water balance that are likely to be specific to catchments and land-use management regimes. We recommend that a constant streamflow reduction be assumed for a given site, based on its MAP and the curves depicted in Figure 5.

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Appendix 1

KwaMbonambi (*Eucalyptus grandis*) MAI = 45 m^3 ha^{-1}						
Tree age (yrs)	Harvestable cumulative volume (m^3 ha^{-1})	Harvestable cumulative mass (t ha^{-1})	Total annual rainfall (mm)	Cumulative estimated ET (mm)	Cumulative estimated transpiration (mm)	Cumulative estimated streamflow reduction (mm)
1	6	3	993	993	914	175
2	79.1	39.6	1746	2739	2520	350
3	173.7	86.9	1085	3824	3518	525
4	260.8	130.4	1261	5085	4678	700
5	308.6	154.3	1174	6259	5758	875
6	344.2	172.1	552	6811	6266	1050
7	355.5	177.7	533	7344	6756	1225
8	375.4	187.7	738	8082	7435	1400
9	414.5	207.2	988	9070	8344	1575
10	452.9	226.4	1361	10431	9597	1750

Tanhurst (*Eucalyptus grandis*) MAI = 33 m^3 ha^{-1}

Tree age (yrs)	Harvestable cumulative volume (m^3 ha^{-1})	Harvestable cumulative mass (t ha^{-1})	Total annual rainfall (mm)	Cumulative estimated ET (mm)	Cumulative estimated transpiration (mm)	Cumulative estimated streamflow reduction (mm)
1			843	843	776	118
2	33.0	16.5	663	1506	1386	236
3	101.8	50.9	462	1968	1811	354
4	136.3	68.1	907	2875	2645	472
5	146.9	73.4	939	3814	3509	590
6	179.0	89.5	1257	5071	4665	708e
7	201.8	100.9	730	5801	5337	826
8	250.7	125.3	1266	7067	6502	944
9	298.3	149.1	693	7760	7139	1062
10	335.0	167.5	1091	8851	8143	1180

Kia-Ora (*Eucalyptus grandis*) MAI = 20 $m^3 ha^{-1}$

Tree age (yrs)	Harvestable cumulative volume ($m^3 ha^{-1}$)	Harvestable cumulative mass ($t ha^{-1}$)	Total annual rainfall (mm)	Cumulative estimated ET (mm)	Cumulative estimated transpiration (mm)	Cumulative estimated streamflow reduction (mm)
1			1192	1192	1097	51
2	17.5	8.8	659	1851	1703	102
3	45.8	22.9	758	2609	2400	153
4	82.9	41.4	685	3294	3030	204
5	123.4	61.7	841	4135	3804	255
6	128.6	64.3	440	4575	4209	306
7	137.8	68.9	735	5310	4885	357
8	151.3	75.6	616	5926	5452	408
9	167.3	83.6	889	6815	6270	459
10	203.6	101.8	1116	7931	7297	510
11	230.9	115.4	951	8882	8171	561

Baynesfield (Eucalyptus grandis) MAI = 16 m^3 ha^{-1}

Tree age (yrs)	Harvestable cumulative volume (m^3 ha^{-1})	Harvestable cumulative mass (t ha^{-1})	Total annual rainfall (mm)	Cumulative estimated ET (mm)	Cumulative estimated transpiration (mm)	Cumulative estimated streamflow reduction (mm)
1			1090	1090	1003	58
2	15.2	7.6	662	1752	1612	116
3	23.2	11.6	575	2327	2141	174
4	36.4	18.2	610	2937	2702	232
5	44.4	22.2	622	3559	3274	290
6	67.9	34.0	1207	4766	4385	348
7	103.2	51.6	863	5629	5179	406
8	129.7	64.9	1065	6694	6158	464
9	145.8	72.9	750	7444	6848	522

