Assessing the costs and benefits of water use for production and the potential of water demand management in the Crocodile Catchment of South Africa

By

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EXECUTIVE SUMMARY

In South Africa, precipitation is extremely variable and water is scarce. South Africa is also a country with great welfare needs. Challenging economic development targets and plans therefore need to be implemented successfully within the constraints of limited water supply and unreliable water availability. These economic development plans are underpinned by the development and growth of economic activities such as agriculture, mining, energy production and many types of small, medium and micro enterprises, which are some of the largest water using sectors in the economy. Within these activities, increased competition places pressure on water users to keep supplying their markets with competitively priced goods, while rising costs of new water supplies puts pressure on water users to allocate sufficient water to their production processes. These market forces and the relative scarcity of water as an economic production factor, impact on financial viability and imply that the economic efficiency of water use becomes increasingly important.

The National Water Act of 1998 (NWA) is a legislative response to this situation, and promotes a radical shift towards efficiency and equity goals in water allocation. Water users who require water as an input to economic activities are consequently seriously revising their water use patterns in response to one of the major implications of the NWA and its related principal strategy: **water demand**

management. Water demand management strives to adhere to the principles of equity, social justice, economic efficiency and environmental sustainability, which are central to the NWA.

This study evaluates the costs and benefits of water use in order to simulate the effects of water demand management activities on a catchment economy. The results of a number of studies were combined to generate an economy-wide model: a Social Accounting Matrix (SAM), for the case study area and to simulate the direct and indirect effects of water demand management on the people, the economy and the natural environment in the area. Water demand management (WDM) is defined as consisting of two phases. In the first phase, goals of full cost recovery, improving water use efficiency and allocating water optimally are targeted. The second phase of WDM arrives when a situation of absolute water scarcity is reached within a catchment. In this phase water demand outweighs water supply and water has to be allocated according to its scarcity value. Water markets play a large role here.

The SAM was used to simulate the direct and indirect impacts on the economy and the environment of a number of WDM related scenarios. Water re-allocation decisions and the effects of various WDM policy instruments, such as reduction of water use subsidies and increases in water tariffs were simulated. Unintended consequences of other environmental policies on water use, in this case, carbon tax, were explored. Water scarcity predictions were done, and some of the transaction costs involved in water trading was quantified.

The study concludes with a discussion on the indirect effects on the economy, the environment and people of changes affecting the agricultural (including forestry) activities. The direct and indirect impacts of WDM policies on the economy and the environment, and the importance of environmental-economic models in water cost benefit modelling are also discussed. Implications for policy and management are highlighted.

This study shows specifically how, through modelling various scenarios, policy decisions aimed at managing specific variables (e.g. water use, carbon emissions) have an economic and environmental impact much wider than the sector in which the policy was targeted for. Each scenario shows how a water transaction, or a change in subsidy in the agricultural (including forestry) sector, could impact on the output of other economic sectors, and therefore the economy as a whole. It is therefore evident that policy decisions, which are implemented at a macro level, and could have a major direct impact on a wider range of economic sectors, should be carefully considered as they could have large, undesirable, unintended consequences.

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ACRONYMS and ABBREVIATIONS

CMA	Catchment Management Agency
CMC	Catchment Management Charge
DWAF	Department of Water Affairs and Forestry
GDP	Gross domestic product
GGP	Gross geographic product
I-O	Input-Output
MAI	Mean Annual Increment
MAR	Mean Annual Runoff
MAP	Mean Annual Precipitation
NWA	National Water Act (No 36 of 1998)
NWPS	National Water Pricing Strategy
RANESA	Resource Accounting Network of Eastern and Southern Africa
RSA	Republic of South Africa
SAAU	SA Agricultural Union
SAM	Social Accounting Matrix
SIC	Standard Industrial Classification
VAD	Value Added
WC/DM	Water Conservation & Demand Management
WDM	Water Demand Management
WMA	Water Management Area
WUA	Water User Association

Chapter 1 - Introduction

1.1 Setting and motivation

Water is scarce and precipitation is extremely variable in South Africa. South Africa is also a country with great welfare needs where challenging economic development targets need to be achieved within the constraints of limited and unreliable water supply. These development targets are underpinned by the growth in economic activities such as agriculture, mining, energy production and many small, medium and micro enterprises, which constitute some of the largest water using sectors in the economy (Crafford et al. 2001). Within these industries, increased competition place pressure on water users to keep supplying their markets with competitively priced goods, while rising costs of new water supplies puts pressure on water users to achieve higher efficiency in water use. These market forces, and the relative scarcity of water as a critical production factor, impact on financial viability and imply that the economic efficiency of water use becomes increasingly important.

In response to this situation, a new National Water Act (NWA) has been instituted in SA in 1998, which signified a radical departure from previous water use policies in the country (NWA, 1998). The NWA accordingly has important implications for future management, allocation and use of water resources in SA. The NWA revolves around the principles of equity, social justice, economic efficiency and environmental sustainability. Major features of the Act include among others:

- Abolishment of private rights to water,
- Application of economic efficiency principles to allocation of water for productive economic uses,
- Priority to correction of inequalities of the past in terms of access to water and water services for poverty reduction, and
- Protection of the people and the environment against the hazards of production and consumption activities that deplete stocks and degrade the quality of water and watershed services.

Pursuance of the above principles in the implementation of the NWA impacts on the design of different policy instruments and strategies for the management and use of water. For instance, the *equity and poverty reduction* goals will lead to increased demand for water for domestic purposes as millions of people are catered for who were previously excluded from this service. The stated *efficiency principle* requires removal of subsidies, which could in the short term negatively influence returns on capital invested during periods of high water subsidies. Efficiency also requires the implementation of water demand management strategies, a major component of which is related to water allocation based on economic efficiency principles, and would therefore have to be carefully designed to ensure that sustainability and equity principles are achieved. *Environmental sustainability* requires water to be managed with a long-term view of sustaining the natural system, while maintaining an adequate supply of good quality water.

Water users who require water as an input to economic activities are consequently seriously revising their water use patterns in response to one of the major implications of the NWA and its related principal strategy, namely: **water demand management**. The water demand management strategies which are implemented through the Act ultimately work towards ensuring equity in satisfying household water demand, the full recovery of financial costs, and promote efficient use of water through increased charges and tariffs, especially in sectors where users have traditionally been subsidised. It is also true that economic activities impact on the natural environment and consequently water demand management decisions must observe possible negative impacts on the natural environment.

This study made an attempt to compare the social, economic and environmental costs and benefits of water use by production sectors in SA, with particular emphasis on the comparative effects of water demand management. The rural area of the Crocodile River Catchment was used as a case study, being a typical example of an area where competition for water will increase in SA. Although the study will not attempt to determine the value of or a price for water, this research will use proxy measures of the economic and environmental costs and benefits of water use in the compared activities. Direct as well as indirect (backward and forward linked) costs and benefits associated with the studied activities will be assessed using the social accounting matrix (SAM) framework to trace multiplier effects throughout the rural economy of the Crocodile River Catchment.

Total economic benefits were used in this study to represent the sum of direct and indirect benefits in the sectors under study. Direct benefits refer to benefits generated directly by an economic activity and do not capture the total benefits from that activity. As its output is further processed by other economic activities (which add further value), the value addition chain of the sectors linked forward with the activity is considered part of its total indirect economic benefits. Indirect benefits are also generated in sectors that supply inputs to the activity in question. Indirect benefits therefore originate from forward and backward linkages in production. Accounting for indirect economic benefits is particularly important and of large orders of magnitude for primary production activities such as agriculture, mining and energy production. This is because these industries are merely a source of the raw material, which supports extensive further processing for higher values in secondary and tertiary production. The indirect benefits discussed above represent spin-off effects of production multipliers only. That means additional outputs need to be generated by sectors supplying the required extra intermediate inputs or processing the extra output. Demand-side multiplier effects caused by spin-offs resulting from spending of the additional value (income) generated throughout the forward and backward chains on more goods and services for final consumption is referred to in the literature as the "income leakage" (Pyatt and Round, 1985). While calculation of production and demand multipliers is very demanding in terms of data requirements, this study intends to account for a feedback effect from consumption or final demand to close the loop of income leakage from the system.

Water demand management decisions also impact on the environment, both directly and indirectly. The direct impacts are attributed to abstraction of water from the natural environment and an adverse effect on water quality of the production activity. The indirect impacts are attributed to the water abstraction and adverse quality impact of the indirect economic activities (of backward and forward linkages).

1.2 Objectives of the study

The main goal of this research is to develop and apply an analytical framework to assess the relative importance of alternative water use options for production in terms of the efficiency and sustainability principles specified by the NWA. The specific objectives are therefore:

- To develop and use a framework that allows for the assessment of direct as well as indirect (economy-wide) benefits and costs of key water use sectors;
- To apply the developed framework to conduct a comparative analysis of the economic and environmental net benefits of alternative major water use options in the rural areas of the Crocodile River Catchment of SA;
- Analyse the implications for management and allocation of water resources of potential eminent changes in the policy environment introduced by the NWA.

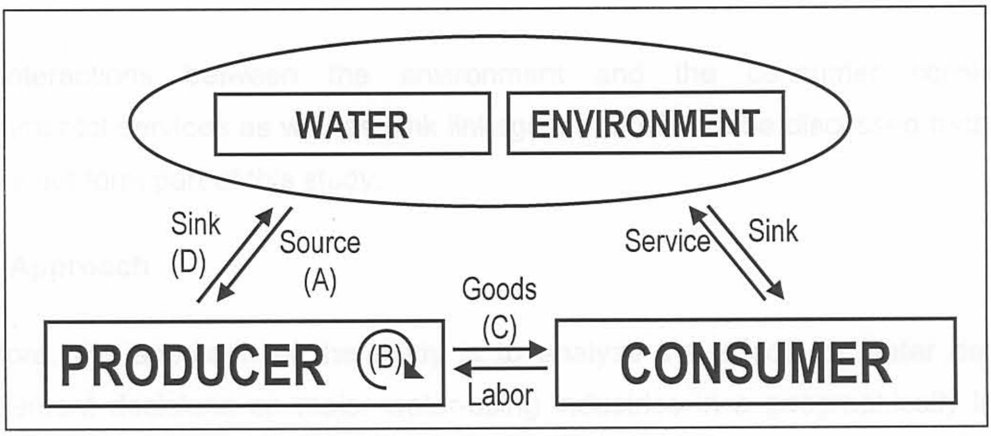
It has to be emphasized that this is not a water valuation study. The total economic benefits approach is not a measure of the marginal value of water. Measures of the marginal contribution of water to total benefits are more appropriate for water pricing purposes.

1.3 Approach and methodology

1.3.1 Background

In the previous sections, three concepts that are key to the analysis of the total economic benefits of water use were discussed: water allocation, economic (backward and forward) linkages and environmental impacts. These concepts can be viewed as interactions between the natural environment, and the production and consumption spheres of the economic system. Figure 1 provides a conceptual framework integrating such linkages between the environmental and economic systems.

Figure 1.1: A simplified framework for modeling the economic and environmental linkages under study.



The Source link (A) relates to water allocation and use by production sectors where the environment supplies water. These linkages are limited by the physical nature of water (its ability to flow and evaporate), the limited geographical distribution of water, and the fixed nature of water distribution systems. Where water markets are functioning in South Africa they are therefore governed by institutional water allocation decisions. Linkage B defines the economic transactions taking place in the backward and forward linkages of production activities and gives rise to intermediate demand for goods and services. Linkage C defines the interaction between final consumption and production activities and is responsible for the final demand for goods and services. The application of the total economic benefit methodology relies on data sourced from transactions A, B and C. Obtaining these data is complicated by the following factors:

- There are practical difficulties in the measurement of water supply and water use, which forces a reliance on hydrological and process estimations for generating data on linkage A.
- The network of all sectors' transactions and value addition chains throughout the entire economy; constitutes a complex system of multiplier effects.

Another dimension of the water allocation and use debate is the significant role water use plays in the life cycle of final consumption of goods and services. This is because the environmental impacts of the backward and forward linkages of activities form an additional consideration in water allocation decisions. The arrow D in Figure

1 designates these transactions as sink linkages for which data are also difficult to obtain.

The interactions between the environment and the consumer consist of environmental services as well as sink linkages, and will not be discussed further as they will not form part of this study.

1.3.2 Approach

Therefore, the approach of the study is to analyse the effects of water demand management decisions on major water-using industries in a geographically limited catchment area. This will be achieved when best available water beneficiation data (a combination of A&B data in Figure 1), detailed value chains (B data in Figure 1), an economy-wide model (B&C data in Figure 1), and environmental impacts (D data in Figure 1) are combined.

The choice of this integrated framework of multi-sector economic model and environmental impact modules was guided by the combination of the results of five relevant studies:

- A study by Hassan (1998) employing a social accounting matrix (SAM) to analyse economy-wide impacts of the new NWA of South Africa.
- A WRC funded study (Crafford et al. 2002 and Hassan, 2002), measuring the social, economic, and environmental direct and indirect costs and benefits of water use in the irrigated agriculture and forestry sectors in the Crocodile River catchment.
- A CSIR study (Crafford et al. 2001) on water resource accounts for South Africa: 1991-1998.
- A Conningarth Consultants (2000) study which developed a SAM (social accounting matrix) for the Komati River Basin.
- Eiolca, a web-based life cycle analysis tool hosted by the Carnegie Mellon Green Design Initiative (www.eiolca.net).

Availability of data from the above studies enabled the analysis of the costs and benefits of water use in the rural areas of the Crocodile River catchment in the Inkomati Water Management Area in South Africa, which was used as the study area.

1.3.3 Methodology

The following methodology was followed:

- The major water users in the Crocodile River catchment were selected for study purposes.
- Primary data, sourced through the CSIR Crocodile River Study (Crafford et al. 2002), was used to calculate multiplier values for the economic transactions taking place in the selected economic sectors. These multipliers were used to construct a partial Input-Output matrix.
- Secondary data were sourced from the Conningarth study (2000) to convert the partial Input-Output matrix to a social accounting matrix (SAM) for the study area.
- Water use data were sourced from the CSIR water accounts study (Crafford et al. 2001) and incorporated into the SAM.
- Eiolca environmental impact coefficients were converted through a random-effects benefits transfer study and built into the Input-Output matrix to construct an environmental impacts Input-Output matrix for the Crocodile River catchment.
- The economic framework with an integrated environmental model was then used to analyse the developed implications of potential water demand management interventions.

1.4 Organisation of the study

This study consists of six chapters. Chapter 1 introduces the research project, and describes the setting, motivation and objectives to the study. It also outlines the approach and methodology followed. Chapter 2 provides an overview of the economic water use in South Africa as well as an overview of the water policy context, and the case study area. The literature on water demand management and water valuation as well as on applications of economy-wide models to water policy analysis and water resources management is surveyed in Chapter 3. Chapter 4 provides a detailed description of the approach followed and methods employed by the study. Chapter 5 presents and discusses the results obtained. The study closes with Chapter 6, which provides conclusions, discusses limitations and suggests future research.

Chapter 2 – Water resource use and allocation in SA and the case study area

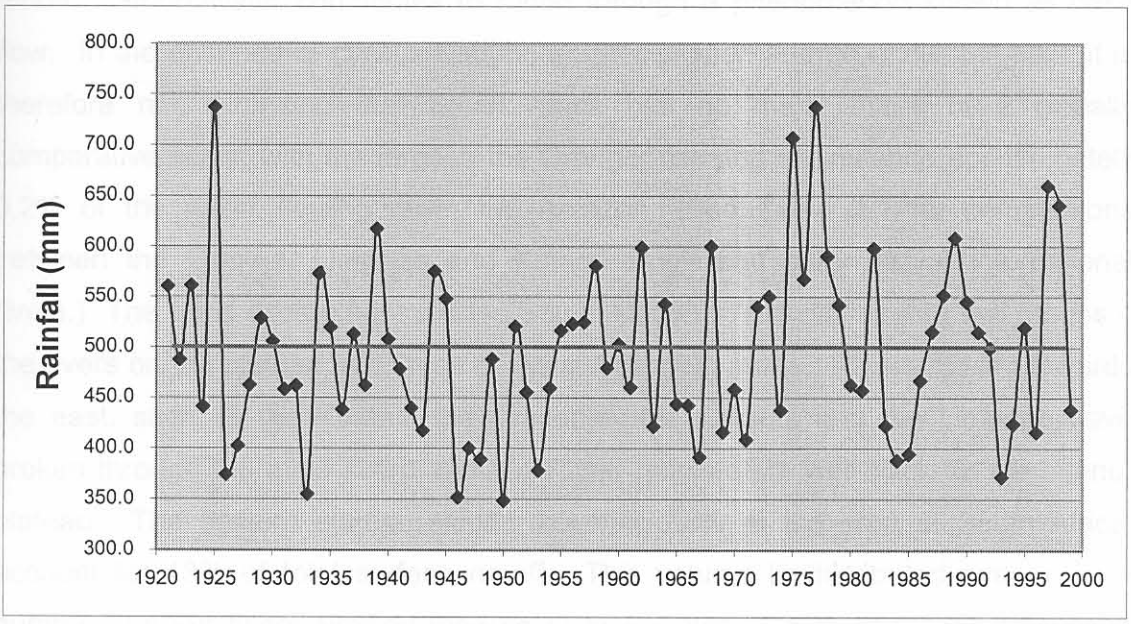
2.1 Water resources in SA

2.1.1 Water availability in South Africa

South Africa depends on two sources of fresh water for annual consumption: **precipitation** and **groundwater**. These two sources interact in a complex hydrological system of evaporation, transpiration, seepage, base flow and run-off (river flow). On average, approximately 90% of the country's precipitation is used in a process of evapotranspiration and deep seepage, while the remaining 10% is available as run-off in rivers (DWAF 2000a).

The average **precipitation** for the country is just over half of the world average at about 500mm per annum. In addition to low levels of precipitation (relative to global average precipitation), rainfall is also highly variable. Over the interior northern regions of South Africa rainfall follows an annual cycle and is almost entirely a summer phenomenon. In the southwestern Cape precipitation occurs in winter. In contrast to the winter rainfall region, the narrow southern Cape coastal belt and interior regions receive precipitation uniformly throughout the year. The arid western-central regions receive rain in a weak semi-annual cycle. Inter-annual variability ranges from more than 40% (year on year rainfall difference) over the drier Northern Cape (where the probability of receiving precipitation of below 100mm/a is 90%) to less than 20% in the wetter eastern parts (where the probability of receiving precipitation of between 600 and 800 mm/a is 90%). Precipitation also varies in a temporally oscillating pattern with an estimated 18-year wet-spell / dry-spell fluctuation (Tyson, 1986). Figure 2.1 shows the annual average rainfall for South Africa for the period 1922 to 2000.

Figure 2.1: Precipitation for South Africa (1922-1999)



Source: SA weather Bureau (2000)

South Africa is poorly endowed with **groundwater** as the country is mainly underlain by hard rock formations that do not contain any major groundwater aquifers (DWAF, 1986). Groundwater occurs in either *primary* or *secondary aquifers*. *Primary aquifers* consist of deposits of sand, gravel and pebbles, which are capable of bearing volumes of water varying between 5% and 30% of the gross volume of the formation. Primary aquifers may cover thousands of square kilometres and vary in thickness from several hundred to more than a thousand metres. *Secondary aquifers*, on the other hand, are weathered and fractured rocks, which lie directly beneath the surface to depths of less than 50 metres. At greater depths, unweathered rock formations occur, which contain very little groundwater because of their dense nature. Across more than 80% of the area of South Africa, groundwater occurs in secondary aquifers. South Africa's groundwater resources can therefore be visualized as being contained in a multitude of mostly secondary and localised aquifer systems with limited quantities of extractable groundwater (DWAF, 1986). The annual groundwater usage in South Africa is estimated to be 1,4 billion m^3/a (DWAF, 2000a).

The maximum quantity of groundwater that would be practically and economically feasible to develop is assessed at approximately 5,4 billion m^3/a (DWAF, 2000a).

Approximately 10% of South Africa's annual precipitation flows down river systems as runoff. Groundwater contributes to runoff through a phenomenon known as base flow. In the absence of constant abundant precipitation and groundwater yield, it is therefore not surprising that South Africa has no major rivers of a globally comparative scale, with the largest, the Orange, carrying for instance approximately 0,2% of the water flowing down the Amazon. (See Table 2.1 for comparisons between the Orange, Limpopo and Komati rivers and some major international rivers.) The great escarpment divides South African river systems into two groups – the rivers on the plateau and those of the surrounding areas. Rivers flowing towards the east, such as the Komati, the Crocodile, the Olifants and the Limpopo have broken through the main scarp and have their headwaters well back on the interior plateau. The eastern plateau slopes, covering 13% of the area of South Africa, account for 43% of total surface runoff. This volume is distributed over a large number of short rivers, limiting the use of their water. South of the Vaal-Limpopo divide, which runs east to west along the Witwatersrand, almost the entire plateau (approximately half of the surface area of South Africa) is drained by the Orange River system, which contributes about 23% of the total annual runoff. In the Southern Cape, the major rivers are the Gamtoos, Gouritz, Breede, Berg and Olifants, which extend in the order given, from a year-round rainfall, to a winter rainfall area.