Usutu (*Pinus patula*) MAI = 23 m^3 ha^{-1}

Tree age (yrs)	Harvestable cumulative volume (m^3 ha^{-1})	Harvestable cumulative mass (t ha^{-1})	Total annual rainfall (mm)	Cumulative estimated ET (mm)	Cumulative estimated transpiration (mm)	Cumulative estimated streamflow reduction (mm)
1			1064	1064	883	127
2	3.0	1.1	901	1965	1631	254
3	10.8	4.1	1276	3240	2689	381
4	58.1	22.1	1405	4645	3855	508
5	123.3	46.9	1131	5776	4794	635
6	167.4	63.6	719	6495	5391	762
7	198.0	75.2	1234	7729	6415	889
8	253.4	96.3	942	8672	7197	1016
9	286.7	108.9	1347	10019	8315	1143
10	314.6	119.5	1056	11074	9192	1270
11	330.0	125.4	1097	12172	10102	1397
12	349.4	132.8	658	12829	10648	1524
13	350.9	133.3	895	13725	11391	1651
14	368.2	139.9	972	14697	12198	1778
15	385.4	146.4	1026	15723	13050	1905

Richmond (*Pinus patula*) MAI = 20 m^3 ha^{-1}

Tree age (yrs)	Harvestable cumulative volume (m^3 ha^{-1})	Harvestable cumulative mass (t ha^{-1})	Total annual rainfall (mm)	Cumulative estimated ET (mm)	Cumulative estimated transpiration (mm)	Cumulative estimated streamflow reduction (mm)
1			1025	1025	871	121
2			1025	2050	1722	242
3			1025	3075	2573	363
4	9	3.4	1025	4100	3423	484
5	25	9.5	1025	5125	4274	605
6	49	18.6	1025	6150	5125	726
7	77	29.3	1025	7175	5976	847
8	105	39.9	1025	8200	6826	968
9	133	50.5	1025	9225	7677	1089
10	163	61.9	1025	10250	8528	1210
11	190	72.2	1025	11275	9379	1331
12	220	83.6	1025	12300	10229	1452
13	246	93.5	1025	13325	11080	1573
14	273	103.7	1025	14350	11931	1694
15	299	113.6	1025	15375	12782	1815
16	325	123.5	1025	16400	13632	1936
17	349	132.6	1025	17425	14483	2057
18	369	140.2	1025	18450	15334	2178
19	387	147.1	1025	19475	16185	2299
20	402	152.8	1025	20500	17035	2420
21	417	158.5	1025	21525	17886	2541
22	429	163.0	1025	22550	18737	2662
23	437	166.1	1025	23575	19588	2783
24	445	169.1	1025	24600	20438	2904
25	449	170.6	1025	25625	21289	3025

Greytown (*Pinus patula*) MAI = 12 m^3 ha^{-1}

Tree age (yrs)	Harvestable cumulative volume (m^3 ha^{-1})	Harvestable cumulative mass (t ha^{-1})	Total annual rainfall (mm)	Cumulative estimated ET (mm)	Cumulative estimated transpiration (mm)	Cumulative estimated streamflow reduction (mm)
1			786	786	652	42
2			786	1572	1304	84
3			786	2358	1957	126
4	3	1.1	786	3144	2609	168
5	13	4.9	786	3930	3262	210
6	27	10.3	786	4716	3914	252
7	42	16.0	786	5502	4566	294
8	60	22.8	786	6288	5219	336
9	76	28.9	786	7074	5871	378
10	94	35.7	786	7860	6523	420
11	111	42.2	786	8646	7176	462
12	128	48.6	786	9432	7828	504
13	145	55.1	786	10218	8481	546
14	161	61.2	786	11004	9133	588
15	177	67.3	786	11790	9785	630
16	192	73.0	786	12576	10438	672
17	206	78.3	786	13362	11090	714
18	219	83.2	786	14148	11742	756
19	230	87.4	786	14934	12395	798
20	238	90.4	786	15720	13047	840
21	246	93.5	786	16506	13700	882
22	254	96.5	786	17292	14352	924
23	260	98.8	786	18078	15004	966
24	264	100.3	786	18864	15657	1008
25	267	101.5	786	19650	16309	1050