Table 2.1: Comparison of three SA rivers with major international rivers

River Basin	Basin Area (km^2)	River Length (km)	Mean Annual Runoff	
			(Mm^3/a)	(mm)
Orange (SA)	850,000	2,300	11,500	14
Limpopo (SA)	415,000	1,750	5,500	13
Komati (SA)	50,000	480	3,500	70
Nile	2,800,000	6,700	86,000	31
Zambezi	1,400,000	2,650	94,000	67
Mississippi	3,100,000	3,780	460,000	148
Zaire	3,800,000	4,700	1,260,000	332
Amazon	6,000,000	6,470	5,600,000	933

Sources: Pallet (1997); Encyclopaedia Britannica (2001)

Naturally perennial rivers occur over only one-quarter of South Africa's surface, mainly the southern and south western Cape and on the eastern plateau slopes.

Rivers that flow only periodically are found over a further quarter of the surface. Over the entire western interior, rivers are episodic and only flow after infrequent storms. In the absence of lakes and permanent snowfields to stabilize flow, even perennial rivers flow irregularly and are often strongly seasonal (DWAF, 1986).

2.1.2 Water supply interventions in South Africa

Economic development, and its associated human presence, is often guided by factors other than natural water availability. Civil construction interventions are therefore made to ensure sufficient water supply. Most of the main metropolitan and industrial growth centres of South Africa have developed around mineral deposits and harbour sites, and are situated in areas remote from major river courses. Some irrigation developments are also located in sub-optimal regions with respect to water use efficiency, having been established during times when water was still relatively abundant. Consequently, in several river catchments, the water requirements already far exceed the natural availability of water. This is especially pronounced in the dry central parts of the country.

Water supply and use balances have thus far been achieved through large water resource development projects and extensive inter basin transfers of approximately 4,5 billion m^3/a of raw water, potable water and effluent between more than 100 catchment areas (DWAF, 2000a). South Africa's total *storage capacity* of more than 35 billion m^3 has been created by the construction of major dams, holding more than half the mean annual runoff (MAR) of 55 billion m^3/a for the country (DWAF, 2000a). It was estimated that approximately 20 billion m^3/a of the MAR and groundwater were already being utilized in 1996, with an additional 15 billion m^3/a potentially available for use through the storage provision. The remaining approximately 20 billion m^3/a represents in-stream flow requirements, water lost to evaporation from reservoirs and conveyance systems, as well as spillage of floodwaters to the ocean (DWAF 1986; DWAF 1997; DWAF 2000a).

2.1.3 An overview of water use in South Africa

For the purpose of this study, water use can be divided into three categories: social, environmental and value adding.

People need relatively little water for survival. Twenty-five litres per person per day is considered *theoretically* sufficient for the so-called basic human requirement of drinking, cooking and washing (DWAF 2000c). The **social use** consists of the basic human requirement and the additional water used by households.

The **environment** requires water for ecosystems to function. The bulk of this water is used as evapotranspiration by natural flora and fauna, above and below the soil surface. The rest of the water journeys to the sea as runoff. Estuaries, lakes, wetlands, nature reserves and riverine habitat require a large amount of this runoff for survival. This water need, the so-called in-stream-flow requirement (IFR), is still being investigated, but is currently estimated to be approximately 30% of the mean annual runoff (MAR) in SA (DWAF, 2000a).

Water is also consumed for **value adding purposes** such as agriculture, industry, and energy generation. Estimations done by the Department of Water Affairs and Forestry (DWAF, 1997a) showed that water use in South Africa is dominated by **irrigation**, using more than half of the total water use. **Domestic and general urban** use of water constituted approximately one tenth of total water use, while **mining and large industries** used a little less than one tenth. Water use by dry-land activities is measured as the additional consumption of water over and above the natural flora it has replaced, which is observable through its reduction of stream flow (run-off). This is also referred to as incremental consumption or induced evapotranspiration and was estimated to be one tenth of water used.

On average, ***social*** and ***value adding water use*** amounted to 4% and 26% of MAR, respectively, in 1998, which is a high volume compared to a **projected** global average of only 9% in 2025 (Seckler, 1999). ***Value adding use*** can be classified into three groups: induced evapotranspiration activities (incremental consumption of dry land agriculture or stream flow reduction); strategic use, and irrigation & industrial use. ***Induced evapotranspiration*** is attributed to the water use of certain dry-land farming activities and evaporation. Induced evapotranspiration is therefore the incremental water use due to these activities (which are associated with value adding activities) as opposed to the natural state of the environment. Induced evapotranspiration activities effectively reduce the MAR by 5%. These activities are most apparent in the wetter Water Management Areas (WMA's). MAR for ***strategic use*** is reserved mainly for activities such as power generation, which amounts to 1% of MAR. Water use by ***irrigation & industrial activities*** amounts to 19% of MAR (Crafford et al. 2001).

Table 2.2: Relative water use in South Africa in 1998

Major water users		Water use as a percentage of mean annual runoff (MAR)
Social water use		4%
Value adding water use	Induced evapotranspiration	5%
	Strategic use	1%
	Irrigation & industrial activities	19%

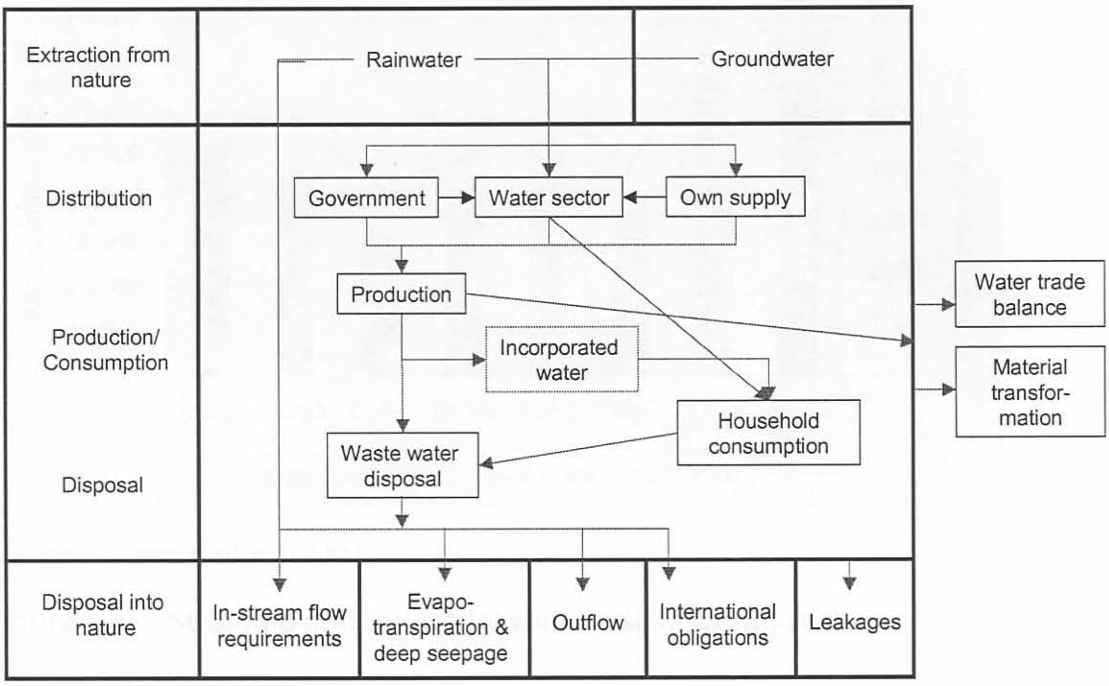
Source: Crafford et al. (2001)

The balance of the MAR is either stored in water supply structures (dams) or flows down rivers. Considering that the dam storage capacity of SA being 57% of MAR, current water use is approximately 30% of MAR, and assuming that current water use and economic development patterns continue, South Africa as a country is headed towards a situation of absolute water scarcity during the period 2025-2030. Absolute water scarcity is defined as a situation where water demand exceeds water supply. Many individual catchments however, are already much closer to situations of absolute water scarcity.

2.1.4 Water Pathways Analysis

Water follows a hydrological pathway of precipitation, flow, transpiration and evaporation, part of which involves human activities. Figure 2.2 shows the pathway water follows from precipitation and groundwater sourcing, through its water supply distribution network, to environmental, social and value adding use, and finally to its disposal back into nature.

Figure 2.2: Simplified water pathways analysis for South Africa

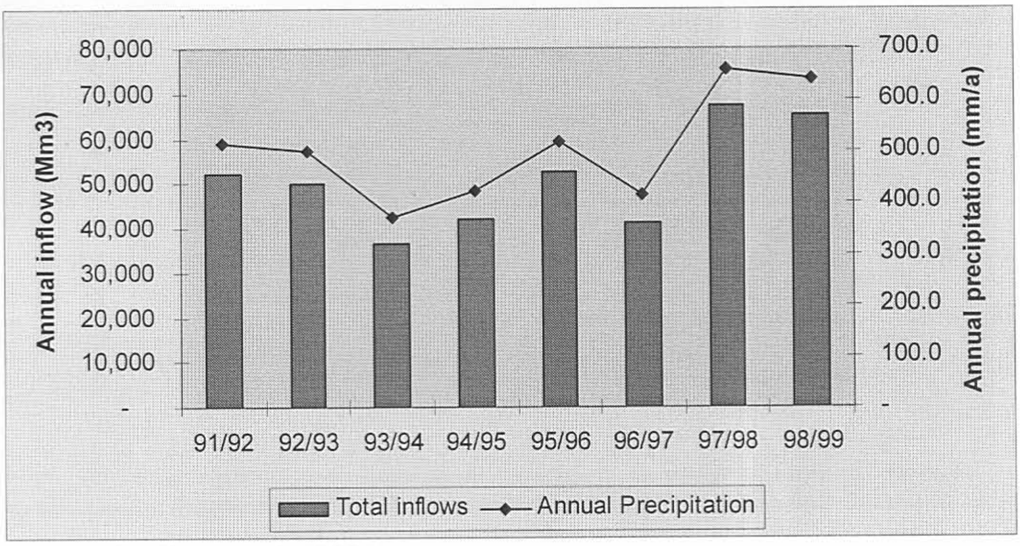


Source: Crafford et al. (2001)

Three important features of the water pathway for SA are worth mentioning:

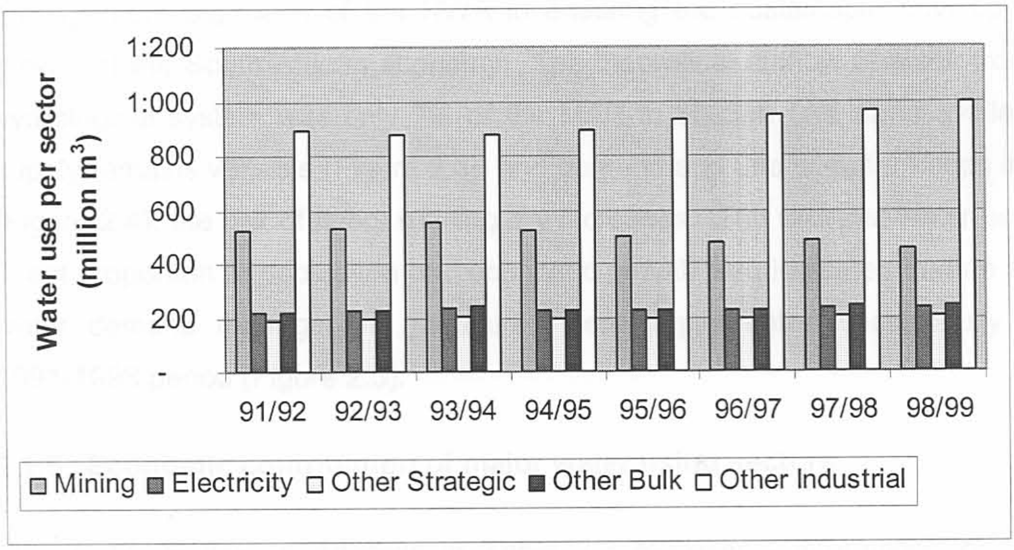
- Water availability is, as can also be seen from Figure 2.3, very dependent on annual precipitation. This is especially evident in drier years (e.g. 93/94). Water availability and consequently also water supply, is therefore highly influenced by the unpredictable and variable rainfall patterns.
- All sectors, excluding the environment (in-stream flow requirements) and mining, display an increasing water use (Figure 2.4). The environmental use stays constant, while the mining sector was the only sector that did not display an increasing water demand. Aggregate demand for water therefore has been constantly increasing at an average annual rate of 1.7% per year for the 1991-1998 period. In the case of irrigation, water use is already limited by water availability.
- GDP growth and increased water usage are to a large extent directly proportional, with the GDP/water use ratio remaining fairly constant around R25/m^3 (Figure 2.5).

Figure 2.3: Annual inflow of water depends on the annual precipitation received



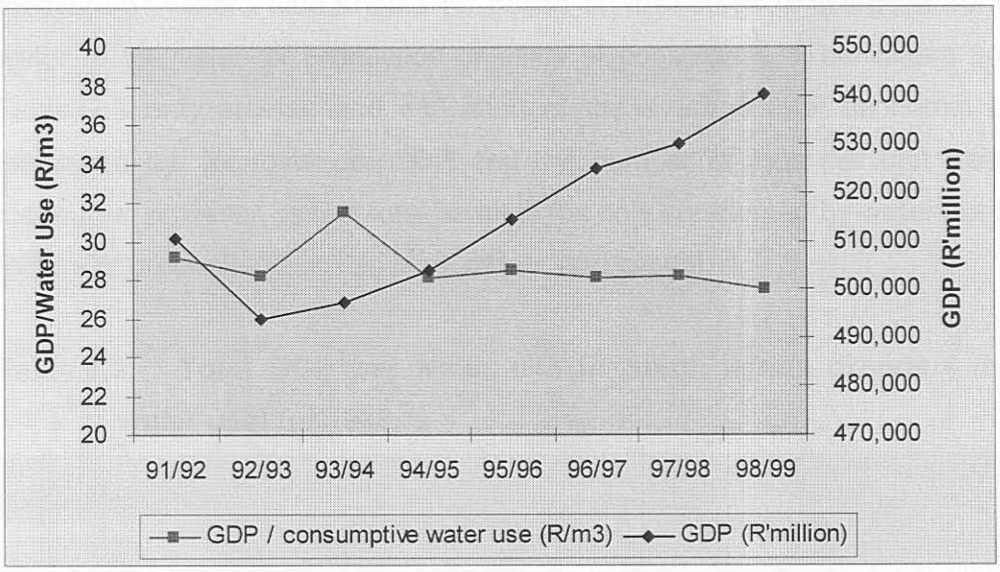
Source: Crafford et al. (2001)

Figure 2.4: Strategic and industrial water use in South Africa



Source: Crafford et al. (2001)

Figure 2.5: The ratio of GDP to water use in South Africa (1991-1998)



Source: Crafford et al. (2001)

The above three features demonstrate the importance of the water demand management approach of the NWA in ensuring the sustainable development and growth of the South African economy: The theoretical outflow of water from the SA hydrological system was only 7% of the MAR in 1993/4. As water availability and supply remains variable (Figure 2.3), and demand and use of water keeps increasing (Figure 2.4), the risk of rivers running dry increases. The fact that water use grew in direct proportion to population and economic growth also indicates that no significant water demand management measures were implemented successfully over the 1991-1998 period (Figure 2.5).

2.1.5 Economic contribution of major water using sectors

The Water Pathways Analysis in Table 2.3 represents information on economic benefits yielded from water use in SA, namely output, GDP, remuneration and gross operating surplus (GOS) expressed per unit of water use. It is clear that the primary sectors, heavily reliant on land and biological processes as economic production factors (e.g. agriculture), have relatively low water beneficiation ratios. Fishing and mining have beneficiation ratios that are two orders of magnitude larger, while the secondary and tertiary sectors (manufacturing and services) are three orders of magnitude larger than primary sectors. It must be emphasized here that these beneficiation ratios do not by any means reflect the value of water. The proper measure of water value should be based on measures of marginal contribution of water to the value of production or utility of consumers. The values presented in Table 2.3 only provide and indication of the average total economic benefits as measured by, for instance, GDP and the number of jobs per unit water. These measures, however, reflect total benefits not only contributed by water but by all other factors of production such as land, labour and capital.

Table 2.3: Total GDP per water use in South Africa (Rands / Incremental water use) for 1998.

Industrial Sector	Value of output/Water (R/m^3)	GDP/Water (R/m^3)	Remuneration /Water (R/m^3)	Gross Operating Surplus/Water (R/m^3)
Agriculture	2.8	1.4	0.5	1.2
Field crops	1.4	0.7	0.3	0.6
Horticultural crops	1.8	0.8	0.3	0.8
Livestock	32.1	15.7	5.7	13.5
Forestry	1.1	0.6	0.2	0.4
Fishing	690	298	161	134
Mining	137	80	42	37
Gold	123	77	44	32
Coal	501	262	126	130
Other	110	62	29	32
Manufacturing	946	296	165	132
Electricity	287	197	56	139
Water	2.0	0.8	0.2	0.6
Construction	779	234	182	50
Wholesale, retail & motor trade; catering & accommodation	442	256	132	117
Transport	328	189	90	97
Communication	545	354	246	110
Finance, real estate, business services	418	277	93	167
Other private services	387	253	206	41
General government services	406	269	238	29
Other (including Government)	162	82	40	39

Source: Crafford et al. (2001)

Trade in virtual water in SA, investigated by Lange and Hassan (2003) indicates that nearly a quarter of SA's water use is exported as virtual water. Put differently, 24.3%

of our water use is consumed to produce products that are eventually exported. Theoretically, if these export products could be substituted by other export goods with lower water consumption, the country could save water.

2.2 Evolution of water policy in SA

The Bill of Rights, as laid out in the Constitution of the Republic of South Africa Act (No. 108 of 1996) (RSA Constitution, 1996), makes provision for *'everyone to have the right of access to sufficient water'* (s27(1)) and for the state to take '*reasonable legislative and other measures, within its available resources, to achieve the progressive realisation of... these rights*' (s27(2)). The Bill of Rights also makes provision for all citizens of South Africa to have an environment 'that is not harmful to their health or well-being; and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that:

- Prevent pollution and ecological degradation
- Promote conservation
- Secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development' (s24).

This provides the broad context for water use in South Africa. This section reviews the major changes brought about by the NWA in water resources use and management strategies in SA.

2.2.1 Water supply management

Since the start of South Africa's main economic development at the end of the 19th century, the country has faced water scarcity. The development of the water sector and the supporting water policies have therefore always implicitly been linked with the solution of water scarcity problems. This has resulted in a water supply industry that is structurally well designed and well managed. Historically policy has focussed on providing large infrastructure such as reservoir construction, infrastructure development, inter-basin transfers and trans-boundary schemes, and institutional support systems to supply areas of water scarcity with more water. However, these approaches have become increasingly expensive and less feasible as potential areas of development are difficult to access and often lie great distances from the end user. Supply-side options have also encouraged the overuse of what was perceived to be a relatively 'cheap' resource, abundant in supply and almost a 'free good'. In the NWA however, water demand management has become the favoured approach to meeting growing water use requirements, while water supply interventions focus on providing affordable water for basic household use through water services projects.

2.2.2 Water demand management

Although some of the findings of the Commission of Enquiry into Water Matters in 1970 indicated that South Africa would have to embark on a water demand management (WDM) route in the future, the NWA formally adopted a WDM approach for SA for the first time (DWAF, 1970). Water demand management is required in a situation of water scarcity where competition arises between water users and water supply interventions are no longer adequate. The approach adopted by DWAF for WDM consists of two phases. The first phase plans to improve intra-sectoral allocatable efficiencies through engineering solutions. DWAF is currently actively exploring this phase of water demand management intervention through the development of their Water Demand Management (WDM) strategies, and the implementation of Water Management Plans. Within this context, a lot of emphasis is currently given to improving water use application (e.g. fixing leaks); evaluation of regulation-based water allocation; and good water management practices (e.g. water accounting, best management practices, training). This first phase requires that the full cost of water supply is recovered. This also means that historical subsidies established under prior legislation, are phased out. In the second phase, it is recognised that engineering and other cost recovery solutions no longer sufficiently address water scarcity, and the only way to effectively balance the water budget is to introduce a policy of inter-sectoral allocative efficiency, diverting water from users with low economic return to users with higher return. Water charges or tariffs, as well as market forces through water pricing are used to address water scarcity during this phase.

The Act calls for the development of a National Water Resources Strategy (NWRS) and individual Catchment Management Strategies for the 19 Water Management

Areas into which SA has been divided. These Water Conservation and Demand Management (WC/DM) strategies form the framework within which water demand and supply will be managed in South Africa.

2.2.3 Property rights

Historically, the value of water has been reflected in land prices, as farms and industrial sites near rivers, dams or other water rich areas were priced relatively higher. Although water laws distinguished between public and private water, the riparian rights principle dominated water entitlements. This principle gives exclusive rights to the use of stream water to the owners of the riparian (adjoining) land. Riparian rights were then modified in a series of acts under the pressure to accommodate non-riparian demands from industrial and urban expansions and in recognition of the high variability of water supply. The first of these modifications restricted riparian access to normal flows, while surplus flows were stored and diverted to non-riparian users. This was known as the principle of proportionate apportionment, and significantly increased state involvement in water supply management. Restriction on afforestation in general, and near riparian lands in particular, was also introduced (the Afforestation Permit System) to reduce its water abstraction and stream flow reduction impacts (Hassan, 1998).

Under the NWA, water is regarded as common to all. Government, through the Minister of Water Affairs and Forestry remains the ultimate custodian of the country's water resources, and therefore manages and allocates the rest of the water on behalf of the country, to all water users. Water use is regulated by the Act through the use of licensing and authorizations, which may have conditions attached specifying management practices and general requirements for any water use, including water conservation measures (s29(1)(b)(i) NWA). To this end, DWAF is currently running a water registration and licensing process, to be completed by 2015 (Rademeyer, DWAF). This is a clear abolishment of the riparian rights principle.