APPENDIX B
Estimated Quadratic Functions

Table B.1: Estimated Quadratic Equation for ET Water Use -Yield Response Functions

Name of Sites	Constant	Coefficient X	Coefficient X^2	R^2	F	RMSE	No.
Eucalyptus							
Kia-Ora	-28.7345	0.0023293	-8.49 e-09	0.973	165.32	5.405	10
	(-2.86)	(5.64)	(-2.25)				
Baynesfield	- 4.4337	0.0005303	7.17 e-09	0.990	347.87	2.492	8
	(-0.79)	(1.91)	(2.39)				
Tanhurst	8.7968	0.0015496	2.50 e-09	0.952	81.33	10.457	9
	(0.55)	(2.12)	(0.35)				
KwaMbonambi	-43.3014	0.0039551	-1.30 e-08	0.989	405.96	7.708	10
	(- 4.56)	(11.03)	(- 4.26)				
Pine							
Richmond	-60.94	0.0014381	-2.00 e-09	0.995	2468.82	3.696	22
	(-14.44)	(22.72)	(- 9.57)				
Greytown	-37.4165	0.0011188	- 2.01 e-09	0.995	2313.85	2.295	22
	(-14.31)	(21.87)	(-9.14)				
Usutu	-50.1288	0.0020478	-5.02 e-09	0.982	373.77	6.737	14
	(- 6.06)	(9.87)	(- 4.42)				

Source: Estimated

Note: All functions, except Baynesfield and Tanhurst, had minus sign on x^2 term. Minus signs were forced on Baynesfield and Tanhurst for generating declining MPPs from predicted values.

Table B.2: Estimated Quadratic Equation for SFR water Use-yield Response Function and Stream Flow Reduction

Name of Sites	Constant	Coefficient x	Coefficient X^2	R^2	F	RMSE	No.
Eucalyptus							
Kia-Ora	-14.91985	0.0282732	-1.09 e-06	0.956	98.54	6.952	10
	(-1.28)	(3.59)	(-0.94)				
Baynesfield	2.92500	0.0002627	2.65 e-06	0.980	176.01	3.490	8
	(0.39)	(0.05)	(3.31)				
Tanhurst	-2.59285	0.0119261	1.96 e-07	0.972	144.37	7.910	9
	(-0.18)	(2.56)	(0.60)				
KwaMbonambi	- 42.5950	0.0284318	-7.85 e-07	0.980	225.6	10.305	10
	(-3.51)	(9.83)	(-5.36)				
Pine							
Richmond	-61.15295	0.0122308	-1.45 e-07	0.995	2522.9	3.656	22
	(-14.65)	(23.05)	(-9.77)				
Greytown	-37.41652	0.0209382	-7.05 e-07	0.995	2313.8	2.291	22
	(-14.31)	(21.87)	(-9.14)				
Usutu	-56.0457	0.019274	- 4.57 e-07	0.990	567.84	5.479	14
	(-8.45)	(13.88)	(-7.26)				

Source: Estimated

Note: All functions except Baynesfield and Tanhurst show minus sign on x^2 coefficient. In case of Baynesfield and Tanhurst, forecasts were generated after forcing minus signs on x^2.

APPENDIX C

Computation of Cost Data

1. Data Source

The cost data were taken from Forestry Economic Services (1996) **Forestry Cost in South Africa: The Green Gold Crop**, Pietermaritzburg. This data is reported for the year 1996. The following items of costs are included:

a. Machinery
b. Labor
c. Plants
d. Fertilizers
e. Protection
f. Land Rentals
g. Overheads

These include the cost incurred in establishment, tending, harvesting, loading, weeding, transport, and all other activities. The breakdown of these costs and details are given in Table B.1.

2. Transport Costs

Transport commences at roadside and ends with delivery to the point of sale, which might be at the receiving mill, free on rail or siding or free on depot at buyer's depot. The average of cost of transshipping, road haulage and railway transport has been taken in this study.