In practice however, the flow of water cannot be fully controlled, as the natural environment determines precipitation, evaporation and its flow properties. The above factors therefore make water somewhat more of a quasi-public good, although by law it is a public good, access to water is geographically limited. In addition, due to the complex hydrological system of water distribution, metering of water supply and demand is sometimes impossible and often not economically viable. This has important implications for water demand management implementation, which would be made considerably easier if the assigned licenses and authorizations could be accurately measured. Under the NWA, water measurement is recognised as a great need and large emphasis is placed on this under the water demand management strategies forthcoming from the Act (Wilkinson et al. 2003).

2.2.4 Water management institutions

Prior to the NWA, water management relied mostly on centralised state involvement. This involved central planning of water resources management. State involvement extended to the establishment of irrigation boards and construction of public water supply works for irrigation and other purposes. In a few instances, some of these irrigation boards privatised and developed their own water supply and demand management strategies and systems (Wilkinson et al. 2003). In a number of cases, Water Boards were instituted by the Minister of Water Affairs to determine the existing and future water demands of user groups in water scarce areas, and to provide the infrastructure needed to supply the required water in time and more economically than would otherwise be possible.

There is major departure in the NWA from the above organisational arrangements. A major emphasis of the NWA is on participative governance in order to ensure the participation of interested parties in the development, apportionment and management of water resources (Hassan, 1998). This dictates that DWAF becomes an enabling organisation, rather than an implementing agent. Implementation is decentralised to privatised Catchment Management Agencies (CMAs) and Water Users Associations (WUAs). Local authorities and Water Boards remain important organisational role players through the WUAs. These bodies are to function on private sector business principles, focussing on efficiency, which may have an important effect on reducing the cost of water supply.

The water supply organisational structure under the NWA therefore has a number of levels:

Government - Department of Water Affairs and Forestry (DWAF): The NWA dictates that no private ownership of water exists and that the country owns the resource. DWAF, as the custodian of the water resources of South Africa, dictates policy goals and management objectives in terms of equity, sustainability, and efficiency. It oversees the allocation of raw water rights and large capital expenditure projects such as dams and transfer schemes within and between catchments. Decision-making is then decentralized through Catchment Management Agencies (CMAs), Water User Associations (WUAs), Water Boards and various local governing bodies (DWAF, 1999).

Catchment Management Agencies (CMAs): CMAs are statutory bodies established under the NWA to manage water resources within a defined WMA (water management area). South Africa has been grouped into 19 WMAs, based on watercourse catchment boundaries; social and economic development patterns; efficiency considerations; and communal interests within the area in question (NWA, 1998). CMAs are to be governed by committees representing the interests of water users, potential water users, local and provincial government and environmental interest groups. The role of the CMA will be to prepare and give effect to a catchment management strategy (DWAF, 1999). It is envisaged that the first CMAs will only start operation by 2005, until then, DWAF regional offices will perform the role of CMAs (Karodia, 2000).

Water User Associations: WUAs consist of cooperative associations of local water users who aim to undertake water-related activities that will lead to communal benefit. They enable the pooling of local resources in order to realize local needs and priorities that are not in conflict with the water strategy for the area. A process is currently in place whereby irrigation and water boards are privatising to form WUAs.

Water Boards: Water Boards remain functioning as under the previous water act. They are supplied with raw water in bulk from national water schemes, and/or groundwater sources. They are responsible for water purification and for bulk distribution to different user groups within their areas of jurisdiction. Normally they would not undertake the distribution of water to individual users within the boundaries of the local authority.

Local Government - District Councils & Local Authorities: The management of water resources is further disaggregated to a local area. Local governments oversee all activities that are not carried out at a national or provincial level by government. They cover the authority of district councils and local authorities or municipalities. They generally buy water from their respective water boards and supplement these supplies through some of their own sources, such as municipal storage dams and groundwater supplies. District councils act to ensure that funds are raised to meet the development needs that would benefit more than one local authority. Local authorities however focus particularly on the metering and management of water within their municipal boundaries.

These organisations will be required to make the NWA work and require good information on water resources management scenarios.

2.2.5 Water tariffs and subsidies

Historically, waterworks were constructed as social welfare projects aimed at developing the country, and focused on the irrigation agriculture sector. However, generic water policy (DWAF, 1970), under the recommendation of the Commission of Enquiry into Water Matters recognized that water resources needed to be allocated among different users in such a way that the marginal benefits were the same for all. On the one hand, therefore, all waterworks were financed and operated on the principles of commercial business, aimed at the full cost recovery of all services. On the other hand, allocations made in the interest of national development objectives became dependent on the payments of regularly reviewed subsidies in order to cover their operating expenses (DWAF, 1970; DWAF, 1986).

Under the National Water Act of 1956, it was decided not to recover only the full cost of services for ***irrigation and stock watering***. Tariffs were set to recover operating costs of the scheme. However, households supplied from agricultural systems were charged the full cost. The policy (Water Act of 1956) on water pricing for domestic and industrial use was to supply water at a tariff that recovered the full-allocated cost of the service. Water tariffs historically formed a small portion of production costs in the ***municipal and industrial sectors*** and subsidization of industrial and municipal water schemes was only considered when the unit cost to the consumer rose above a specified level. The tariff was set at a level that recovered the capital, interest charges, and operating costs of the supply scheme, adjusted for inflation and deviations in water sales patterns (DWAF, 1970). A subsidy for the care or construction of ***water works,*** including sewerage treatment works of local authorities, water boards and regional water service corporations was applied at the discretion of the Minister of Water Affairs.

The NWA determines that the administered price paid by major users for water be progressively increased to meet the full financial costs of making it available and to reflect its benefit to society. Therefore, the NWA identifies four policy goals for its (administered) pricing policy: improving social equity, ensuring ecological sustainability, ensuring financial sustainability and improving efficiency. It is also recognized that subsidies should be reviewed on an annual basis, made public and paid annually, based on the annual cost of water supply, so that the annual price of water may fairly reflect the current price-structures and economic conditions within the country.

The pricing policy has three tiers:

- In the first tier, raw water tariffs are set by DWAF, based on catchment management budgets and water use quantities.
- In the second tier, Water Boards administer the wholesale price for much of the water supplied to urban areas in South Africa. These prices are based on management costs.
- In the third tier, local government sets the administered price (Eberhard, 1999).

The National Water Pricing Strategy (DWAF, 2003) proposes that the full financial cost of 1st tier water eventually be recovered from water users. The effect of this policy is evident from analysis of the tariffs for the 1995/6 to 2000/1 period, where real tariffs for ***urban & industrial*** and ***irrigation*** water use increased by 6% and 27% per year, respectively (Crafford et al. 2001).

The Water Trading Accounts (WTA) of DWAF displayed in Table 2.4 indicate that subsidies on bulk water supply decreased from 57% in 1997/98 to 35% of total expenditure by bulk water supply programmes in year 2000 (Hassan and Blignaut, 2003). This can mainly be attributed to the gradual application of the NWA principles, which aim to reduce water subsidies. Nevertheless, the financial subsidy on water services in SA amounted to about US$121 million in the year 2000.

Table 2.4: Water Trading Accounts for SA (1997/98 to 2000/01): R million

Sub-programme	Expenditure outcome		
	Audited 97/98	Audited 98/99	Preliminary outcome 99/00
Integrated catchment management	224	253	242
Integrated systems	155	989	1 139
Bulk water supply	224	281	291
Water services	845	655	727
Total estimated expenditure	1 448	2 178	2 399
Less: estimated revenue	*618*	*1 458*	*1 560*
Deficit to be voted (subsidy)	*830*	*720*	*839*
Subsidy as % of total expenditure	*57.3*	*33.1*	*35.0*

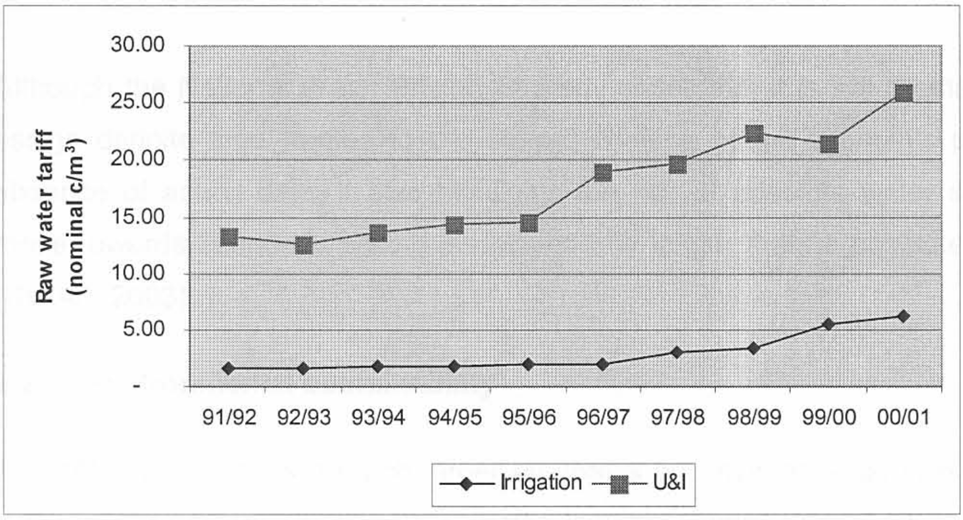
Source: Hassan and Blignaut (2003)

According to the recent water resource accounts in SA, agriculture received the highest financial subsidy on water use reaching more than 80 per cent of delivery costs while other use sectors were subsidized at about 46 per cent of delivery costs (Crafford et al. 2001). However, it is important to note that while large commercial farmers received the biggest share of water subsidies in the past, most of the subsidies in recent years went to extending basic water and sanitation services to previously disadvantaged communities who were excluded from such a service in the past.

Therefore, the planned pricing at full cost recovery for commercial uses and the cost implications for plantations and dry land farming as well as uses of underground water could induce major adjustments in water allocation and water use patterns. This is demonstrated by the increase in average water tariffs charged by DWAF-operated raw water supply schemes as shown in Figure 2.6. Raw water tariffs stayed relative constant until 1995/6, and have since nearly doubled for the urban &

industrial sector and trebled for the irrigation sector. During the 1995/6 to 2000/1 period, tariffs for urban & industrial and irrigation water use increased by 6% and 27% respectively, per year in real (inflation excluded) terms (Crafford et al. 2001).

Figure 2.6: Nominal water tariffs for South Africa (c/m³)



Source: Crafford et al (2001)

2.2.6 Water Pricing

The approach of the NWA to cost recovery and subsidisation of water supply has an important bearing on water pricing. Flowing from the Act is the National Water Pricing Strategy. This document does not use the term "water price" in an economically correct sense. Its economic definition implies that the price of water is determined by the market clearance of demand and supply in a well functioning market. In layman's terms, therefore we can only talk of a price for water where a market for water exists. The water charges, based on cost of water supply, that is often referred to as water price, is therefore rather an administered price or a tariff. The National Water Pricing Strategy accordingly recognises the role of water pricing in a market system (phase 2 of water demand management) as it states that financial charges (administered prices or tariffs) may be supplemented by an economic charge in water-scarce catchments, in order to reflect the relative scarcity of water as a commodity at a given time and place and thus to promote the efficient allocation and beneficial use of water. These economic charges (water prices) will therefore reflect the long-run marginal cost of supply and distribution, and will prevent water from being overused by those economic sectors that add relatively low marginal economic output. A pricing system whose charges are equal to the marginal costs of providing the water (as would happen in a well-functioning water market) will allocate resources most efficiently. It will encourage the innovation and adoption of new water-saving technologies and processes for which water demand management strives.

Although the National Water Pricing Strategy states that it is still premature to even assign definite time frames to the staged phasing of full economic pricing in the absence of actual data, it also highlights the risk of absolute water scarcity if the move towards economic pricing is delayed any longer than is absolutely necessary (DWAF, 2003).

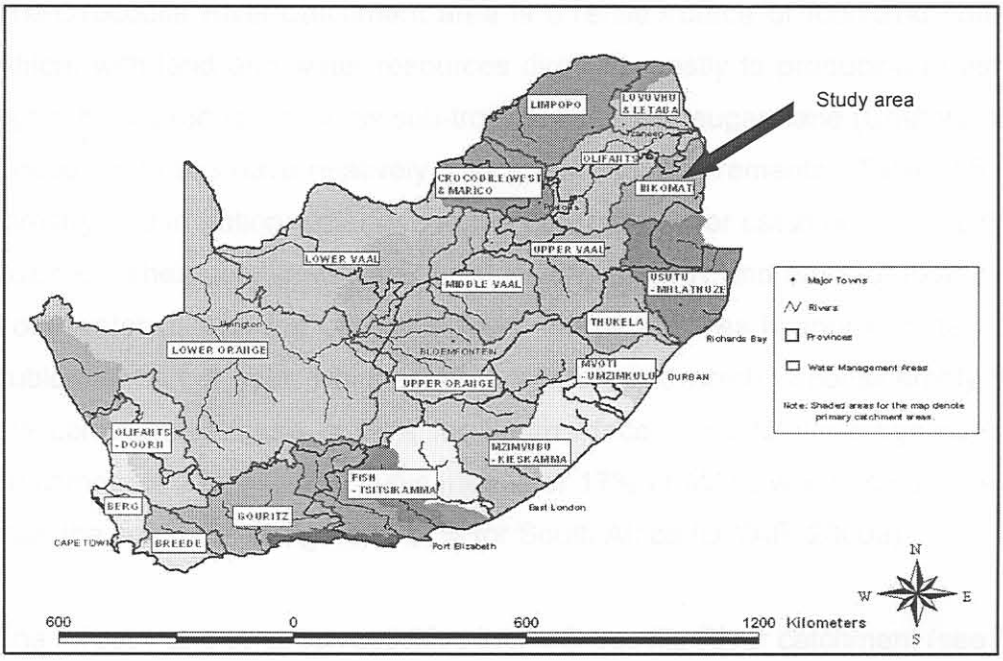
2.2.7 Environmental sustainability

The NWA also places a much larger emphasis on environmental sustainability and water conservation. Historically, water law did control industrial water pollution through permits, however, the NWA aims to set and maintain environmental standards relating to stream flow and groundwater and wetland sources. There is an increased emphasis on correcting environmental externalities and internalising their social costs. This is especially evident in the establishment of water resource quality objectives, and the development in the sector of water ***conservation*** and demand management strategies.

2.3 Water resource use and allocation in the study area: the Crocodile River Catchment

The Crocodile River catchment forms part of the Inkomati Water Management Area within the Mpumalanga province (Figure 2.7). It is located approximately 300 km east of Johannesburg, and covers an area of approximately 10 500 km^2 (14% of the land area of Mpumalanga). The Crocodile River is the largest tributary of the Komati River, and joins the Komati River shortly before it enters Mozambique, although the Komati does not form part of the catchment area. The Crocodile River basin comprises the X200 drainage region as defined by the DWAF Quaternary Drainage Regions Map (Olbrich and Hassan, 1999).

Figure 2.7: Water Management Areas of South Africa.



The Crocodile River catchment receives a mean annual precipitation (MAP) of approximately 865mm, which is 13% of the total precipitation in the province, and carries nearly 17% of the province's runoff. Rainfall is the major source of water supply in the catchment. In addition to eight major dams, with capacity ranging from 0,85 to 161 million m^3, there are over 200 small farm dams within the catchment (Olbrich and Hassan, 1999).

Table 2.5: Runoff availability and water use in South Africa, Mpumalanga, and the Crocodile Catchment.

	Total precipitation (10^6 m^3 yr^{-1})	MAP** (mm yr^{-1})	MAR*** (10^6 m^3 yr^{-1})	Water Use (10^6 m^3 yr^{-1})			
				Households	Forestry	Irrigation	Industrial*
South Africa	611,601	500	54,677	2,026	1,610	9,026	1,973

Mpumalanga	66,173	883	7,509	213	736	1,503	462
Crocodile	8,614	865	1,263	19	230	243	37

*Industrial, mining, commercial, strategic, other

** Mean Annual Precipitation

*** Mean Annual Runoff

Source: Crafford et al. (2002)

The Crocodile River catchment area is a fertile source of food and fibre for South Africa, with land and water resources directed mostly to producing forest and other agricultural products such as sub-tropical fruits and sugar cane (Crafford et al. 2002). These land uses have relatively high water use requirements. Table 2.5 shows that forestry and irrigation water use in the Crocodile River catchment are fairly similar in volume. Their combined water use[3] is 37% of MAR and 5,5% of total precipitation. Total water use for the Crocodile River catchment area is approximately 529 million cubic metres per year, which is 42% of MAR, and which is considerably higher than the comparative figure of 28% for South Africa. The total storage capacity in the catchment is 221,7 million cubic metres or 17% of MAR, which is considerably lower than the comparative figure of 57% for South Africa (DWAF, 2000a).

The forestry and irrigation activities in the Crocodile River catchment (see Figure 2.8) produce round wood, sugar cane and sub-tropical fruit. These commodities are extremely important to the Mpumalanga economy as they support extensive forward-linked sectors, contribute substantially to GDP and employment creation, have large amounts of capital invested and contribute positively to the national balance of payments (see Table 2.6). Mpumalanga contributed 8.2% to the national GDP in 1994 (DBSA, 1998).

[3] The hydrological impact of plantation forestry is measured as incremental use. This can be described as the difference in evapotranspiration between the forestry plantation and the natural vegetation it has replaced. The hydrological impact of irrigation is measured as direct abstraction from the river.

Table 2.6: A comparison of major water using sectors and their associated value chains in Mpumalanga (R 'Million) for 1998 (unless otherwise indicated).

	Agriculture			Manufacturing	
	Forestry	Sugar cane	Sub-tropical fruit*	Wood & Paper Products	Food & Beverages
Total Output (R' million)	R1 258[4]	R225[10]	R350[10]	R1 657[5]	R1 843[10]
GGP Contribution (R' million)	R686[6]	R77[11]	R110[11]	R943[10]	R632[10]
Land area (ha)	647 570[7]	32 520[12]	11 200[12]	na	na
Employment (number)	54 275[8]	10140[13]	na	18 110[10]	11 084[10]

The Mpumalanga economy is divided into three sub-regions by the DBSA (1998): Lowveld, Highveld and Eastveld. The GGP at factor cost in 1994 was R5 304M, R10 865M and R15 372M, respectively, in each of these regions (see Table 2.7). The Highveld and Eastveld regions are dominated by mining, manufacturing and energy generation activities, associated mainly with the extensive coal mining activities of these regions. The study area for this research project is concentrated within the Lowveld region, where agriculture plays a much larger role. The Nelspruit magisterial district, where the bulk of manufacturing and commerce takes place, dominates the Lowveld economy. The other nine magisterial districts have mainly agriculture-based economies. No additional economic data for the Crocodile River catchment were available.

[4] Estimate, based on national average production

[5] in 1994, DBSA, 1998

[6] Estimate, based on Total Production and Supply & Use Tables (StatsSA, 2000)

[7] Estimate, based on Total Production and national yield values

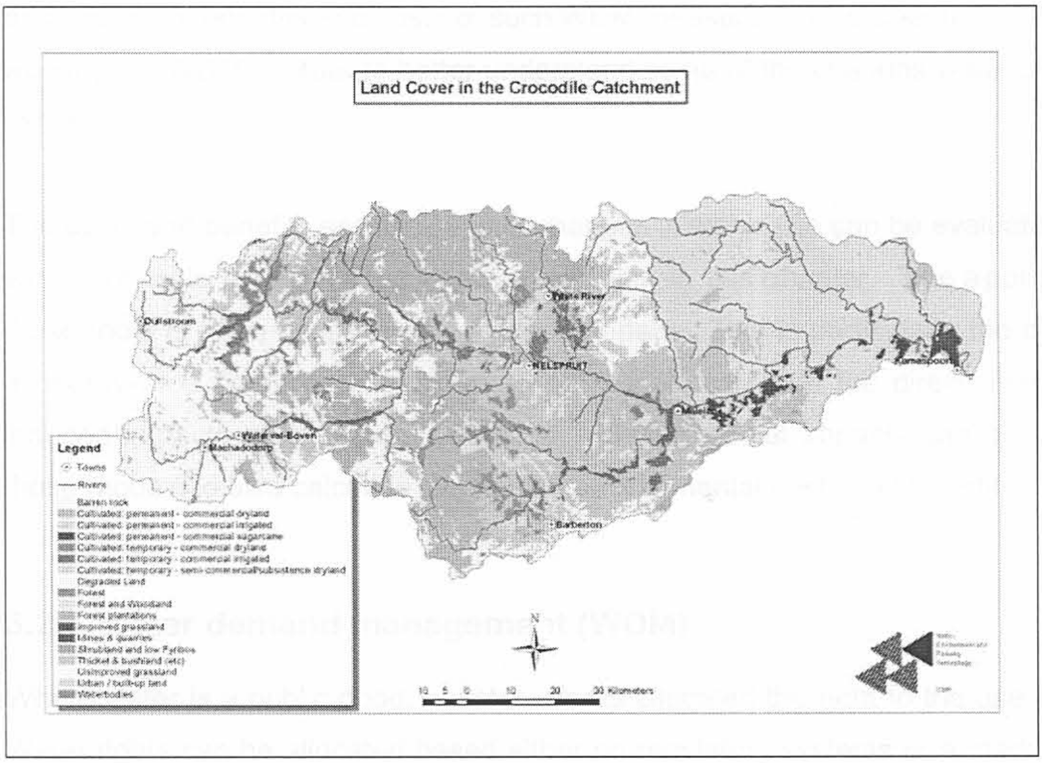
[8] Estimate, based on Total Production and national employment values

Table 2.7: The GGP at factor cost and current prices (1994) in the regional economy of Mpumalanga

	Lowveld		Highveld		Eastveld		Total Mpumalanga	
Agriculture	711	13%	633	6%	1,118	7%	2,462	8%
Mining	360	7%	2,672	25%	3,337	22%	6,369	20%
Manufacturing	1,426	27%	1,459	13%	4,963	32%	7,848	25%
Energy	98	2%	2,987	27%	3,306	22%	6,391	20%
Construction	176	3%	255	2%	235	2%	665	2%
Commerce	739	14%	824	8%	681	4%	2,245	7%
Transport	331	6%	482	4%	363	2%	1,176	4%
Finance	458	9%	535	5%	480	3%	1,472	5%
Services	1,005	19%	1,020	9%	890	6%	2,916	9%
Total	5,304		10,865		15,372		31,544	

Source: DBSA (1998)

Figure 2.8: Land use in the Crocodile River catchment.



Chapter 3 – A survey of the relevant literature on water demand management and measurement of the costs and benefits of water use for production

3.1 Background

Water users in South Africa can expect to experience a range of WDM measures that will impact on the way they use water. These measures include: reduction of subsidies, changes in water tariff strategies, greater emphasis on environmental conservation, greater emphasis on metering of water quality and quantity, and changes in water allocation mechanisms. In order to prepare for these changes, and to ensure that the equity, efficiency and sustainability principles of the NWA are adhered to, policy makers and water users need information on the expected social and economic benefits and costs of such WDM measures. This Chapter explores the workings of WDM in order to better understand some of the changes water users can expect.

The costs and benefits associated with changes in water use can be evaluated with a variety of tools, which will be briefly introduced in this chapter. The application of these tools is often constrained by a lack of data. This is particularly the case with economy-wide modelling. Economy-wide models calculate the direct, indirect and induced impacts of changes in demand. Environmental impacts can be linked to these models to also calculate associated environmental costs and benefits.

3.2 Water demand management (WDM)

Where water is a public good, a water user is allocated the right to the use of water. Water rights can be allocated based either on regulatory systems or a market-based system of water trading. The three regulatory systems are: riparian rights, prior (appropriative) rights and public allocation (Rosegrant, 1994). Riparian rights link the use of water to ownership of adjacent or overlying lands; while the prior rights system is based on the appropriation principle where the water right is acquired by actual use over time (this is also referred to as a grandfather right). Public allocation systems can make use of instruments such as licences, permits, and administered tariffs or even opportunity cost pricing to allocate water. Water trading, on the other hand, is a market driven system that allocates water to the highest valued use of water. Many arguments exist against and in favour of each of these systems, and certainly in South Africa much debate still awaits the implementation of water allocation systems as we approach situations of absolute water scarcity.

In the normal course of economic development, the riparian rights and/or appropriative systems are usually the first to be in place. Public allocation systems are implemented after water demand has reached a level where water supply systems have become inadequate (see section 3.2.2) and it is under these conditions that WDM focuses on water application efficiency and full cost pricing. Water allocation according to the economic or scarcity value of water is normally the last to be introduced (Rosegrant, 1994). This is the so-called ***second phase*** of water pricing as defined in the NWPS (section 2.2.2)

Where water is scarce, ensuring equity, efficiency and sustainability in water allocation and use (as defined by the NWA) is of concern. WDM interventions that focus on application efficiency are primarily concerned with reducing water wastage; whereas water trading strives, in addition, for efficient allocation of water. Equity of water allocation is a contentious issue in all the water allocation systems discussed, as special interventions have to be undertaken to ensure the desirable equitable allocation and use of water. As many catchments in South Africa approach situations of absolute water scarcity, the uncertainties surrounding water allocation based on its scarcity value need to be better understood.

3.2.1 Water Trading and Water Markets

Trading water in water markets is a means of allocating water supplies in South Africa (Backeberg, 1997) according to its scarcity value (as indicated by the second phase of the NWPS approach to water pricing). At the same time adherence to the core principles of the NWA: ensuring equity, efficiency and sustainability in water allocation and use, has to be achieved. Therefore, before a water market can function as a formalised WDM system, a number of important elements need to be in place and/or addressed (Rosegrant, 1994, Armitage et al. 1999):

- Well-defined and non-attenuated property rights need to be wholly specified, exclusive, transferable, and enforceable. The water licensing process currently being implemented by DWAF is an example of this.
- Externality issues need to be addressed. Property rights need to be defined well enough in order to make the user of the water right internalise the effects of overuse of water, negative impacts on water quality and other environmental impacts.
- The assumption of zero transaction costs does not hold true in markets for water rights, where information, conveyance, and enforcement costs may be high. In the case of water markets a regulatory structure is required to enforce contracts, protect third-party interests and resolve conflicts and effective water metering needs to be implemented. The initial water allocation rights also need to be allocated equitably.
- User involvement in the establishment of a water market and in subsequent investment decisions needs to be formalised.
- The natural variance of water supply and the design of water rights need to be dealt with.
- The inherent value or scarcity of the water must be sufficiently high for the benefits from water trading allocation to be realised. This means that the long run supply of delivered water becomes inelastic; the demand for delivered water increases rapidly; inter-sectoral competition emerges; and environmental externality problems arises (water quality reduction: land and groundwater salinity, pollution; other negative environmental impacts)

In spite of the above types of constraints, economists have favoured markets as the solution to the allocation of most commodities and inputs. Coase (1960) showed that market allocation would be efficient, given well-defined and non-attenuated initial property rights and zero transaction costs. However, even in a world of transaction costs, markets in tradable water rights may lead to considerable equity, efficiency and sustainability gains (Rosegrant, 1994):

- Empowerment of water users by requiring their consent to any reallocation of water and compensation for any water transferred.
- Provision of security of water rights tenure to the water users. If well-defined rights are established, the water users could invest in water-saving technology knowing that they would benefit from the investment.
- Forcing of water users to consider the full opportunity cost of water, including its value in alternative uses, thus providing incentives to efficiently using water and to gain additional income through the sale of saved water.
- Providing incentives for water users to take account of the external costs imposed by their water use, reducing pressure to degrade resources.
- In situations and areas of absolute water scarcity, markets provide a more acceptable allocation approach to major water users than mere volumetric pricing (based on opportunity cost tariffs). Major water users would see volumetric pricing as expropriation of traditional water rights, which could create capital losses especially in established irrigation or forestry areas.
- Provision of maximum flexibility in responding to changes in commodity (e.g. crops) prices and water values as demand patterns and comparative advantage change and diversification of production (e.g. crop proceeds). The market-based system is more responsive than centralised allocation of water.

The formalisation of a WDM water market system requires a thorough understanding of the above elements and benefits. This is important so that planning and preparations for dealing with scarcity can be done. In particular, the measurement of water use efficiency is required to better understand the direct and indirect contribution of water to the economy. Sustainability of water use refers to the maintenance of institutions and infrastructure but also environmental sustainability, this also has to be measured. One of the tools used for the analysis of water use efficiency, sustainability and social equity, is economy-wide modelling.

3.2.2 WDM defined in SA

As discussed in section 2.2.2, water demand management (WDM) plays a fundamental role in the NWA. Although much has been written about the subject, and the definition and purpose of a WDM paradigm is self-explanatory, recent South African literature approaches water demand management differently:

- Firstly, the ***National Water Pricing Strategy (NWPS)*** (discussed in section 2.2.2 above) approaches WDM as two phases, with the ***first phase*** intending to improve intra-sectoral allocative efficiencies through engineering solutions with emphasis on improving water use application, regulation-based water allocation; and good water management practices. The ***second phase***, which is dealt with very briefly, introduces water allocation mechanisms that depend on the pricing of water at its scarcity or economic value. The Strategy makes provision for the second phase in catchment areas where situations of absolute water scarcity exist, i.e. where water demand outweighs supply.
- Secondly, in a Workshop on WDM in South Africa held on 20-21 July 1998 by DWAF, WDM was defined as a *water resources management approach* that involves the application of *sector specific technical, economic, and social methods and incentives*, to promote *efficient, equitable and beneficial use of both water and financial resources* (Haasbroek, 1999). This definition is further explained in Table 3.1; where WDM attributes are spread across a matrix of technical, social and economic; versus crisis, operation and long-term methods. When comparing this definition of WDM to the approach of the NWPS, it becomes apparent that the bulk of the attributes listed in Table 3.1 relate to improving water use application, regulation-based water allocation; and good water management practices, which are aims of the so-called first phase of the NWPS. The attributes highlighted in Table 3.1 represents the "phase 2" of the WDM definition according to the National Water Pricing Strategy.

Table 3.1: A definition according to Haasbroek (1999) of the attributes of water demand management.

Method	Crisis: (Drought/ non-payment)	Operation	Long term (Planning and design)
Technical	Pressure reduction, Scheduled use, valve	Flow control Manipulate orifices	Metering Loss control
Social	Appeal, social persuasion Advertisements	Legislation	Consumer education
Economic	Fines Punitive measures	Differential tariffs Trade	Supply and demand economics. Marginal prices

- Thirdly, during the course of 1999 and 2000, ***DWAF developed WDM Strategies*** for all the major water-using sectors in South Africa (DWAF, 2003). From these processes, another definition of WDM arose through the identification of three approaches to WDM:
  - Approaches to achieve efficient **allocation** of water,
  - Approaches to **apply** water efficiently and without waste,
  - Approaches to maximize water **productivity**.

  The ***allocation element*** is deemed to have an inter-sectoral, as well as an intra-sectoral component and deals with approaches through which decisions on water allocation are made. The ***application element*** deals with activities such as fixing leaks, and reducing other losses that occur during the transport of water from the source to the use. The ***productivity element*** relates to the total benefits produced per volume of water consumed. The emphasis here is on the elements that are important to WDM, whether a regulatory or a market-based approach to water allocation is taken, wastage has to be minimised (application) and productivity maximised.
- Finally, ***Turton (2000)***, in an article entitled "Water Wars in southern Africa", gave context to WDM by mapping the social response to increasing water scarcity in three phases, the onset of which are indicated by three "squeezes":

- At the first "squeeze", water changes from being an open-access resource, into a socially managed good. Water ceases to be a free good, but has a price tag, mainly determined by its distribution costs. This phase focuses on supply-side solutions to scarcity.
- At the second "squeeze", competition arises, and the winner is usually the user that can afford the larger transfer schemes. This phase is typically characterized by a shift to water demand management interventions with the intention to improve intra-sectoral allocative efficiencies.
- At the third "squeeze", engineering solutions are no longer sufficient, and the only way to effectively balance the water budget is to introduce a policy of inter-sectoral allocative efficiency, taking water from users with low economic return, and allocating it to users with higher return.

It can be deduced that WDM will first improve intra-sectoral efficiencies, thereafter, once absolute water scarcity has been reached, WDM will be guided by allocations according to economic return.

Although the authors of the above-mentioned definitions are from diverse backgrounds (regulatory, hydrology and engineering, economics, political science), they all appear to agree that WDM aims to firstly ensure efficient use and application of water; but once absolute water scarcity exists, economic allocation mechanisms are required. In the context of the National Water Pricing Strategy, this means WDM firstly requires full cost recovery (which will buy time[9]), and secondly pricing water at the economic, scarcity, value.

According to the above definitions, water users in South Africa can therefore expect to experience a range of WDM measures which could include changes in water tariffs (reduction of subsidies, changes in water tariff strategies), greater emphasis on environmental conservation, greater emphasis on metering of water quality and quantity, and changes in water allocation mechanisms. In order to prepare for these

[9] In a WDM case study done in Hermanus, a town in the Western Cape Province of SA, water authorities have determined that intensive WDM application efficiency measures have bought the town an additional 9 years of water supply (Haasbroek, 1999).

changes, policy makers and water users need information on the expected beneficial and costly effects of these WDM measures.

3.3 Measuring the benefits and costs of water use

The single largest difficulty in measuring the costs and benefits of water use is the absence of reliable water use and water market data for valuation purposes. This is mainly attributable to the fact that water is in many instances not traded in the market as well as the practical difficulties associated with measuring water quality and quantity. However, a number of techniques have been used for measuring the value of access to water services (of suitable quality and quantity) as listed in Table 3.2.

Table 3.2: Techniques for measuring the benefits and costs of water use

Technique		Major Uses	Type of Value
Revealed preference			
1	Sales and rentals of water rights	Irrigation, municipal use	Marginal value
2	Hedonic pricing	Irrigation, recreation, water quality	Marginal value
3	Demand functions from water utility sales	Industry, consumer	Total economic value
4	Residual value	Irrigation	Average value
5	Change in net income	Irrigation, industry	Marginal value
6	Production function approach	Irrigation, industry	Marginal value
7	Mathematical programming models	All direct uses	Marginal value
8	Alternative cost	Irrigation, industry, municipal	Marginal value
9	Travel cost	Recreation, water quality	Total economic value
10	Benefits from damage averted	Water quality, waste assimilation	Marginal or average cost
11	Costs of averting damage	Water quality, waste assimilation	Marginal or average cost
Stated preference			
12	Contingent valuation method: willingness-to-pay (WTP or WTA)	Consumer demand, recreation, water quality, ecosystem function	Total economic value
13	Conjoint analysis	Consumer demand, recreation, water quality, ecosystem function	Total economic value

Source: Hassan and Lange (2003)

The theoretically correct method of measuring water value is to measure the marginal contribution of water to the value of output or utility of its user. This is based on the principles of micro-economic theory. These marginal values are derived from the optimality conditions of maximizing the profits of water using firms or the utility of the water consumer. Such behavioural models are used to derive the input demand for water use by producers or consumers. Depending on the type of data available, the said theoretically correct measures can be derived directly from observed market data (dual approaches) or indirectly from production or utility function optimisation (primal approaches). To apply the dual (direct) approaches, one needs to observe market information on prices and quantities of water traded, revealing the preferences of water buyers and sellers. In many instances however, water is not traded and hence no such market information is available to enable direct specification of water demand curves. In some instances, although water is not exchanged in the market, one can indirectly construct a demand curve for water from a measure of the physical contribution of water to production (i.e. output-water response production functions). In many cases, neither the required market information nor data describing the technical relationship between water and output (production functions) are available. In such a case alternative methods used include cost-based criteria (preventative expenditure, damage costs, water purification costs, opportunity costs of time, etc). Cost-based methods, however, also require certain data that are often not available, in which case; non-market valuation techniques (such as willingness-to-pay) are used.

In broad terms, these techniques can either be classified as marginal or average analysis techniques. The marginal value of water is the price of water, and reflects the scarcity value of water by showing how an incremental change in water consumption or supply will influence the contribution of water to utility or profits. The average analysis techniques produce results that provide proxy measures of water value, and are often used at a macro level for strategic planning.

Marginal analysis techniques are greatly constrained by the absence of data. It requires time-series and/or cross-sectional data on water use and water price or production activities. Water use data for many activities are unreliable or not available due to poor water metering infrastructure. Water prices are not available when water is not traded or charged. Information on the technical production relationships between water and output or yield is often highly confidential. Average valuation methods, on the other hand, are much less data intensive, but indicate the direct benefits and costs associated with water use.

In order to gain a better understanding of the total benefit from water, the indirect benefits and costs of water use also need to be assessed. The indirect effects have two components: an economic multiplier effect and an environmental externality effect. The multiplier effects are calculated by the use of economy-wide models that capture the linkages between various economic sectors (Hassan, 2003). The externality effects are calculated from the environmental impacts associated with the economy-wide model.

The selection of the most appropriate technique is dependent on data availability. In the case of the Crocodile River Catchment, a recent study captured primary data and used average analysis to determine the costs and benefits of water use (Crafford et al. 2003). This study made use of the value added (VAD) technique for assessing the direct and indirect benefits and costs of water use for production purposes in the case study area. Every economic activity uses final goods and services produced by other sectors as intermediate inputs to generate new goods and services. The proceeds from the new production (value of the generated products) minus the cost of intermediate inputs bought from other sectors give VAD in the economic activity in question. This represents an extra value generated from the employment of primary factors of production such as labor, land and capital over and above the cost or value of intermediate inputs produced and supplied by other activities. Accordingly, VAD contains the returns to all resource factors employed in the production process, i.e. wages and remuneration of employees, profits and surplus margins to resource/capital owners, taxes to government, etc. In general VAD is defined as:

VAD = Remuneration of employees + Operating surplus + Government tax revenue

VAD however, does not derive an estimate of the price of or return to an individual resource factor, but rather the residual value of the total contribution of all resource factors exclusive of intermediate input costs. It is important to emphasize that while

VAD provides a better crude proxy to the average residual benefits from resources' use; it is not a measure of the marginal value of water (Hassan, 2002). Similar data were generated in a South African water resources accounting study, commissioned by the Resource Accounting Network of Eastern and Southern Africa (Crafford et al. 2001). This study also used VAD as a proxy measure of the economic benefit of water use.

3.3.1 Economy-wide models

Direct and indirect economy-wide effects of economic transactions can be captured using multi-sector models. These models are extensively used in the literature to generate production and operations plans and to perform general equilibrium analysis. The Input-Output (I-O) framework based on the linear structure of inter-industry production linkages pioneered by Wassily Leontief (1953) marked the beginning of multi-sector planning. The most important product of the I-O framework is what is known as "the total input requirements matrix", which is used to calculate the direct and indirect intermediate inputs' requirements per extra unit of output or VAD to be generated in any particular sector. For more details on the structure and use of I-O tables models see the more technical section 4.2.

I-O models and multipliers have been extensively used in the early literature analysing growth linkages between various economic sectors and especially investigating the role of agriculture and industry as engines for economic growth. The said literature arrived at the conclusion that agriculture had weaker linkages to other sectors of the economy compared with manufacturing industries and hence the focus on promoting growth should be placed on non-agricultural sectors (Hirschman, 1958). The major problem with and limitations of the I-O framework is that it only captures production or supply-side linkages. It has been later argued by others that while agriculture may have small effects on growth outside agriculture due to its relatively weaker production linkages, demand linkages from agriculture through consumption spending have large impacts on growth in other economic sectors. This is thought to be mainly due to the high impact of agricultural expansion on income and the consequent demand for consumer goods by rural populations, especially in developing countries where large segments of the population are employed in agriculture (Mellor, 1976; Adelman, and Morris, 1973; Hazell and Roell, 1983).

The later views and research results led to the emergence of alternative approaches to analysing growth linkages that incorporate demand and consumption feedback effects (Mellor, 1976; Bell and Hazell, 1980; Delgado et al. 1998). Most of this literature was based on the use of one or another version of the SAM-based general equilibrium approaches with variations in modelling demand and measuring marginal propensities of consumption (MPC) out of current income (Hassan, 2003). The SAM represents a direct extension of the open Leonitief multi-sector I-O models. It extends the linear structure of production to account for feedback effects from the final demand sectors. Final demand is typically disaggregated into factors by capital and various labour categories, households of different income and social classifications, government and foreign sectors (Hassan, 1998). In a SAM, the final demand sectors are regarded as exogenous to the model, which implies that they are determined outside the model. The effects of these exogenous changes in final demand have endogenous direct, indirect and induced effects (due to "income leakage"). The direct effects are the changes in output; gross operating surplus and remuneration of employees that takes place in the sector(s) that experience changes in final demand. The indirect effects are the indirect impacts on the sectors that provide inputs to the directly affected sectors. The induced effect (or income effect) refers to an additional effect that takes place in the economy as a result of the change in consumer spending due to higher or lower salaries and wages (Conningarth, 2000).

Like I-O models, SAM models do not allow for substitution and flexibility in supply and demand adjustments as it has a fixed coefficient linearity structure. Computable general equilibrium (CGE) models, on the other hand, do accommodate substitution and flexibility in supply and demand, but are very demanding in terms of data and parameter specification (Hassan, 1998).

A very important aspect of economy-wide modelling is the definition of the geographical area of the economy under study. Different economic regions have different economic structures with different multi-sector linkages.

3.3.2 Environmental impacts and indicators

Environmental impacts are the physical changes in the environment that take place as a result of human activities. These changes are not always easy to measure for a number of reasons:

- The physical change in the environment is not always measurable.
- The direct linkage between a specific human activity and its environmental impact is not always clear and/or measurable.

Data on environmental impacts are consequently very difficult to obtain. There are relatively few or no incentives or legislative measures that guide the capturing and auditing of such data, which are often time consuming, complicated and expensive to measure. Even Environmental Impact Assessments (EIAs) contain little or no environmental impact data, unless specific specialist studies are commissioned during the EIA (Batchelor, 2001).

The environmental impact data used in this study were sourced from a WRC study (Crafford et al. 2003) and the Carnegie Mellon University Green Design Initiative (CMUGDI, 2001). These data are a mixture of environmental impacts and indicators. An example of this is best explained by the air pollution data: air emissions such as CO_2, CH_4, N_2O, and CFCs can be measured and used as ***indicators*** of atmospheric temperature increase (the greenhouse effect). However, because the relationship between these gasses and global warming is known (by calculating their equivalent carbon dioxide contents), their collective global warming potential, the ***environmental impact***, can be calculated.