3. Land Cost

The rental value of land is used as land cost. The market value of bare, unimproved afforestable land is R 1995 per hectare. The rental value is computed as 5% of the market value i.e. R 99.75/ha.

4. Other Costs

Other costs include: (1) Management and administration (2) Depreciation, (3) other overheads including costs incurred in the community development.

5. Fixed and Variable Costs

Fixed cots are computed on per hectare and include primarily costs of machinery , land, and other overheads. Variable cost is presented in this study in R/ton and includes costs incurred on harvesting, loading, and transportation. .

Table C.1: Costs and Prices Used in the Computation of Water values for Eucalyptus and Pine, KwaZulu-Natal

Particulars	**Eucalyptus**		**Pine**
	Midlands	Zulu land	All Natal
Fixed Costs	R/ha	R/ha	R/ha
Establishment	1356.59	1519.23	1452.24
Tending	115.38	158.34	85.75
Land rental	99.75	99.75	99.75
Interest on capital	98.30	98.30	98.30
Protection plus conservation	186.75	165.24	165.24
Management and administration	457.25	462.64	457.25
Depreciation	9.95	17.28	9.95
Other overheads	70.77	58.05	92.28
Total Fixed Costs (R/ha)	2394.74	2578.83	2460.76
Variable Costs	R/ton	R/ton	R/ton
Harvesting	29.13	19.72	22.19
Loading and transportation	52.59	47.40	57.35
Total Variable Costs (R/ton)	81.72	67.12	79.54
Average price of timber (R/ton)	180.15	188.43	132.21

Source: Constructed from data from FES (1996).

APPENDIX D

Computation of Water Values with and without Land Cost

Whether land cost should be included or not in the computation of water values, is a controversial issue. We have hence computed water values with and without land cost included in the analysis. This analysis was carried out for Kia-Ora and Richmond sites. The results are summarized in Tables E.1 and E.2. Note that the difference between water values with and without land cost is very small or negligible-- less than one percent. For example, this difference is only 0.35 and 1.1 percent for Kia-Ora and Richmond.

Table D.1: A Comparison of Water Value with and without Land Cost Kia-Ora[a]

ET (Cubic metre)	Water value with land X1	Water value without land X2	X2-X1 / X1	% Difference
18510	-0.083	-0.077	-0.072	-7.2
20030	-0.062	-0.057	-0.081	-8.1
21550	-0.045	-0.040	-0.111	-11.1
23070	-0.030	-0.026	-0.133	-13.3
24590	-0.017	-0.013	-0.235	-23.5
26090	-0.005	-0.002	-0.600	-60.0
27610	0.010	0.013	0.300	30.0
29130	0.023	0.026	0.130	13.0
30650	0.035	0.038	0.086	8.6
32170	0.046	0.049	0.065	6.5
32940	0.051	0.054	0.059	5.9
34460	0.059	0.062	0.051	5.1
35980	0.067	0.070	0.045	4.5
37500	0.074	0.076	0.027	2.7
39020	0.080	0.083	0.038	3.8
40540	0.086	0.088	0.023	2.3
41350	0.089	0.091	0.022	2.2
42870	0.088	0.090	0.023	2.3
45750	0.086	0.088	0.023	2.3
47270	0.085	0.087	0.024	2.4
48790	0.084	0.087	0.036	3.6
50310	0.084	0.086	0.024	2.4
51830	0.083	0.085	0.024	2.4
53100	0.083	0.084	0.012	1.2
54620	0.083	0.085	0.024	2.4
56140	0.084	0.086	0.024	2.4
57660	0.085	0.086	0.012	1.2
59260	0.085	0.087	0.024	2.4
60780	0.085	0.087	0.024	2.4
62300	0.085	0.087	0.024	2.4
65340	0.085	0.087	0.024	2.4
66860	0.086	0.087	0.012	1.2
68150	0.086	0.087	0.012	1.2
69670	0.087	0.089	0.023	2.3
71190	0.089	0.090	0.011	1.1
72710	0.090	0.092	0.022	2.2
74230	0.092	0.093	0.011	1.1
75750	0.093	0.094	0.011	1.1
77270	0.094	0.096	0.021	2.1
78790	0.096	0.097	0.010	1.0
80830	0.097	0.098	0.010	1.0
82350	0.098	0.099	0.010	1.0
83870	0.099	0.100	0.010	1.0
88430	0.101	0.102	0.010	1.0
88820	0.101	0.102	0.010	1.0
54399.2	**0.066**	**0.069**	**0.003**	**0.3**