Various literature sources classify environmental impacts into one of three broad frameworks: a production, an ecological and a sustainability framework. The ***production framework*** follows the methodology of conventional life-cycle analyses, and groups environmental impacts based on two criteria: raw materials acquisition and manufacturing. The former specifically includes all aspects related to the direct extraction or use of raw materials such as water, soil, biodiversity and air. The latter incorporates all aspects involved in transforming energy and raw materials into products and services such as transportation, equipment, chemicals, energy and fuel and water (EPA, 2002; Crafford et al. 2003). The ***ecological framework*** classifies environmental impacts into the four categories that constitute the natural environment. These are the lithosphere (soil components); the biosphere (biological diversity); the hydrosphere (water) and the atmosphere (air) (Crafford et al 2003). The ***sustainability framework*** classifies environmental impacts into ***sources*** (providers of materials and inputs), ***sinks*** (accumulators of waste and pollutants) and ***services*** (De Wit, 2001). For the purposes of this study, the sustainability structure was selected, as it best accommodates environmental economic principles and modelling.

Within this framework, the ***Source Impacts*** describe the use of natural resources as it is extracted (mined, harvested) from the natural environment, and typically includes electricity, energy, and various soil and water use impacts (these are the A transactions defined in Figure 1.1). Electricity use is expressed in kilowatt hours (kW-hr). Energy use typically includes electricity use in addition to other fuels, such as petrol, diesel, coal, wood and bagasse. Soil impacts can include impacts such as erosion, salnisation, loss of fertility, but due to data difficulties may be broken down into the main fertiliser classes, and therefore estimate the consumption of soil nutrients to support each value chain. Water impacts can be broken down into five categories: precipitation use, incremental water use, water intake from water supply sectors other than irrigation schemes, recycled water and discharged water. Incremental water use is defined as the so-called stream flow reduction due to forestry and the use of irrigation water for agriculture (sub-tropical fruits and sugar cane). The combination of Precipitation use and Incremental water use are defined as the total primary water use. The "consumption" of biodiversity by replacing natural vegetation with cultivated or built up land can also be regarded as a source impact.

The ***Sink Impacts*** describe the effect of waste generated by human activities on the natural environment (these are the D transactions defined in Figure 1.1). It includes solid waste generated that is dumped or land filled, water pollution and air emissions. Solid Waste includes dust, sludges and other waste that requires land filling. Water pollution includes sedimentation, and organic and inorganic pollution of water. Air emissions include all the major emissions that contribute to local pollution (SO_2, CO, NO_2, VOC, Lead, PM10) and greenhouse gas effects (GWP, CO_2, CH_4, N_2O, CFCs).

Carbon sequestration, also a sink impact, is becoming increasingly prominent, especially in the forestry sector, particularly in light of carbon trading initiatives.

Environmental services result from biosphere functioning that protects natural water, air and land resources. Biosphere functioning is critical for maintaining the resilience of ecosystems allowing them to respond to changes induced by economic activity. The resilience of ecosystems refers to the capacity of an ecosystem to maintain its characteristic patterns and rates of processes such as primary productivity in response to environmental conditions. Therefore, the more diverse a system, the greater its ability to withstand shocks and stresses (Khan, 1995:360). ***Service Impacts*** data are therefore extremely site specific, complex to evaluate, and not easily available and are often qualitative rather than quantitative. Included in the biosphere component is biodiversity, a term used to describe the number, variety and variability of living organisms with respect to genes, species and ecosystems (Brown *et al.,* 1993:8).

3.3.3 Economy-wide models and environmental impacts: Recent work of relevance in SA

Environmental impacts can be linked to economy-wide models by methods described by Hassan (1998, 2000). This study linked water use as an environmental externality to a SAM, and proceeded to analyse some of the implications of the NWA for water users. However, much scope exists to expand the investigation of environmental impacts. Environmental indicators and impacts can be classified to have direct and indirect components. In the case of water, direct effects relate to the water quantity and quality changes associated with production or consumption activities, while the indirect effects are the changes in all other categories of environmental indicators and impacts. For the direct effects, a water subsidy transfer sector can be added to the SAM model to handle water pricing policy scenarios and water quantity and quality changes (Hassan, 1998). Furthermore, indirect environmental source and sink impacts can be modeled by extending the SAM to accommodate environmental modules using environmental source and sink indicators and impacts matrices. The linkage between environmental impacts and economy wide models therefore provides a mechanism with which one can assess the direct and indirect socio-economic and environmental interactions as defined by transactions A, B, C and D in Figure 1.1. This mechanism can be described as an integrated environmental-SAM model.

Once an integrated environmental-SAM model is developed for a catchment, the effect of economic and policy changes on the economy and the environment can be analysed. This is done by first isolating the endogenous variables matrix within the SAM for deriving the Leontief inverse matrix, which contains all the direct as well as indirect and induced impacts. In a similar fashion, an environmental impacts matrix is developed by determining the environmental impacts per unit of economic output per sector. The combined Leontief inverse and environmental impacts matrices are then used to evaluate the impacts of changes in the exogenous accounts of the economy on endogenous attributes (e.g. generation and distribution of income and output). Where these changes result in negative values (e.g. reduction in economic activity, reduction in household income, or increases in pollution levels) they are expressed as costs, whereas positive values are expressed as benefits. This method will be explained in greater detail in the following chapter.

The development of an integrated environmental-SAM model from primary data is not a trivial exercise. It is therefore important that the benefits gained from such a model need to be well understood by its potential users before such a development is undertaken. For the purpose of this study therefore, existing models and data, not originally intended for total economy-wide environmental-economic analysis, were used as building blocks for an environmental-SAM of sufficient accuracy to model WDM policy implications. The studies used were:

- A study by Hassan (1998) employing a social accounting matrix (SAM) to analyse economy-wide impacts of the new NWA of South Africa.
- A CSIR study (Crafford et al. 2002), measuring the social, economic, and environmental direct and indirect costs and benefits of water use in the irrigated agriculture and forestry sectors in the Crocodile River catchment.
- A CSIR study (Crafford et al. 2001) on water resource accounts for South Africa: 1991-1998.
- A Conningarth Consultants (2000) study which developed a SAM (social accounting matrix) for the Komati River Basin.

- Eiolca, a web-based life cycle analysis tool hosted by the Carnegie Mellon Green Design Initiative (www.eiolca.net).

This study followed the method described in Hassan (1998, 2000), which used a national SAM to investigate some of the headline effects of the NWA and limited environmental impacts. The present research extended the said framework to produce a catchment-specific SAM and a greatly expanded environmental sector component and policy impacts due specifically to WDM policy interventions. The CSIR (2002) study investigated the economic and social multiplier (direct and indirect) effects of the large land-using sectors in the Crocodile River catchment and collected primary data to conduct a partial input-output analysis. However, the CSIR study did not produce a SAM and therefore could not account for the full economy-wide effects of water pricing changes. For this reason, data from the Conningarth SAM (2000), which was developed to assess the economy-wide impacts of a new dam in the Komati River basin, were used to describe the induced multiplier effects. The CSIR (2001) and Carnegie-Mellon studies were intended to produce physical data (volumetric, mass) on resource use and sink impacts of economic activities. Data from these studies were used to develop the environmental component of this study.

The impacts of aspects of the two phases of WDM (as defined by the NWPS) on the economy and the environment could therefore be evaluated using this integrated framework and data. The effects of water allocations between water users; the effects of changes in water pricing (tariff) policies, such as reduction of water subsidies, introduction of a catchment management charges, and changes in raw water and industrial water tariffs could be modelled. In addition, the impact of policy decisions dealing with environmental externalities could be investigated within this framework. Rough prediction of when to expect absolute water scarcity to occur and some of the aspects related to water trading (property rights and transaction costs) could also be investigated.

The structure and empirical specifications of the integrated environmental and macro-economic management model for the study area are presented and discussed in the following chapter.

Chapter 4 - Approach and methodology

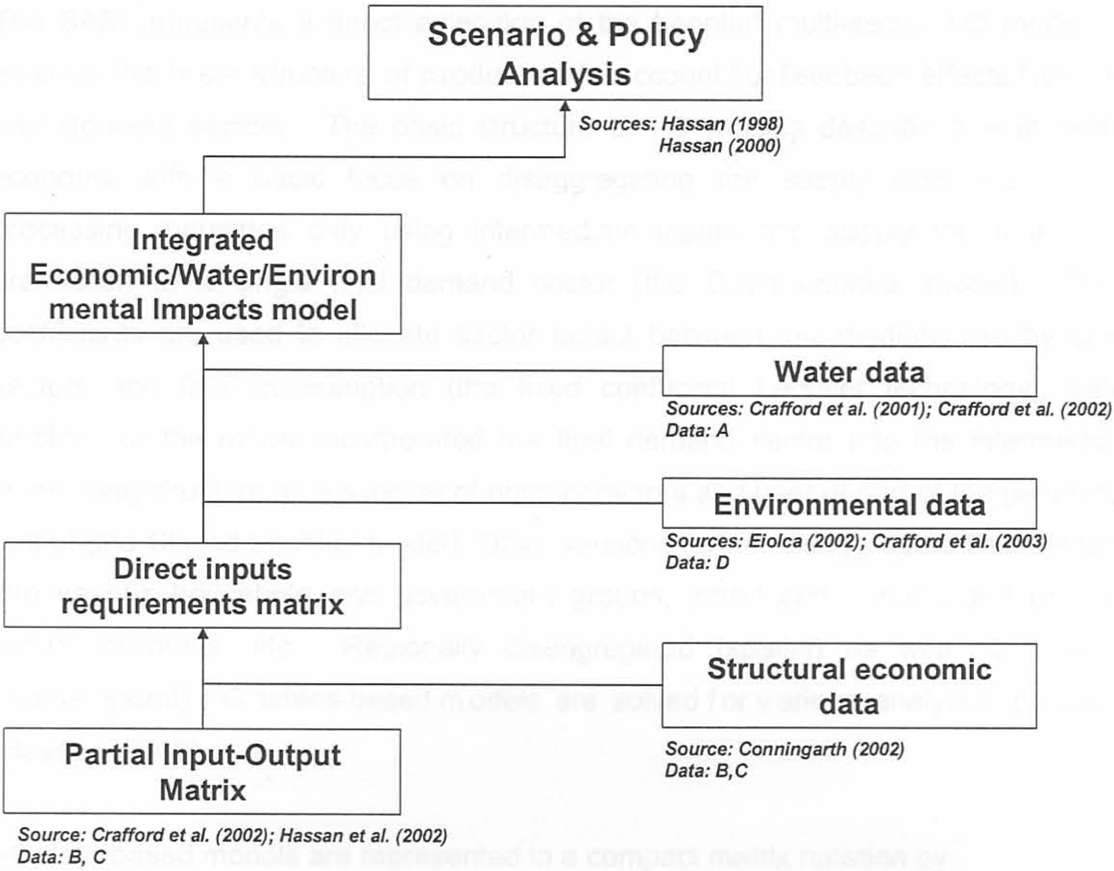
4.1 Introduction

As mentioned earlier, the purpose of this study is to analyse the economy-wide impacts of possible shifts in water policies and allocation regimes introduced by water demand management (WDM) policies, by adopting an integrated macro-economic and environmental management approach. The case study area used is the Crocodile River catchment. The approach employed by the study traces multi-sector linkages of the economic activities under investigation, making use of adapted catchment level social accounting matrix (SAM) data tables. The SAM tables were updated using new catchment specific information on the structure of production activities and economic linkages in the catchment. An environmental module was then constructed to trace the environmental impacts of likely changes in the production environment brought about by water demand management policies. This module was then linked to the economic model to form the integrated analytical framework presented in Figure 4.1. The following sections provide detailed descriptions of the various components of the analytical framework.

4.2 Approach

The approach followed was to combine best available water beneficiation data, detailed value chains, an economy-wide model, and environmental impacts into an integrated model for conducting policy analysis. As mentioned in Chapter 3, the approach was guided by the combination of the results of the five reviewed studies. The framework presented in Figure 4.1 depicts how the elements of the research questions addressed in the reviewed literature are brought together and integrated in a unified analytical framework.

Figure 4.1: A framework showing the approach followed by the study



The partial direct inputs requirements matrix for the rural areas of the Crocodile River Catchment (Hassan et al. 2002) and the structural economic data from the Conningarth (2000) study were used and augmented to generate a direct inputs requirements matrix for the study area (Komati River basin). Water use (Crafford et al. 2001, 2003) and environmental impact data (Eiolca 2002, Crafford et al 2003) were then linked to this matrix to construct an integrated multi-sector economic / water use / environmental impacts model. Finally, investment and policy scenarios were designed, simulated, and analysed following the methods described in Hassan (1998 & 2000). The data for the interlinkages between the economic and environmental processes described in Figure 1.1 are indicated in Figure 4.1.

The following sub-sections describe in more detail the various components of the integrated environmental-economic model used and how these components were integrated and applied to conduct the intended analysis.

4.3 The SAM Framework

The SAM represents a direct extension of the Leontief multi-sector I-O model. It extends the linear structure of production to account for feedback effects from the final demand sectors. The basic structure of I-O models describe a multi-sector economy with a basic focus on disaggregating the supply side into several processing industries only using intermediate inputs and supply the rest of its production to a single final demand sector (the Open Leontief model). Fixed coefficients are used to allocate sector output between intermediate use by other sectors and final consumption (the fixed coefficient Leontief technology). Later versions of the model incorporated the final demand sector into the intermediate processing structure as a supplier of primary factors and user of part of the generated output (the Closed Leontief model). Other versions further disaggregate final demand into various household and government groups, introduced imports and exports, capital accounts, etc. Regionally disaggregated (spatial) as well as dynamic (intertemporal) I-O tables-based models are solved for various analytical purposes (Hassan, 2003).

I-O data-based models are represented in a compact matrix notation by:

$$X = AX + d \qquad (1)$$

Where X is a vector of total outputs of the various economic sectors, A is the I-O coefficient matrix, AX calculates intermediate inputs required by the various members of X (producing sectors) and d is the vector of final demands (VAD). This formulation describes the general situation that total output X is allocated between intermediate use by other sectors for further production (intermediate demand) and the remainder is absorbed in final demand (final consumption and investment demand) or exported. I-O models are concerned with solving for sector output levels (X) that satisfy final demands for those outputs (d) given the inter-industry structure of production (A). In other words, model 1 can determine the production plan that is consistent with a desired final demand vector (d) given the inter-sector transaction matrix (A), i.e. generating direct intermediate demands necessary to generate the target net output (d). Making use of matrix algebra, model 1 can be solved to determine X as follows:

$$X - AX = d$$

$$(I-A)X = d \qquad (2)$$

$$X = (I-A)^{-1} d$$

Where I is an nxn identity matrix. As the inverse matrix $(I-A)^{-1}$ is defined one can solve for X given d. The matrix A is known as the direct input requirements matrix (Leontief inter-industry transactions' coefficient matrix). The elements of A (a_{ij}) define the value or amount of input required from all sectors to produce one unit of output of a given sector j:

$$[\, a_{ij} \,] = \begin{vmatrix} a_{11} & a_{12} & . & . & a_{1n} \\ a_{21} & a_{22} & . & . & a_{2n} \\ . & . & . & . & . \\ . & . & . & . & . \\ a_{n1} & a_{n2} & . & . & a_{nn} \end{vmatrix} \qquad (3)$$

On the other hand, the inverse matrix $(I-A)^{-1}$ gives the total (direct and indirect) output requirements per unit of output to be generated in sector j. This is known as the total input requirements matrix, which is used to calculate production or supply-side multipliers. This matrix is used to derive various types of multipliers the most common of which are the output and income multipliers. With additional information on employment by various sectors, it is also used for calculating job multipliers (Hassan, 2003).

In a SAM, the final demand sectors (FD) are regarded as exogenous (independent) to the model, which implies that they are quantitatively analysed outside of the model. This means that the effect of changes in final demand (FD) on total output (X) can be modelled by taking the multiple of the total input requirements matrix $(1-A_1)^{-1}$ and the change in final demand (FD). The resultant economic impact can be quantified, depending on the structure of the SAM, in terms of production/output, income/GDP, employment, income distribution and/or industry impact (Conningarth, 2000). In the case where environmental impacts are linked to the SAM, the effect on the environment is quantified in terms of increased source and sink pressure on the environment.

4.4 The empirical SAM for the Crocodile River Catchment

This study developed a model which included the economic sectors and environmental elements required for analysis of the impacts of WDM policies. In order to introduce water allocation decisions' shocks, the model was disaggregated to explicitly model major water using production activities in the study area. In order to achieve this, the following methodology was followed:

Step 1: A direct input requirements matrix (A_i) was developed for the Crocodile River catchment through a combination of two economic data sources:

a) A partial direct input requirements matrix (P_i) developed from primary data by Hassan et al. (2002), which describes the multiplier effects of the value chains of the selected sectors.

b) The Conningarth (2000) SAM was adapted to describe the structure of economic activity in the Crocodile River catchment.

A total input requirements matrix $(1-A_1)^{-1}$ (kxk) was then derived from these two sources.

Step 2: Environmental impact coefficients (E) for the catchment, including water use data, were determined through a transfer study, using a random effects approach. The data used here are presented in Appendix 1 (Table A1.1).

Step 3: Scenarios of change in final demand (ΔFD) were designed and their effects on the composition of the total economic output (ΔX_t) and the environment (ΔE) were analysed using the total input requirements matrix $(1-A_1)^{-1}$ and the environmental impacts matrix (E): $(1-A_1)^{-1}.\Delta D = \Delta X_t$ and $E.\Delta X_t = \Delta E$, respectively.

A detailed description of the above outlined methodology follows.

4.4.1 Step 1: The direct input requirements matrix A_i

A. ***Selection of major water users and sectors to be modelled.*** Agricultural land uses, specifically irrigation agriculture and forestry, comprised the major water users in the catchment (see Table 4.1).

In 1998 forestry was the largest intensively managed land-use in the catchment, and covered slightly more than 172,000ha. About two thirds of the area was planted under Pine species, while the remainder consisted mostly of Eucalypt species. Irrigation agriculture comprised a total area of over 11,000ha between the Kwena dam and the Crocodile River Gorge and approximately 17,000 ha (mostly sugar cane) below the Gorge (DWAF, 2002a). Irrigation and forestry comprised nearly 90% of the non-environmental water use in the catchment. Industrial use (which includes mining, electricity generation, and water use for other commercial purposes) comprised about 7%, while households consumed about 4% of the total water use. Within irrigation agriculture, sub-tropical fruits and sugar cane comprised the major users (Crafford, et al 2002).

It was therefore decided, based on the outputs of the 2002 WRC study (Crafford et al. 2002) to focus on irrigation agriculture and forestry and their respective value addition chains, as the point of departure for the partial input-output analysis. Other sectors investigated were selected based on their reliance on raw materials from, and provision of inputs to, the identified major water users. In addition, activities that played a major role in the economic and environmental shocks to be investigated were selected for this analysis. Selection of these sectors was based on the structure of the SAM used. The SAM that was used, was originally built to investigate specific transactions in the Inkomati basin, and included a set of transactions between *Commodities* and *Activities*. The purpose of this distinction was to investigate the production of a commodity by different activities. For instance, both small farmers (activity) and commercial farmers (activity) produce sugar (commodity). Also, some commodities are produced on the same farming unit, e.g. mangos and oranges may both be produced by the same activity - fruit farming. This process yielded k=38 endogenous sectors, which are listed in Table 4.1:

Table 4.1: Economic activities identified for the SAM (endogenous sectors)

1	Fertilizer
2	Agrochemicals & other
3	Fuel
4	Sugar cane farming
5	Sugar Cane
6	Sugar mills
7	Sugar
8	Animal feed
9	Animal Feed (& Molasses)
10	Sub-tropical orchard farming
11	Orchard sub-tropical fruit
12	Citrus
13	Bananas
14	Juice factories
15	Other food & beverages
16	Other food & beverages
17	Forestry
18	Raw Wood
19	Wood products & furniture
20	Wood products & Building Board
21	Furniture
22	Paper products
23	Freight transport
24	Trade
25	Other Activities
26	Other Commodities
27	Water Activity
28	Electricity Activity
29	Electricity Commodity
30	Labour
31	Capital
32	Large Commercial Farmers
33	Smallholders (Commercial Farmers) Nkomazi
34	Self Subsistant Farmers
35	Agro-Industries
36	Forestry
37	Other Capital (urban & other)
38	Households

B. Construction of a partial input requirements matrix (P_i). A quasi input-output matrix by Hassan (Hassan et al. 2002) and the 2002 WRC study (Crafford et al. 2002) were used to trace the chains of value addition of the major water users, between primary production and final use, by mapping the production linkages chain, starting from the final product to the primary sector activity (Hassan et al; 2002). Product flow data, economic returns, value added (including employment), and intermediate consumption data were obtained from the WRC study. These data (on forward and backward activities) were used to derive production multipliers.

These two studies aimed to provide new information on the economic benefits related to water use, and therefore used value added (VAD) in each sector as a basis for calculating production multipliers. Value is added ***directly*** to the economy by an economic sector through the remuneration of its employees, operating surplus generated and taxes paid to government. Value is also generated ***indirectly*** through the increased purchases (from suppliers) of the economic activity, and the subsequent increased effect these purchases have on the remuneration, operating surplus and taxes of suppliers. The total economic benefits to the economy was therefore expressed as the sum of direct and indirect benefits (Hassan et al. 2002):

$V_{iT} = V_i + V_{iB}$

Where: V_{iT} Total value added generated by sector i

V_i Direct value added in sector i

V_{iB} Indirect value added by sector i

The production multipliers were calculated as the ratio of total value added to indirect value added, and were derived using an additive approach, using the following computational method:

V_{iT} / V_i where: $V_i = X_i - \sum_j a_{ji} X_i$ and $V_{iB} = \sum_j a_{ji} X_i (V_j/X_j)$

Where: X_i is the total output of sector i

a_{ji} is the input-output coefficient denoting intermediate demand for units of product j per unit of sector i's output

$a_{ji} X_i$ measures the total (gross) value of intermediate input j used to produce the total value of output i (X_i)

V_j denotes value added in input supply sector j and hence (Vj/Xj) is the share of VAD in total (gross) value of output in the sector of origin j

A partial input requirements matrix, P_i, was derived from the inverse of the production multipliers: $P_i = V_i / V_{iT}$

The P_i matrix did not contain sufficient information to analyse the total economy-wide impact of economic changes, as it did not account for the effect of increased demand generated throughout the economy. However, the partial inputs requirements matrix P_i is a subset of the direct input requirements matrix A (Leontief inter-industry transactions' coefficient matrix) defined in section 4.2. The conversion of the P_i matrix to a full input requirements matrix was therefore needed.

C. ***Construction of a full input requirements matrix (A_1).*** In order to account for the missing production activities' linkages as well as for effects of increased demand generated throughout the economy, the P_i matrix was extended to a full input requirements matrix A_1 (kxk). This was done using secondary data sourced from the WRC study by Conningarth (2000), which developed a SAM (118x118) for the Inkomati Water Management Area and Swaziland. Not all the transaction details provided in the Conningarth SAM were required, and accordingly the original SAM was reduced to a 51x51 matrix, $X_n+D = X_t$, (including endogenous and exogenous sectors) using the following procedure:

- The Swaziland transactions were removed where applicable or consolidated with import/export transactions,
- Production activities were consolidated to correspond to the value chains of the 2002 WRC study (Crafford et al. 2002),
- Production data were updated with the data sourced from the 2002 WRC study (Crafford et al. 2002), and
- Transactions with production factors, households and government, respectively, were consolidated.
- The sectors endogenous to the system were selected and yielded a matrix A_0. The partial input requirements matrix P_i and matrix A_0 (jxj) were then adapted into a new direct input requirements matrix A_1(kxk). This was done using computational method:

  $A_1 = A_0.(\sum_j a_0/P_i)$, where:

  a_{0i}= The amount of product k required as an input to produce one unit of j.

  A_1 was successfully tested against the condition that $\sum_j a_1 < 1$.

This yielded a 46x46 matrix, $X_n+D = X_t$, which implied that 2209 (46^2) transaction sets in the economy of the Crocodile River catchment were represented[10].

[10] That means that 5 sectors of the 51x51 constructed SAM were considered exogenous. These were Households, Government, Water Subsidy Transfer, Rest of SA and Rest of the World sectors.

D. Derivation of the total input requirements matrix $(1\text{-}A_1)^{-1}$. This was done by subtracting the new direct input requirements matrix A_1 from the corresponding identity matrix I of the same dimensions to calculate the inverse matrix:

$1\text{-}A_1$ and $(1\text{-}A_1)^{-1}$ (see Appendix 1 Table A1.1)

The structure of the final empirical SAM constructed is shown in Figure 4.2. The matrix was developed using 1998 prices.

The various value chains and their backward and forward linkages are shown in detail in Figure 4.2. Labour and Capital are the Factors of production investigated. The endogenous Enterprises sectors represent the equity holders of forestry, irrigation, and primary and other production business activities. These sectors are the receivers of gross operating surplus (GOS) and feed back into the economy payments (such as dividends and interest) to Capital and Household investments, taxes to government and imports from the Rest of the World sectors.

The five exogenous sectors were Households, Government, a Water Subsidy transfer sector (to transfer subsidies), Rest of SA and Rest of the World sectors. The Water Commodity Sector receives payments from the various water users and in turn makes payments to intermediate consumption sectors (as defined in Figure 4.2). This Sector therefore transfers water subsidies and taxes between the water users and Government. The Water Subsidy Transfer sector, Government sector (government consumption, taxes and subsidies), and Rest of SA and Rest of the World sectors (i.e. import and export into and out of the catchment area) were considered to be part of final demand for the purposes of this study.

Figure 4.2: The structure of the SAM model for the rural areas of the Crocodile River Catchment.

		EXPENDITURE										
	INCOME	Backward Linkages	Sugar value chain	Fruit value chain	Forestry value chain	Transport	Other Backward Linkages	Factors	Gross operating surplus	Institutions	Water Subsidy transfer	Rest of SA / World
Backward Linkages	Fertilizer											
	Agrochemicals & other											
	Fuel											
Sugar value chain	Sugar cane farming											
	Sugar Cane											
	Sugar mills											
	Sugar refining											
	Sugar											
	Animal feed											
	Animal Feed (& Molasses)											
Fruit value chain	Sub-tropical orchard farming											
	Avoes											
	Mangoes											
	Citrus											
	Bananas			Intermediate consumption				Investment		Purchases for final consumption	Tax / Subsidy	Export Demand
	Juice factories											
	Other food & beverages											
	Other food & beverages											
Forestry value chain	Pine Forestry											
	Gum Forestry											
	Raw Wood											
	Saw milling											
	Mining Timber											
	Poles											
	Charcoal											
	Boards											
	Wood products & Building Board											
	Furniture											
	Furniture											
	Pulp&Paper											
	Paper products											
Transport	Freight transport											
Other Backward Linkages	Trade											
	Other Activities											
	Other Commodities											
	Water Activity											
	Electricity Activity											
	Electricity Commodity											
Factors	Labour			Wages						Transfers		Payments
	Capital			Profit								
Gross operating surplus	Large Commercial Farmers											
	Smallholders (Commercial Farmers)											
	Self Subsistant Farmers								Payments	Tax / Subsidy		
	Agro-Industries											
	Forestry											
	Other Capital (urban & other)											
Institutions	Households							Income		Transfers	Tax / Subsidy	Payments
	Government			Taxes				Taxes	Taxes			
Water Subsidy transfer				Tax / Subsidy						Tax / Subsidy		
Rest of SA				Intermediate imports				Payments	Imports	Imports		
Rest of the World												

It was very difficult to verify the correctness of the absolute values (economic output) of the resultant SAM. This was partly due to the fact that the Inkomati SAM of Conningath only partly overlaps the Crocodile River Catchment, and partly due to absence of regional economic data for the Crocodile River Catchment. Regional data are to a large extent neglected in South Africa (Conningarth, 2000). In spite of this, the total input requirements matrix $(1\text{-}A_1)^{-1}$ of the South African component of the Inkomati SAM provides valuable information on the interrelationship between economic activities, and is expected to be very similar to that of the Crocodile River Catchment. It is expected though that a complete (rural and urban) Crocodile River Catchment SAM will produce a larger induced (income) effect due to the addition of economic activities in the Nelspruit area.

4.4.2 Step 2: The environmental module

Water use data were sourced from the primary data of the 2002 WRC study (Crafford, et al. 2002), and other published literature (Crafford, et al 2000, DWAF, 2000a; StatsSA, 2000).

Data on environmental impacts are in general difficult to obtain. There are relatively few or no incentives or legislative measures that guide the capturing and auditing of such data, and it is often time consuming, complicated and expensive to compute. Even Environmental Impact Assessments (EIAs) contain little or no environmental impact data, unless specific specialist studies are commissioned during the EIA (Batchelor, 2001). Ideally the data input into environmental impact analyses should be primary data, specific to the study area. However, in the absence of such data for this study area, transfer studies were used to quantify emission factors. A random-effects approach was adopted. This means that studies of relevance, conducted in other areas were used to transfer parameters and measures of environmental indicators and impacts to the Crocodile catchment model. In other words, the model borrowed from similar studies their parameter indicators and impacts estimates. Consequently, data were based on surveys (Crafford, et al. 2002; CMUGDI, 2001), and government and industry censuses (Crafford, et al. 2002).

The selection and definition of environmental indicators and impact categories (e.g., global warming, acidification, terrestrial toxicity) was therefore done based solely on data availability. The characterisation of environmental impact coefficients within impact categories using science-based conversion factors (e.g., modelling the potential impact of CO_2 and methane on global warming) could not be done in all cases, as not enough data were available. Table 4.2 lists these coefficients and impacts.

Water use coefficients and other environmental coefficients and impacts were integrated as part of the SAM framework by constructing an (lxk) environmental impacts matrix. Table A1.2 in Appendix 1 provides actual environmental impacts data.

Table 4.2: Environmental indicators and impacts parameters used in this study

Source	Water	Intake	m3
	Energy	Electricity	Mkw-hr
		Energy	TJ
		Bitum	mt
		Anth	mt
		NatGas	mt
		LNG	mt
		LPG	mt
		MotGas	mt
		Kero	mt
		AvFuel	mt
		JetFuel	mt
		LFO	mt
		HFO	mt
	Soil	Nitrogenous	Rmill
		Ammonium Nitrate	Rmill
		Ammonium Sulfate	Rmill
		Organic	Rmill
		Phosphatic	Rmill
		Super Phosphates	Rmill
		Mixed	Rmill
Sink	Air	SO2	mt
		CO	mt
		NO2	mt
		VOC	mt
		Lead	mt
		PM10	mt
		Non-Point Air	mt
		Point Air	mt
		Air Releases	mt
		CO2	MTCO2E
		CH4	MTCO2E
		N2O	MTCO2E
		CFCs	MTCO2E
		Non-Point Air	mt
		Point Air	mt
	Water	Recycled/Reused	m3
		Discharged Untreated	m3
		Discharged Treated	m3
Soil	Waste	Generated	mt
		Managed	mt
		Shipped	mt

4.4.3 Step 3: Policy simulation analyses

Policy analysis was done by exogenously determining the effect of various WDM policy scenarios on final demand (FD) and then calculating the consequent impacts of such change on the economic system and the environment. This is implemented in the following two steps:

A. First, the change in final demand (ΔFD) for one or more sectors due to a particular policy change was determined. Then, this change in final demand was applied to the system using the inverse matrix to calculate the impact on all other sectors' output: $\Delta Xt = (I-A)^{-1}.\Delta FD$. For instance, a reduced water allocation would result in reduced production levels, and a subsequent loss of income (ΔX) to the producer. The resultant change in final demand, ΔFD, was calculated by multiplying ΔX by a ***FD/X*** ratio calculated from the Conningarth SAM (2000).

B. The resultant change in levels of sector output ΔXt calculated in A above was then used to derive impacts on the environment: $\Delta E = e.\Delta Xt$.

The impacts of the following investment and policy scenarios, which are described in full detail in Chapter 5, were evaluated:

1- The effects of changes in current water allocations between users.
2- The Economic Impacts of selected pricing policies:
   a. Reduction of water subsidies
   b. Introduction of a catchment management charge (CMC)
   c. Changes in raw water and industrial water tariffs
3- The potential impact of policy changes/measures dealing with environmental externalities on water use.
4- Absolute water scarcity – when can allocation according to scarcity value be expected to be implemented?
5- A sensitivity analysis was done to investigate one of the aspects of determining water property rights through water measurement: The effect of the price of installing water meters.

These experiments were designed to provide information on the two phases of water demand management interventions as identified in section 3.2.1, and can be classified as follows:

WDM Phase	Experiment number
Phase 1	1, 2a, 2b, 2c, 3,
Phase 2	4, 5

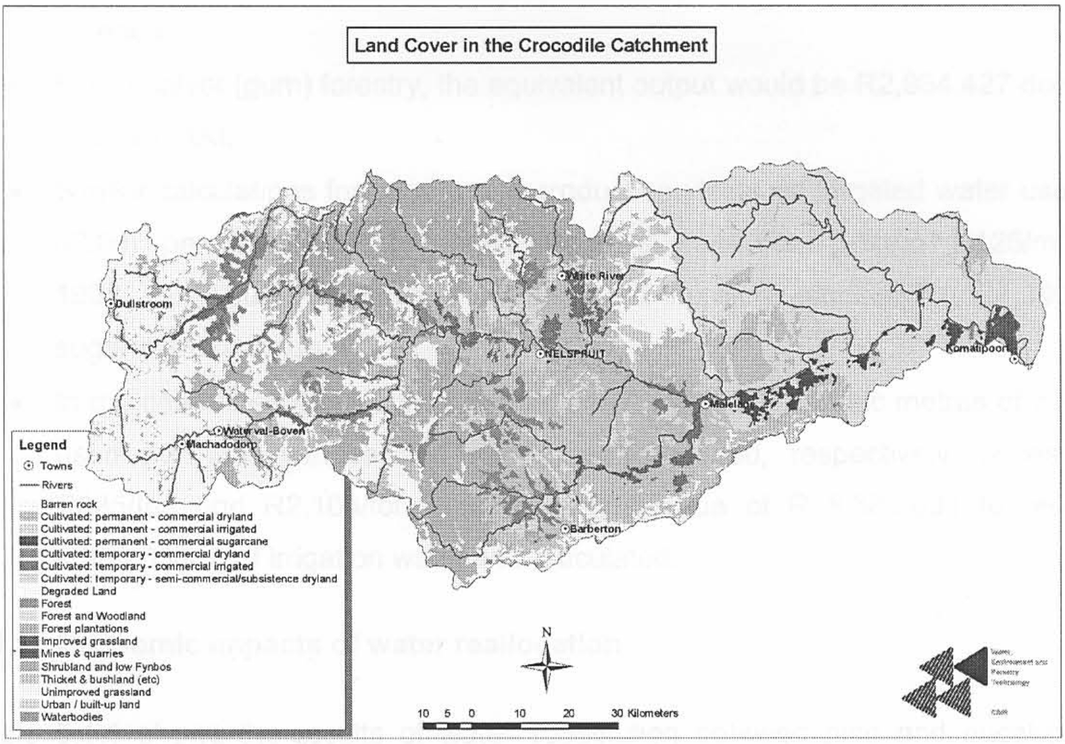
Chapter 5: Results & Discussion

In this Chapter, the results of the various scenarios simulating the impacts of changes in certain selected policy measures are presented and discussed in detail. Unless otherwise indicated, the prices used were for 1998. In all instances, scenarios were generated by first determining the change in Output (ΔX) based on specific assumptions, and thereafter calculating the resultant change in Final Demand (ΔFD) by applying the ***FD/X*** ratio calculated from the original Conningarth SAM (2000).

5.1 Scenario 1: Reallocation of water between major users

In the Crocodile River Catchment, water transfers among major water users in the agriculture sector could take place between forestry, irrigated horticultural crops and irrigated sugar cane farming. Figure 5.1 shows the distribution and extent of land use by these activities.

Figure 5.1: Land use patterns in the Crocodile River Catchment.



Transfer of water between forestry in the upper part of the catchment and the irrigated crops in the lower parts would be complex due to the large distance between their locations, and the subsequent hydrological complexities involved. It is much more probable that reallocation may occur between and within the fruit and sugar farming activities in the lower lying regions of the catchment. However, at a macro level, it is possible to simulate the effect of substituting plantations with sugar cane and sub-tropical fruit farming or vice versa.

In these policy experiments, substitution scenarios of 1,000,000m^3 of water between forestry, sugar and fruit growers were simulated. Changes in final demand due to these substitutions were calculated based on the following assumptions:

- Pine forestry, at an average mean annual increment (MAI) of 15m^3/ha/a, and an average incremental water use of 100mm (equivalent to 1000m^3 of water per hectare), has a water usage of 66.5m^3 per cubic metre of round wood produced. At an average round wood price of R126/m^3 at roadside in 1998, 1,000,000m^3 of water would therefore produce R1,894,737 in round wood revenue.
- For Eucalypt (gum) forestry, the equivalent output would be R2,964,427 due to a higher MAI.
- Similar calculations for sugar cane production yields an irrigated water use of 82.0m^3 per ton of cane produced. At an average cane price of R125/m^3 in 1998, 1,000,000m^3 of irrigation water would therefore produce R1,524,390 in sugar cane revenue.
- In the case of subtropical fruit farming (137.8 and 528.3 cubic metres of water used per ton oranges and avocadoes produced, respectively, prices of R835/ton and R2,108/ton, and an output value of R 8,583,691 for every 1,000,000m^3 of irrigation water was calculated.

5.1.1 Economic impacts of water reallocation

Table 5.1.1 shows the results of water substitution between pine and eucalyptus forestry and sugar cane production. In the case of the pine-sugar cane substitution, an economy-wide reduction in total output of -0.005% is observed for every 1 million m^3 of water reallocated from pine forestry to sugar cane. The main contributors to this effect are the direct impacts of increased Sugar Cane production (0.013%) and reduced Round wood production (-0.617%); and the indirect impacts of Other Commodities (-0.001%), Labour (-0.003%), Large Commercial Farmers (0.006%) and Forestry Enterprises (-0.032%). Large Commercial Farmers' enterprises show increased returns, as sugar is a commodity in which they invest. Forestry Enterprises show decreased returns due to decreased forestry activities. These results indicate that Forestry is a more efficient user of water than sugar cane, in the Crocodile catchment. In the case of eucalypt-cane substitution, similar multiplier effects are observed in the value chain activities discussed above, but due to the higher MAI of eucalyptus compared to pines, the economy-wide effect is even more pronounced, yielding a decreased output of -0.008% for every 1 million m^3 of water reallocated from eucalypt forestry to sugar cane.

Table 5.1.1: The economy-wide effect (ΔX) of water reallocation (1,000,000m^3) between forestry and sugar

Water use efficiency (m^3 water/ton sugar or m^3 roundwood): sugar = 82.0; pine = 66.5; eucalypt = 50.6

	Sectors	Pine forestry substituted by sugar	Eucalypt forestry substituted by sugar
5	Sugar Cane	0.013%	0.013%
21	Roundwood	-0.617%	-0.966%
35	Other Commodities	-0.001%	-0.002%
39	Labour	-0.003%	-0.006%
41	Large Commercial Farmers	0.006%	0.005%
45	Forestry Enterprises	-0.032%	-0.050%
	Total (excluding Activities where duplicate commodity exists)	-0.005%	-0.008%

Table 5.1.2 shows the same experiments in a situation of different crop water usages. In the pine-sugar cane case, it was assumed that sugar water use productivity increased by 10% to 73.8m^3 water per ton of cane produced, due to favourable climatic conditions; while in the eucalypt-sugar cane case eucalypt water use efficiency was improved to 38.6m^3 per cubic metre round wood produced, based on modelling by the CSIR (Gush et al. 2002).

Table 5.1.2: The economy-wide effect of water reallocation (1,000,000m^3) between forestry and sugar

Water use efficiency (m^3 water/ton sugar or m^3 round wood): sugar = 73.8; pine = 66.5 in the pine-sugar scenario; sugar = 82.0 and eucalypt = 38.6 in the eucalypt-sugar scenario

Sectors		Pine forestry substituted by sugar	Eucalypt forestry substituted by sugar
5	Sugar Cane	0.015%	0.013%
18	Other food & beverages	0.000%	0.000%
21	Roundwood	-0.617%	-1.266%
35	Other Commodities	-0.001%	-0.002%
39	Labour	-0.003%	-0.007%
41	Large Commercial Farmers	0.006%	0.005%
45	Forestry Enterprises	-0.032%	-0.066%
Total (excluding Activities where duplicate commodity exists)		-0.005%	-0.011%

These results show that the effect of favourable climatic conditions on sugar cane, that increased sugar cane yield by 10% per cubic metre water used, improved Sugar Cane output increase to 0.015% from 0.013% (Table 5.1.1) for a 1,000,000m^3 water reallocation from pine to sugar cane, but did not significantly affect the total economic impact (0.005%) when compared to the results of Table 5.5.1. Further sensitivity analysis showed that the Total economic effect reduced to -0.004% only at an increased sugar cane yield of 30% per cubic metre water used.

In the case of Eucalypt forestry, new research, producing new estimates of eucalypt water use (Gush et al. 2002); changed water use efficiency of Eucalypt from 50.6 cubic metres water used per cubic metre timber harvested to 38.6. This meant that the total economic effect of a 0.008% reduction in Output (Table 5.1.1) was underestimated by 0.003% and is in fact -0.011% (Table 5.1.2). This result demonstrates the danger of basing decisions with far reaching economic effects on inaccurate water use estimates.

The main conclusion from Tables 5.1.1 and 5.1.2 is that non-market water allocation decisions between major water users need to be treated with great care. Although these results confirm previous work by Hassan (2002) and Crafford et al (2003) where value chain analyses of major water users in Mpumalanga have shown forestry to have larger direct and indirect economic impacts than the sugar value chain, the economic effects on other sectors such as labour and enterprises are also demonstrated here. However, both the forestry and sugar cane land uses support extended value chains, beyond the boundaries of the catchment, in which large multi-national companies play a large role. Water allocation decisions within a small catchment area may have economic multiplier effects that are only noticeable outside the catchment area. Water allocation to producers according to its scarcity value, as suggested by the National Water Pricing Strategy, therefore has to be done through a market driven process where the marginal value is determined by transactions between the producers.

It is also interesting to note that the production of additional sugar does not have a positive impact on the Other Food & Beverages sector. This counter-intuitive result is probably due to the fact that the bulk of the produced sugar gets exported to value adding facilities outside the catchment area, and is another strong argument for policy makers to take great care when making non-market related water allocation decisions.

Table 5.1.3 shows the economy-wide effect of water transactions of 100,000m^3 within irrigated land uses.