[a] All the points are not reported without affecting the average

Table D.2: A comparison of Water Value with and without Land Cost for Richmond

ET (Cubic metre)	water value with Land	water value without Land	X2-X1	% Difference
	X1	X2	X1	
4100	-0.056	-0.053	-0.054	-5.4
4305	-0.052	-0.049	-0.058	-5.8
4510	-0.048	-0.046	-0.042	-4.2
4715	-0.044	-0.042	-0.045	-4.5
4920	-0.041	-0.039	-0.049	-4.9
5125	-0.038	-0.036	-0.053	-5.3
5330	-0.035	-0.033	-0.057	-5.7
5535	-0.032	-0.030	-0.063	-6.3
5740	-0.029	-0.027	-0.069	-6.9
5945	-0.027	-0.025	-0.074	-7.4
6150	-0.024	-0.022	-0.083	-8.3
6355	-0.022	-0.022	0.000	0.0
6560	-0.019	-0.020	0.053	5.3
6765	-0.017	-0.018	0.059	5.9
6970	-0.015	-0.015	0.000	0.0
7175	-0.013	-0.013	0.000	0.0
7380	-0.011	-0.011	0.000	0.0
7585	-0.009	-0.010	0.111	11.1
7790	-0.007	-0.008	0.143	14.3
7995	-0.006	-0.006	0.000	0.0
8200	-0.004	-0.005	0.250	25.0
8405	-0.003	-0.003	0.000	0.0
8610	-0.002	-0.002	0.000	0.0
8815	0.000	0.000	0.000	0.0
9020	0.001	0.001	0.000	0.0
9225	0.002	0.002	0.000	0.0
9430	0.003	0.003	0.000	0.0
9635	0.005	0.004	-0.200	-20.0
9840	0.006	0.006	0.000	0.0
10045	0.007	0.007	0.000	0.0
10250	0.008	0.008	0.000	0.0
10455	0.009	0.009	0.000	0.0
10660	0.010	0.010	0.000	0.0
10865	0.010	0.010	0.000	0.0
11070	0.011	0.011	0.000	0.0
11275	0.012	0.012	0.000	0.0
11480	0.013	0.013	0.000	0.0
11685	0.014	0.014	0.000	0.0
11890	0.014	0.014	0.000	0.0
12095	0.015	0.015	0.000	0.0
12300	0.016	0.016	0.000	0.0
12505	0.016	0.017	0.063	6.3
12710	0.017	0.017	0.000	0.0
12915	0.017	0.018	0.059	5.9
13120	0.018	0.018	0.000	0.0
13325	0.018	0.019	0.056	5.6
13530	0.019	0.019	0.000	0.0
13735	0.020	0.020	0.000	0.0
13940	0.020	0.020	0.000	0.0
14145	0.020	0.021	0.050	5.0