Table 5.1.3: The economy-wide effect of water reallocation (100,000m^3) between sugar and oranges; and oranges and bananas

Water use efficiency (m^3 water/ton sugar or m^3 round wood): sugar = 82.0; oranges = 137.8 and avocadoes = 330.3

Sectors		Sugarcane substituted by oranges	Bananas substituted by oranges
3	Fuel	0.010%	0.002%
5	Sugar Cane	-0.001%	0.000%
12	Avoes	0.006%	0.001%
14	Citrus	0.268%	0.266%
31	Paper products	0.003%	0.001%
35	Other Commodities	0.001%	0.000%
39	Labour	0.002%	0.000%
41	Large Commercial Farmers	0.029%	0.005%
44	Agro-Industries	0.000%	0.000%
Total (excluding Activities where duplicate commodity exists)		0.007%	0.002%

The results show that in both cases it appears more beneficial to allocate water to the production of oranges. However, these analyses do not account for risk and investment factors taken into account by farmers when they decide which crops to produce. A drop in the price of oranges may completely change the outcome of this analysis. Both sugar cane and sub-tropical fruit producers may plant different fruit types and sugar cane in order to hedge against price fluctuations. For example, if the price of bananas were to increase by 10% and the price of oranges to drop to R708/ton, the net total economic benefit of allocation of water from oranges to avocadoes would be zero (assuming zero transaction costs). Once again, this emphasizes the care that needs to be taken in water allocation decisions.

This is a very important result, which, at a first glance, appears to contradict findings in earlier studies by Hassan (2002) and Crafford (2002). These studies found the value chain of sugar cane to outperform that of sub-tropical fruit if measured in terms of value added produced per unit water consumed. On closer examination, the reason for this apparent contradiction is found in the definition of the catchment area investigated and the structure of the economy in that catchment area. The Hassan (2002) and Crafford (2003) studies defined and traced the value chains for the three land uses forestry, sub-tropical fruit and sugar cane production at a provincial (Mpumalanga) level, whereas the Conningarth (2000) study, on which the present analysis is based, investigated the economic structure of the Nkomazi and part of the Barberton magisterial districts, a small component of Mpumalanga, where the local economies are largely agriculture-reliant, and relatively few manufacturing and commerce activities take place. It can therefore be expected that the amount of value adding as well as the total economic output would be less in the smaller, more rural area. Although insufficient structural economic data (multipliers) exist to demonstrate this, analysis of the total output of the various geographical areas support it: the SAM model shows the total output in the Inkomati area of Mpumalanga (Nkomazi and a part of Baberton magisterial districts) to be R8,8bn while for the rural parts of the Crocodile River Catchment area (this excludes the urban part of Nelspruit) the total output is R11,7bn (in 1998). Estimates of GGP for

1998, based on the 1994 DBSA GGP data, gives a total output of R19,2 for the Lowveld area and R111,1bn for Mpumalanga.

The model developed in this study combined the multipliers and typical output of a small, regional, rural, agricultural economy with the multipliers of its extended value chains.

5.1.2 Environmental indicators and impacts

Table 5.1.4 shows the environmental impacts of the water re-allocation between pine and sugar cane. Re-allocation of 1,000,000m^3 of water by substituting pine plantations with sugar cane results in a reduction in water use of 101,000m^3 in the rest of the economy. This result must not be interpreted as a water "saving", as it goes hand in hand with a reduction in total economic activity of 0.005% (section 5.1.1). In the eucalypt to sugar cane case, the change in water use is a larger negative (-175,000m^3) – because Eucalypt has a higher efficiency than Pine, the re-allocation of water from Eucalypt to Sugar cane has a higher indirect water use impact than in the case of Pine, as there are fewer round wood to process, especially in the higher water use pulpwood industry. The indirect water use impact can therefore also be very significant, and water allocation decisions should not be made in isolation of this impact.

Energy use does not increase significantly, neither does the global warming potential (GWP) calculated by the sum of the CO_2-equivalent emissions. Only small reductions in air pollution and fertiliser requirements are observed.

For most of the environmental impacts it becomes clear that more analysis is required to quantify the impact of the source or sink activity on humans and the ecology. Analyses of SO_2, CO, NO_2, VOC and Lead emissions for instance, are meaningless if the dose-response relationship between the emissions and human and/or ecological health is not understood. The indicators of soil source use and fertiliser consumption, only become meaningful when their site-specific impacts, such as soil salinisation (due to over-fertilisation and water pollution) and reduced soil fertility (due to under-fertilisation) are captured. Soil erosion is a form of Sink impact, and cannot be captured in this type of analysis due to its close association with poor land management practices. This leads to an important conclusion: the analysis of environmental impacts as part of an economy-wide framework (such as a SAM) is limited to indicators and impacts that can be quantitatively linked to economic activities as part of a mass balance. For instance, transport of goods will require the use of a minimum amount of fuel, which can be expressed as a coefficient of the transport economic activity. These environmental impacts also have in common the fact that they can be measured at a specified entry or exit point into or out of the economic activity (e.g. a conveyor belt, pipe or exhaust). In the literature, these are referred to as point-source/sink indicators or impacts. On the other hand, the non-point source environmental indicators and impacts are difficult to measure and mostly have to be modelled according to site-specific conditions. Examples of non-point source/sink environmental *indicators* are fertiliser application, soil erosion, non-point source water pollution (mostly due to over-fertilisation) and over-grazing, all of which have in common a large "poor" management variable. Examples of non-point source/sink environmental *impacts* are the ill-health effects suffered by humans and the environment due to for instance water and air pollution. These effects are site specific and are influenced by many factors such as concentration of the impact, proximity and the relative vulnerability of the community(ies) or ecology and the dose-response relationship. It therefore becomes clear that the framework used in this study to analyse environmental impacts also (as in the case of the economic impacts) is insufficient for fully quantifying environmental impacts. It is however possible to draw strategic conclusions on the expected change in magnitude of some of the impacts. In further discussion only the relevant environmental impacts will be analysed.

Table 5.1.4: Environmental impacts of substituting pine and eucalypt with sugar cane.

Environmental indicators / impacts			Unit	Pine subst by sugar		Eucalypt subst by sugar	
				ΔE	ΔE	ΔE	ΔE
Source	Water	Intake	1000 m3	-101	-0.016%	-175	-0.028%
	Energy						
		Electricity	Mkw-hr	-0.0048	-0.002%	-0.0089	-0.004%
		Energy	TJ	-0.0143	0.000%	-0.0687	-0.001%
		Bitum	mt	0.3673	0.000%	-0.2066	0.000%
		Anth	mt	0.0002	0.000%	-0.0001	0.000%
		NatGas	mt	0.0110	0.000%	-0.0075	0.000%
		LNG	mt	0.0078	0.001%	0.0048	0.000%
		LPG	mt	0.1548	0.003%	0.1428	0.002%
		MotGas	mt	-0.4321	-0.005%	-0.9331	-0.011%
		LFO	mt	0.1100	0.001%	0.0840	0.001%
		HFO	mt	0.0037	0.000%	-0.0222	0.000%
	Soil	Nitrogenous	Rmill	-0.0000	-0.084%	-0.0000	-0.131%
		Ammonium Nitrate	Rmill	-0.0006	-0.084%	-0.0010	-0.131%
		Ammonium Sulfate	Rmill	-0.0009	-0.073%	-0.0014	-0.115%
		Organic	Rmill	-0.0014	-0.082%	-0.0023	-0.129%
		Phosphatic	Rmill	-0.0000	-0.084%	-0.0000	-0.131%
		Super Phosphates	Rmill	-0.0017	-0.084%	-0.0027	-0.131%
		Mixed	Rmill	-0.0022	-0.075%	-0.0034	-0.118%
Sink	Air	SO2	mt	0.0020	0.000%	-0.0087	0.000%
		CO	mt	0.0881	0.005%	0.0839	0.005%
		NO2	mt	0.0971	0.005%	0.0916	0.005%
		VOC	mt	0.0146	0.003%	0.0127	0.002%
		Lead	mt	0.0000	0.000%	-0.0000	0.000%
		PM10	mt	-0.0006	0.000%	-0.0016	-0.001%
		CO2	MTCO2E	-0.4249	0.000%	-4.1271	-0.001%
		CH4	MTCO2E	-0.0090	-0.005%	-0.0182	-0.010%
		N2O	MTCO2E	0.2816	0.005%	0.2657	0.005%
		CFCs	MTCO2E	-0.0173	-0.002%	-0.0278	-0.004%
	Soil	Waste Shipped	mt	0.0144	0.000%	-0.0281	0.000%

Abbreviations used:

Bitum = Bituminous Coal
Anth = Anthracite Coal
Nat Gas = Natural Gas
LNG = Liquified Natural Gas
MotGas = Motorcar Fuel
LFO = Light Fuel Oil
HFO = Heavy Fuel Oil
SO2 = Sulfur Dioxide
CO = Carbon Monoxide
NO2 = Nitrogen Dioxide
VOC = Volatile Organic Compounds
Lead = Lead particulate emissions (air)
PM10 = Particulate Matter (less than 10 microns in diameter)
MTCO2E = metric tons of CO2 equivalent

mt = metric tons
Mkw-hr = Millions of kilowatt hours
MTCO2E = metric tons of CO2 equivalent
TJ = Terajoules of Energy (1 TJ = 1,000,000,000,000 Joules)

The environmental impact data used in the modelling were largely based on United States sourced data (CMUGDI, 2001). As the direct benefits transfer method was used, the environmental impacts coefficients generated by the modelling will therefore not accurately reflect Crocodile River catchment conditions. This is mainly due to two reasons: resource sourcing and technology application in the US will differ from those within the study catchment area. Electricity generation in South Africa for instance, will be much more dependent on coal use (Bitum and Anth in the model results) than on other energy sources (e.g. NatGas, LNG, LPG). This highlights the need for a South African database for environmental indicators and impacts.

Table 5.1.4 shows that most of the environmental impacts decreases with the substitution of forestry with sugar cane. This confirms results of the WRC study (Crafford et al. 2002), where the primary land use activities with the longer value chain and higher value addition multiplier, also had larger environmental impacts. The most significant exception to this trend is in the air pollution emissions, where the burning of sugar cane appears to result in a larger negative impact on air quality.

Table 5.1.5 shows the environmental impacts of substituting 100,000m^3 water for oranges with sugar cane and avocadoes, respectively. In both instances the indirect water use, resulting from additional water use in the value chains, are relatively small or negligible. These results once again show that the value chain with the larger value addition multiplier effect (see Table 5.1.3), also has larger environmental impacts.

Table 5.1.5: Environmental impacts of substituting sugar cane and bananas with oranges.

Environmental indicators / impacts			Unit	Sugar subst by oranges		Bananas substituted by oranges	
				ΔE	ΔE	ΔE	ΔE
Source	Water	Intake	1000 m3	47	0.008%	-9	-0.001%
	Energy	Electricity	Mkw-hr	0.01	0.006%	0.00	0.001%
		Energy	TJ	0.2	0.005%	0.0	0.001%
		Bitum	mt	4	0.003%	1	0.001%
		Anth	mt	0.00	0.003%	0.00	0.000%
		NatGas	mt	0.1	0.003%	0.0	0.000%
		MotGas	mt	1	0.014%	0	0.003%
	Soil	Nitrogenous	Rmill	0	0.100%	0	0.025%
		Ammonium Nitrate	Rmill	0	0.100%	0	0.025%
		Ammonium Sulfate	Rmill	0	0.089%	0	0.022%
		Organic	Rmill	0.0017	0.098%	0.0004	0.025%
		Phosphatic	Rmill	0.0000	0.100%	0.0000	0.025%
		Super Phosphates	Rmill	0.0021	0.100%	0.0005	0.025%
		Mixed	Rmill	0.0026	0.091%	0.0007	0.023%
Sink	Air	SO2	mt	0.0677	0.003%	0.0122	0.001%
		CO	mt	0.0366	0.002%	0.0080	0.000%
		NO2	mt	0.0315	0.002%	0.0074	0.000%
		VOC	mt	0.0	0.002%	0.0	0.000%
		Lead	mt	0.0	0.003%	0.0	0.000%
		PM10	mt	0.0	0.004%	0.0	0.001%
		CO2	MTCO2E	16.6	0.004%	3.3	0.001%
		CH4	MTCO2E	0.0219	0.012%	0.0053	0.003%
		N2O	MTCO2E	0.0915	0.002%	0.0214	0.000%
		CFCs	MTCO2E	0.1009	0.013%	0.0175	0.002%
	Soil	Waste Shipped	mt	1	0.009%	0	0.002%

5.2 Scenario 2: Impacts of Pricing Policies

5.2.1 Reduction of water subsidies

As discussed in section 2.2.5, water for agricultural use was heavily subsidised under the legislation preceding the NWA. The NWA and its National Water Pricing Strategy aims at full recovery of water supply costs. Subsidies for agriculture are being phased out in accordance with agreements between the AgriSA and DWAF. In the case study area, four irrigation water prices exist. Above the Krokodilpoort, the full quota for irrigation was (in 1998) 8,000m^3/ha, and the basic water price R26.67/ha (0.35 cent/m^3) with a stepped tariff of R75.27/ha (0.94 cent/m^3) for additional water use. Below the Krokodilpoort, the full quota for irrigation was (in 1998) 13,000m^3/ha, and the basic water price R26.67/ha (0.21 cent/m^3) with a stepped tariff of R122.43/ha (0.94 cent/m^3) for additional water use (DWAF, 2000b). According to the agreement between the SAAU and DWAF, the basic prices would be increased by

50% from 1998/9 to 1999/2000, resulting in basic prices of R41.51/ha (0.52 cent/m^3) above the Krokodilpoort and R41.51/ha (0.32 cent/m^3) below the Krokodilpoort. The effects of these subsidy reductions on the economy are evaluated in this section. Two scenarios were simulated. In the first, the economy-wide impact of the reduction in water subsidies on irrigation agriculture is evaluated. Based on the number of hectares irrigated in the catchment, and the above-mentioned subsidy reductions, sugar cane irrigators and sub-tropical fruit irrigators paid an additional R44 000 and R131 000, respectively, for water. The change in final demand is calculated taking into account the price responsiveness of the water users – the change in subsidy is therefore multiplied by the price elasticity of water demand. A price elasticity of demand for water in SA of –0.6 was used (Hassan, 1998) and an additional simulation was done using an elasticity of –0.4, which indicates a smaller demand sensitivity of water users to price changes.

The results show that the additional water tariff amounts paid by the irrigation sector had an economy-wide impact of –0.002% under an elasticity scenario of -0.6 and -0.001% under an elasticity scenario of -0.4. As expected, a higher responsiveness of agriculture to water tariffs (i.e. higher (negative) elasticity) would lead to a corresponding higher decrease in water use and a corresponding reduction in crop output. The irrigated fruit crops are also much more affected by the subsidy reduction than sugar cane. The reason for this is the higher increase in subsidies paid by sub-tropical fruit irrigators.

Table 5.2.1: Economic impacts (ΔX) of reductions in water subsidies to irrigation agriculture

	Sectors	Reduction of subsidies Elasticity = -0.6	Reduction of subsidies Elasticity = -0.4
5	Sugar Cane	0.000%	0.000%
12	Avoes	-0.009%	-0.006%
13	Mangoes	-0.025%	-0.016%
14	Citrus	-0.035%	-0.023%
15	Bananas	-0.042%	-0.028%
35	Other Commodities	0.000%	0.000%
41	Large Commercial Farmers	-0.009%	-0.006%
	Total (excluding Activities where duplicate commodity exists)	-0.002%	-0.001%

Table 5.2.1E shows that the effect of these subsidy reductions has a very small effect on total water use. The reduction in water use varies between 12,300m^3 and 18,400m^3 depending on the elasticity (-0.4 and -0.6, respectively). This is equivalent to more or less one hectare under irrigation (8,000m^3/ha above the Crocodile Gorge, and 13,000m^3/ha below the Gorge).

Table 5.2.1E: Water use impacts of reductions in water subsidies to irrigation agriculture

Environmental indicators / impacts			Unit	Red. of subsidies	
				ΔE	
Source	Water	Intake	1000 m3	-12.3	Elasticity = -0.4
	Water	Intake	1000 m3	-18.4	Elasticity = -0.6

5.2.2 Introduction of a catchment management charge (CMC)

Under the NWA, the National Water Pricing Strategy makes allowance for a catchment management charge (CMC) to be levied on all water users. This charge is built into the water tariff paid by agriculture and industrial, urban and rural households. Forestry has traditionally not been expected to pay this levy. The introduction of a charge of R2/ha on an afforested area of 287 000ha, results in a direct reduction in output in pine and eucalypt forestry of R574k and a change in Final Demand of R128k (using the ***FD/X*** ratio from the Conningarth SAM). The price elasticity of demand used was – 1.0: as tree water use is a biological process, the only scope for reducing forestry water use would be to liquidate (reduce) afforested area in the long run. Liquidation of afforested areas is however a long-term process due to the long rotation-cycles of crops. An economy wide decrease in output of 0.002% resulted (Table 5.2.2). Table 5.2.2E shows a reduction in water use of 40,100m^3, which, based on water use efficiency ratios (66.5 and 38.6 m^3 water/m^3 round wood for Pine and Eucalypt, respectively) and MAI's (15 and 25 m^3 /ha /year), equals a reduction of 40-42 hectares of plantation area in the long run.

Table 5.2.2: Economic impacts (ΔX) of introducing a catchment management charge (CMC) on pine and eucalypt forestry

Sectors		Introduction of CMC
21	Roundwood	-0.187%
35	Other Commodities	0.000%
39	Labour	-0.001%
45	Forestry Enterprises	-0.010%
Total		-0.002%

Table 5.2.2E: Water use impacts of an introduction of a catchment management charge (CMC) to forestry

Environmental indicators / impacts			Unit	Introduction of CMC	
				ΔE	
Source	Water	Intake	1000 m3	-40.1	Elasticity = -1.0

5.2.3 Changes in Industrial water tariffs

Table 5.2.3 shows the results of increases in municipal water tariffs to industrial water users. In this experiment the typical sectoral output/water use ratios published in the StatsSA 1998 Supply and Use Tables (StatsSA, 2000) were multiplied by the output per sector in the study area to determine sectoral water use. A 10% increase in water tariff from a respective baseline price of R1.50/m^3 for urban industrial users and R0.69/m^3 for other industrial users were assumed (Bate et al. 2002). These increases were multiplied with the sectoral water use figures. A price elasticity of water demand of –0.6 was applied. The total economic impact was a reduction of 0.065% (Table 5.2.3). The industries most impacted here are those in the forest products value chain, especially the saw milling and pulp and paper industries. The impact on water use was a decrease of 117,000m^3 (Table 5.2.3E).

Table 5.2.3: Economic impacts (ΔX) of changes in Industrial water tariffs *(Elasticity = -0.6)*

Sectors		Change in Industrial Water Tariffs
2	Agrochemicals & other	-0.063%
3	Fuel	-0.018%
18	Other food & beverages	-0.012%
21	Roundwood	-0.260%
27	Wood products & Building Board	-0.462%
29	Furniture	-0.146%
30	Pulp&Paper	-0.081%
32	Freight transport	-0.024%
33	Trade	-0.024%
35	Other Commodities	-0.022%
38	Electricity Commodity	-0.031%
39	Labour	-0.032%
41	Large Commercial Farmers	-0.008%
45	Forestry Enterprises	-0.455%
46	Other Capital (urban & other)	-0.048%
Total		-0.065%

Table 5.2.3E: Water use impacts of an increase in Industrial Water Tariffs

Environmental indicators / impacts			Unit	Change in Industrial Water Tariffs	
				ΔE	
Source	Water	Intake	1000 m3	-117.0	Elasticity = -0.6

5.2.4 Comparative Analysis of changes in water tariffs on forestry, irrigation and industry

The economic and water use impacts of changes in water tariffs for forestry, irrigation and industry that results from WDM policy interventions show that an inflation-based increase (10%) in water tariffs have by far the largest impact on urban users (Table 5.2.4). Table 5.2.4 demonstrates the importance of the three variables water use proportion, water use responsiveness (elasticity) and water tariff level, in using water tariffs as a tool for water demand management. The change in water tariff was calculated by multiplying the elasticity of demand, the water tariff and the water tariff increase. Firstly, the proportionate share of water use should be considered to ensure that a water tariff strategy targets the correct sector. Secondly, the price elasticity of water demand has been based on assumptions of -1.0 for forestry and -

0.6 for the other water users. An elasticity of -0.6 effectively means that the water tariff effect is "diluted" by a factor of 60%. It is therefore very important to have accurate elasticity data as every 0.1 error in elasticity value can cause a 10% error in water tariff, which will have economy-wide effects. Finally, water tariffs at such low levels as those of forestry and irrigation crops require different (probably much higher) levels of tariff increases to influence water demand.

Table 5.2.4: The comparative impact on water use sectors of a 10% increase in water tariffs across all sectors.

	Forestry		Agriculture		Industry
	Pine	Eucalypt	Sugarcane	Fruit species	Urban
Proportionate water use	27%	18%	34%	14%	7%
Elasticity of demand	-1.0	-1.0	-0.6	-0.6	-0.6
Water tariff (cents/m^3)	0.0013	0.0008	0.21	0.35	150
Water tariff increase	10%	10%	10%	10%	10%
Change in water tariff (cents/m^3)	0.00013	0.00008	0.01	0.02	9.00

5.3 Scenario 3: The potential impact of environmental externalities on water use

Indicators of environmental the impacts of economic activity in the Crocodile River catchment in 1998 are shown in Table 5.3.1. These quantities were calculated using the SAM economic activity levels at 1998 prices and the environmental impacts vector E. The data indicate that the total water use in the catchment was 623 million m^3 in 1998. This was just under 50% of the mean annual runoff of 1,263 million m^3. Electricity use was 0.2 MkW-hr (million kilowatt hours), and total energy use 5.0 TJ (terra joules). The impact on soil as a source of essential elements required for plant growth was measured by the use of fertiliser expressed in Rands. The model estimated fertiliser use in the Catchment to be R35 million. This indicator does not provide useful information and qualitative data are required to better describe the Source impact on Soil. Such data would include salinisation, erosion and other factors that lead to a lower soil productivity. The contribution to greenhouse effect of CO_2, CH_4, N_2O and CFCs were approximately 401 $MtCO_2$ (metric tons CO_2) equivalent. A very important externality to investigate for its impact on water use would be water pollution. Unfortunately no suitable water pollution data were available for incorporation into the model, due to the fact the model relies on point-source data, whereas water pollution is often non-point source in nature.