14350	0.021	0.021	0.000	0.0
14555	0.021	0.022	0.048	4.8
14760	0.022	0.022	0.000	0.0
14965	0.022	0.022	0.000	0.0
15170	0.023	0.023	0.000	0.0
15375	0.023	0.023	0.000	0.0
15580	0.023	0.024	0.043	4.3
15785	0.024	0.024	0.000	0.0
15990	0.024	0.024	0.000	0.0
16195	0.024	0.025	0.042	4.2
16400	0.025	0.025	0.000	0.0
16605	0.025	0.025	0.000	0.0
16810	0.025	0.026	0.040	4.0
17015	0.025	0.026	0.040	4.0
17220	0.026	0.026	0.000	0.0
17425	0.026	0.026	0.000	0.0
17630	0.026	0.027	0.038	3.8
17835	0.026	0.027	0.038	3.8
18040	0.026	0.027	0.038	3.8
18245	0.027	0.027	0.000	0.0
18450	0.027	0.027	0.000	0.0
18655	0.027	0.027	0.000	0.0
18860	0.027	0.027	0.000	0.0
19065	0.027	0.027	0.000	0.0
19270	0.027	0.027	0.000	0.0
19475	0.027	0.028	0.037	3.7
19680	0.027	0.028	0.037	3.7
19885	0.027	0.028	0.037	3.7
20090	0.027	0.028	0.037	3.7
20295	0.027	0.028	0.037	3.7
20500	0.027	0.028	0.037	3.7
20705	0.027	0.028	0.037	3.7
20910	0.027	0.028	0.037	3.7
21115	0.027	0.028	0.037	3.7
21320	0.027	0.028	0.037	3.7
21525	0.027	0.028	0.037	3.7
21730	0.027	0.028	0.037	3.7
21935	0.027	0.028	0.037	3.7
22140	0.027	0.028	0.037	3.7
22345	0.027	0.028	0.037	3.7
22550	0.027	0.028	0.037	3.7
22755	0.027	0.028	0.037	3.7
22960	0.027	0.027	0.000	0.0
23370	0.027	0.027	0.000	0.0
23575	0.027	0.027	0.000	0.0
23780	0.027	0.027	0.000	0.0
23985	0.026	0.027	0.038	3.8
24190	0.026	0.027	0.038	3.8
24395	0.026	0.027	0.038	3.8
24600	0.026	0.027	0.038	3.8
24805	0.026	0.027	0.038	3.8
25215	0.026	0.026	0.000	0.0
25420	0.026	0.026	0.000	0.0
25625	0.025	0.026	0.040	4.0
14862.5	**0.0**	**0.0**	**0.0**	**1.1**

APPENDIX E

Mathematical Interpretations of Water Values Estimated by Residual Value (RV) and Marginal Value Product (MVP) Methods

1. The RV method estimates the value of water as returns to water after having paid all other inputs in the production process. For example, if there were only two inputs (labour and water) in the production process, and if they are paid according to their marginal value product, then the value of water will amount to the following expression:

$$\frac{P_T Q_T - MPP_L P_T - FC}{Q_W}$$

where P_T = Price of timber

Q_T = Quantity of timber produced from a tree

MPP_L = Marginal physical product of labour

FC = Fixed costs of production

Q_W = Quantity of water used to produce Q_T

2. The MVP method estimates the value of water as area under the MVP curve or

$$= (\int MVP \, dQ \;) / Q_W$$

A comparison of the above (1 and 2) reveals that RV measures the water value after paying for all other inputs in the production process, while the MVP method rewards water according to its marginal value productivity before other inputs are remunerated. Under the MVP method, water is thus paid first before all other inputs are remunerated in the production process and fixed costs do not impact the water productivity as such.

Other related WRC reports available:

The development of a methodology to determine the true value of water and the impact of a potential water market on the efficient utilisation of water in the Berg River basin

DB louw

The primary objective with this project was to develop a methodology to determine water values and the impact of a potential water market on efficiency. This included the methodology to analyse water values and water markets as well as the quantification of variables, which will be influenced by the implementation of water markets as an alternative for administrative water allocation in the Berg River basin. Modelling of water markets in South Africa has received very little interest in the past. This is probably because there was an emphasis on supply management through command and control in the old Water Act (1956).

An increasing number of economists believe that market mechanisms should be incorporated in water allocation policies. It is widely recognized that central planning as an economic system has been inefficient. In fact, it is impossible to plan efficiently from the centre, and the bigger and more open the economy is, the more impossible it becomes.

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