Table 5.3.1: Selected environmental indicators and impacts in the Crocodile River Catchment (1998)

Environmental indicators / impacts			Unit	E
Source	Water	Intake	million m^3	623
	Energy	Electricity	Mkw-hr	0.2
		Energy	TJ	5.0
		Bitum	mt	118
		Anth	mt	0.1
		NatGas	mt	3.3
		MotGas	mt	8.3
	Soil	Fertiliser Use	Rmill	35.8
Sink	Air	SO2	mt	2.2
		CO	mt	1.9
		NO2	mt	2.0
		VOC	mt	0.6
		Lead	mt	0.0
		PM10	mt	0.2
		CO2	MTCO2E	395
		CH4	MTCO2E	0.2
		N2O	MTCO2E	5.8
		CFCs	MTCO2E	0.8
	Soil	Waste Shipped	mt	12

Policy interventions that strive to minimise environmental impacts may affect water demand. The environmental-SAM could be used to model this. For instance, if it were decided to reduce carbon emissions in the catchment, what would the effect of a carbon tax be on water demand? In other words, what are the water demand management implications of environmental taxes? Table 5.3.2 shows such effect reflecting an environmental (carbon) tax policy experiment.

The first column shows the CO_2 equivalent emission (**e**) factors for each sector. The total CO_2 equivalent emission was calculated by multiplying the emission factors (**e**) with the total output (**X_t**). A carbon tax of R20/ton was imposed on the prices of all carbon producing activities. A –0.54 price elasticity of carbon supply was assumed (McRae, 2000), and multiplied by the Connigarth SAM (2000) ***FD/X*** ratio, yielding the changed final demand (Δ**FD**). The resultant impact on the total economy of a carbon tax bill of R8,028k (k = x1000), resulted in a change in final demand of –R1,377k and an economy-wide impact of –R2,611k. Although the main purpose of this tax would be to achieve a reduction in CO_2 equivalent emissions amounting to 0,8% (total $MtCO_2$ equivalent emissions, see Table 5.3.3), it also has an indirect economic impact of -0.026% (ΔX) and a subsequent 1,215,000 m^3 reduction in water use. This experiment demonstrates the importance of considering the economy-wide effects of non-water policy decisions on water demand management.

A major limitation of this model is the fact that it does not incorporate carbon sequestration activities. The model does not include the effect of carbon sinks as in the case of Forestry. Carbon uptake forms part of the photosynthesis process that occurs during tree growth. If the xylem (wood) remains intact in a solid wood form (mostly timber) for a period of longer than 25 years, the carbon is considered sequestered (Van der Merwe, 2002). The carbon sequestration effect in the Forestry value chain is mainly due to the application of timber in a solid wood form, in underground mine packs. Modelling of carbon sequestration in forestry value chains by Crafford and co-workers (2002) showed a 1,97kg and 3.60kg equivalent CO_2 **sequestration** per cubic metre water used in Pine and Eucalypt forestry respectively. The study further showed that carbon **emissions** from these value chains were 1,82 kg and 0.93kg /m^3 equivalent CO_2 sequestered per cubic metre water used in Pine and Eucalypt forestry. As the emission values were lower than the sequestration values, Forestry has negative net carbon emissions. More research is required to determine the carbon sequestration coefficients of the economic sectors evaluated in this study.

Another limitation lies in the fact that the model uses the same elasticity of supply for all sectors. Different economic sectors respond differently to changes in input prices.

Table 5.3.2: The economic impact (ΔX) of a carbon tax on industries in the Crocodile River catchment

All values given in R'000		Carbon tax = R20 / mt CO2 Eq					
Sectors		mtCO2Eq / R'M Output	Tons CO2	Carbon tax paid (R)	ΔFD	ΔXt	ΔXt
1	Fertilizer	0.254	9.1	181.8	-3.3	-4.7	-0.01%
3	Fuel	0.118	15.6	312.6	-52.6	-58.6	-0.06%
5	Sugar Cane	0.041	16.8	336.5	-6.0	-6.6	0.00%
8	Sugar	0.079	4.1	81.2	-41.3	-45.4	-0.01%
12	Avoes	0.008	0.6	12.0	-0.4	-1.0	0.00%
13	Mangoes	0.008	0.2	4.3	-0.2	-0.8	0.00%
14	Citrus	0.008	1.5	29.8	-13.2	-16.4	-0.01%
15	Bananas	0.008	1.3	25.5	-11.3	-12.2	-0.01%
16	Juice Factories	0.029	2.1	41.5	0.0	-9.2	-0.03%
18	Other food & beverages	0.010	6.8	136.1	-59.7	-64.1	-0.03%
21	Roundwood	0.008	0.6	11.3	-1.4	-24.9	-0.04%
22	Saw Milling	0.015	6.2	124.2	0.0	-167.9	-0.10%
23	Mining Timber	0.015	2.4	48.3	0.0	-2.3	-0.01%
26	Boards	0.037	6.2	123.4	0.0	-5.4	-0.01%
31	Paper products	0.171	69.0	1381.0	-372.9	-379.3	-1.26%
32	Freight transport	0.021	4.8	95.1	-0.3	-13.2	-0.01%
33	Trade	0.031	6.4	127.5	-17.6	-26.5	-0.02%
38	Electricity Commodity	1.973	243.0	4860.6	-775.4	-798.9	-0.84%
	Rest of Sectors		4.8	96.1	-21.8	-973.9	2.40%
	Total (excluding Activities where duplicate commodity exists)		401.4	8 028.7	-1 377.3	-2 611.4	-0.026%

Table 5.3.3: The environmental impact (ΔE) of a carbon tax on the Crocodile River catchment

Environmental indicators / impacts			Unit	Carbon tax = R20/mtCO2Eq	
				ΔE	ΔE
Source	Water	Intake	1000 m3	-1215	-0.2%
	Energy	Electricity	Mkw-hr	0.000	0.0%
		Energy	TJ	-0.019	-0.4%
	Soil	Fertiliser Use	Rmill	0.000	0.0%
Sink	Air	SO2	mt	-0.010	-0.5%
		CO	mt	-0.001	0.0%
		NO2	mt	-0.005	-0.2%
		VOC	mt	0.000	0.0%
		Lead	mt	0.000	-0.6%
		PM10	mt	0.000	-0.1%
		CO2	MTCO2E	-1.645	-0.42%
		CH4	MTCO2E	0.000	-0.13%
		N2O	MTCO2E	-0.014	-0.24%
		CFCs	MTCO2E	0.000	-0.02%
	Soil	Waste Shipped	mt	-0.005	0.0%

5.4 Scenario 4: Projecting Absolute Water Scarcity

Absolute water scarcity is a situation where water demand exceeds water supply. Within the next 20 years, many water scarce countries and catchments can expect to reach this situation. The onset of this situation will also require the second phase of

WDM, as defined by the NWPS, to be implemented: allocation according to scarcity value, or water markets.

Table 5.4.1 shows the relationship between economic growth and water supply. The economic output as modelled by the SAM for 1998 was used as a baseline, and a constant 2,5% economic growth rate was assumed. The annual economic output ($\mathbf{X_{tn}}$) for the years indicated (**n** = 2000, 2005, 2010, 2015, 2020) were then calculated (using the formula $\mathbf{X_{t1998}}$*(1+2,5%)$^{(n-1998)}$). It was also assumed that water use coefficients stayed constant, implying no improvement in water use efficiency, in other words, there were no technical changes in water utilisation. The resultant water use ($\mathbf{E_{wn}}$) for each of these periods was then calculated using the formula $\mathbf{E_{wn} = e_w.X_{tn}}$ and expressed as a percentage of the MAR (Mean Annual Runoff) of 1,263 million m^3 ($\mathbf{E_{wn}}$ / **MAR**).

Under economic growth conditions of 2.5% per annum, the water use-MAR ratio increases from 50% in 1998 to 85% in 2020 (Table 5.4.1). The interpretation of this ratio is important, as it is an indicator of imminent absolute water scarcity in a catchment. Not included in this ratio is the environmental (ecological) water use requirement, or the in-stream flow requirement and river losses. Based on national averages (Crafford et al. 2001), this component could be expected to be 30% of MAR. If this assumption also holds for the study area, absolute water scarcity is reached when the water use-MAR ratio is approximately 70%.

Therefore, if the assumed conditions prevail (2.5% growth, constant water use coefficients and a constant water supply) it can be assumed that a situation of absolute water scarcity will be reached between 2010 and 2015, and possibly by 2012. This implies that water users in the catchment can expect water allocation systems that are based on water scarcity values, to be implemented much sooner than the widely publicised "water scarcity" date of 2025. It is important to realise that individual economic sectors will experience variable growth rates, while the technologies and management practices that underlie the water use coefficient vector $\mathbf{e_w}$ may also change for each sector as WDM interventions are implemented. These calculations may therefore be refined on a sector-specific basis for economic growth and water technology improvement.

Table 5.4.1: Projecting absolute water scarcity in the Crocodile River Catchment ***(2.5% growth and no change in efficiency of water use)***

All values given in R'000		Xt					
	Sectors	1998	2000	2005	2010	2015	2020
5	Sugar Cane	406 019	426 574	482 629	546 050	617 806	698 991
8	Sugar	51 616	54 229	61 355	69 418	78 540	88 861
12	Avoes	75 316	79 129	89 527	101 292	114 602	129 662
13	Mangoes	26 765	28 120	31 815	35 996	40 726	46 078
14	Citrus	186 788	196 244	222 032	251 209	284 220	321 569
15	Bananas	159 709	167 794	189 844	214 791	243 016	274 951
21	Roundwood	70 681	74 259	84 017	95 058	107 549	121 682
	Other (Urban & Industrial)	9 104 155	9 565 053	10 821 979	12 244 076	13 853 048	15 673 453
	Total	10 081 049	10 591 402	11 983 200	13 557 890	15 339 509	17 355 246
				E			
	Water Use	623 066	654 609	740 630	837 954	948 069	1 072 653
	Water Use / Mean Annual Runoff (%)	49%	52%	59%	66%	75%	85%

5.5 Scenario 5: The role of water metering in water trade

Well-defined and secure water use rights are at the core of well-functioning market systems. In the case of water markets, accurate water metering is an important prerequisite to ensure the volumetric measurement of water use. Agricultural water use in SA has historically been based on a pre-determined per hectare quota, which was calculated based on climatic and other geographical conditions of a specific area. Water charges have subsequently been based on flat rates on planted areas. One major implication of implementing WDM measures such as volumetric charges will require the use of water metering, an aspect which is a future source of conflict between irrigators and water regulators. Farmers claim that it is too expensive and inaccurate to install water meters, whereas DWAF's WDM strategies rely for the most part on accurate water metering. The question can then be asked what the economic impact will be of an intensive water meter installation programme.

In the study area, the registered irrigation areas and their quotas are 11 206 ha between the Kwena dam and the Crocodile River Gorge, with a quota of 8 000m^3/ha/annum, and 17 089 ha below the gorge with a quota of 13 000m^3/ha/annum (DWAF, 2002). The water tariffs in 1998 were R31.78 and R51.64 above and below the gorge, respectively. Inter-sector water trading will bring about a move away from the hectare-based tariff in favour of a volumetric system, which will enable users to trade volumes of water[11]. Monitoring water use volumetrically will therefore require accurate water metering.

Water metering is however, not a trivial exercise. Studies by the University of Pretoria have revealed two challenges to ensuring that agricultural water use is properly measured: the cost of water meters and their installation, and the accuracy of water meters (Van der Stoep, 2003). A policy simulation experiment was accordingly designed and implemented to analyse the implications of water metering, and imminent change in water management in SA.

This section evaluates the cost implications to the economy of installing water metering systems for the irrigation agriculture activities in the study area. The following assumptions were made (Van der Stoep, 2003):

- The total cost of a water meter and its installation is R20,000 (R10,000 equipment + R10,000 installation);
- This cost would be depreciated over 5 years by the farmers using a straight-line formula;
- One water meter is required for every 50 hectares irrigated.

This means that the cost of installation of water metering would amount to an increased cost of capital for irrigators of R80/ha/year that is equivalent to an increase in water price of nearly 300% for irrigators.

Water metering implies a move away from a quota based system to a volumetric measurement and pricing of water. This is important as it creates incentives for water users to use less water. However, it remains important for policy makers to assess the net benefits of a water meter installation programme. There are both private and social costs that need to be assessed. The private costs are the costs to the water user as calculated above. In return for these costs, the user gets the benefit of only having to pay for the water used, and not the total allocation whether its is used or not, as is currently the case, especially in a wet season where little irrigation is

[11] Most of the water trading that currently takes place are intra-sectoral, i.e. within an irrigation area between irrigation farmers, and are hectare-based.

required. In addition, the user can now trade excess water, and can therefore get financial gains from excess water sold or from additional production from extra water bought. The main social benefit lies in the fact that water can now be allocated to the most efficient users.

Unfortunately the scope of this study did not allow the modelling of such a scenario to determine the economy-wide impact as this would require a complete restructuring of the SAM model. However, it can be expected that a water metering installation programme results in a transaction cost that impacts on the total economy. The benefits of water metering should outweigh this transaction cost in order to result in a positive total economic impact (ΔX). These benefits can only be realised through reducing water losses, and allocation of water to its most productive uses and users. Water metering however, is only one of the cost aspects of moving to a water trading system. These and other transaction costs need to be carefully considered and planned for as each additional transaction cost component will impact the economy.

Chapter 6: Conclusions, Implications and Limitations of the Study

6.1 Conclusions and Implications

This study evaluated the economic and environmental costs and benefits of changes in water policies and management regimes in the Crocodile River Catchment, employing a SAM framework. The study particularly focussed on assessing the effects of water demand management regimes on the catchment economy. The cost and benefit analysis scenarios generated information about:

- The direct and indirect impacts of various WDM policies on the economy and the environment.
- The importance of environmental-economic models in water cost benefit modelling.

6.1.1 The direct and indirect impacts of various WDM policies on the economy and the environment

In sections 2.2.2 and 3.2 of this study, water demand management was defined to consist of two phases of intervention. The first phase deals with regulatory aspects of WDM, whereas the second phase deals with water allocation according to its scarcity value. As these two phases are implemented, water users can expect to experience a range of WDM measures that will impact on the way they use water. The study evaluated five water policies and other water management considerations:

1 - The effect of water re-allocations between various sectors,

2 - The effect of water pricing policies,

3 - The effect of environmental externalities,

4 - The prediction of absolute water scarcity,

5 - The investigation of the effect of a water-metering programme on water trade.

A discussion on each of these follows:

1 - The effect of water re-allocations between various sectors:

Economic, social and environmental activities are governed by a very large, and very complex, integrated set of transactions. Individual transactions occur at a micro-economic level: they are made in the context of the decision-makers' individual needs and environment. However, every transaction has, to a lesser or greater extent, a multiplier effect which indirectly affects the transactions of other decision-makers:

- Water allocations between large primary water users impact widely on the economy. New water allocations can have widely realised positive effects, whereas re-allocations may have widely distributed negative impacts in the sector losing water, and also in its associated value adding sectors. This is especially true for agricultural activities, which support such long value chains of economic activity.
- Changes in economic conditions, such as a change in a commodity price due to a drought or exchange rate fluctuations, can radically change the economy-wide impact of a water re-allocation.
- Longer, resource intensive, value chains, with their larger value addition components, have been shown to have generally higher environmental impacts. This confirms the findings of an earlier WRC study (Crafford et al, 2002).
- Policy implementation decisions have to be made based on sound, verified water use data. It was shown how new scientific data changed the estimated economy-wide effect of a water transaction between eucalypt forestry and sugar cane farming: improved estimates of forestry water use had an effect of 0.003% on total economic output in a simulated sugar-forestry water transaction. As new research is done on water use patterns of various land uses, data will therefore have to be continuously updated to ensure that the correct conclusions are drawn.

The results of this study have shown the complexity of economic and environmental transactions taking place in an economic system, and the resultant multiplier effects of WDM decisions. As such an economic system comprises of a multitude of individuals making decisions at a micro-economic level, it will be important for policy-makers to decentralize water use decision-making as far as possible. Water users carry the ultimate economic risk of their decisions, and appropriate WDM policies should transfer the risk of water scarcity to water users. For instance, section 5.1.1 discussed how a drop in the price of oranges could negate a water re-allocation from an alternative land use to oranges. With the volatility of the Rand since 1998, and the subsequent impact on exporters, such a scenario is entirely possible. Properly regulated water markets may play an important role in putting a value to scarce water resources.

2 - *The effect of water pricing policies*

The price responsiveness of various sectors is determined to a large extent by the elasticity estimates used. In the scenarios simulated in this study, price elasticities of -0.6 and -1.0 were used for irrigated agriculture and forestry respectively, and -0.6 for industrial water users.

In the agricultural sector, the simulated reduction of subsidies and changes in water tariff strategies (such as a catchment management charge for forestry), did not have a major effect on the economy or result in major water savings. The possible reasons for this are:

- the high level of integration of agricultural value chains;
- the long rotation periods of these crops;
- the relatively small incremental changes in tariffs that were brought about by the pricing policies: for instance, irrigation water tariffs increased by only 0.3-0.5 cents per cubic metre and the forestry water charge was R2/hectare. These subsidy changes therefore did not have a major impact on the cost of business of these sectors.

On the other hand, industrial water users were much more price responsive to an inflation based increase in water tariff. An inflation-based increase in water tariff of 10% was simulated, which meant that the cost of water of the large water-using industries increased by 10%. Such an increase impacted relatively more on the cost of their business that was the case for the agriculture sector.

It has to be recognised that accurate elasticity estimation is important to ensure that tariff policies achieve its goals.

The subsidy reduction and tariff changes experiments done in this study showed that the achievement of a NWA principle such as full cost recovery, does not necessarily achieve water savings. If a water scarcity situation occurs in a specific catchment area and water demand has to be reduced, an appropriate set of pricing policy interventions need to be targeted towards reduction of demand. For instance, policy-makers have to quantify the water use by the various sectors, understand the economic and other contributions of these sectors, identify those sectors where water savings can be achieved most effectively and then design and implement water pricing policies appropriate for each individual sector.

3 - The effect of environmental externalities

It was demonstrated how a carbon tax may reduce economic activity, and subsequently decrease water demand. A carbon tax of R20/ton levied on carbon-generating activities, and intending to reduce CO_2 equivalent emissions by 0.8%, reduced water demand by 1,215,000m^3, and economic output by 0.026%. Alternatively, WDM policies may have a positive effect on carbon emissions if it leads to a decrease in economic activity in an industry with high carbon emission levels.

In this scenario, an environmental protection policy had the unintended consequence of reducing water demand. There is therefore a need to assess the integrative effects of various policies.

4 - The prediction of absolute water scarcity

A combination of factors causes situations of water scarcity in various parts of South Africa. The variability of rainfall, location of economic activities and the existence of water supply infrastructure determine the water demand and supply in specific catchments. Therefore some in some catchments demand are catching up with water supply at a faster rate than in others. WDM measures are therefore necessary policy interventions for South Africa. The implementation of WDM measures do however need to be taken with great care and planning, as they could have major impacts on the economy. Catchments that face absolute water scarcity situations require well-planned, targeted interventions, and immediate implementation.

5 - The investigation of the effect of a water- metering programme on water trade

Metering of the quantity of water use is desirable for water management as it provides incentives for efficient water use. However, the net benefits of water metering installation programmes have to be assessed to ensure a net positive effect on the economy and the environment. It was estimated that a comprehensive water metering system could increase the cost of irrigation water by 300%. The benefits gained from the metering system should outweigh this increase in water cost.

Moving towards the second phase of WDM, water trading, will bring about complex new water management situations. In order to prepare for this, the various transaction costs of water trading (of which water metering is an example) need to be assessed and planned for. These transaction costs need to be limited to a level where the benefits accrued from water savings and productive allocation of water yields an economy-wide benefit. If not, water trading will fail as a WDM mechanism.

6.1.2 The importance of environmental-economic models in water cost benefit modelling

WDM implementation decisions are mostly made at a catchment level, which is a much smaller geographical unit than the provincial level. The economy may also differ in structure from that of a province. In addition, economic value chains span across catchment boundaries and therefore the economic and environmental impacts related to water management decisions may differ widely from catchment to catchment and between catchment and provincial levels. WDM policy makers and implementers include DWAF, CMAs and WUAs. Therefore, in facing complex water management problems, a SAM framework can be a helpful tool, to ensure that the equity, efficiency and sustainability principles of the NWA are adhered to. A regional SAM will be a worthwhile tool, especially at the CMA level, to assess regional economic effects of market and policy changes, and to help determine the approach of absolute water scarcity for the WMA.

It is therefore evident that policy decisions, which are implemented at a macro-economic level, and could have a major direct impact a wide range of economic sectors, should be carefully considered as it could have unintended consequences.

In order to make WDM decisions that adhere to the NWA principles of equity, efficiency and sustainability, decision-makers require tools, such as appropriate SAMs to inform their decision-making process. These tools can, however, only be effective if decision-making parameters and management objectives are clearly defined, and accurate data are used.

A regional economy, such as a CMA, may use a SAM to do strategic planning of various water demand management interventions and other assess various economic and environmental effects:

- a CMA may for instance use a SAM to determine the parameters for water use in order to manage water scarcity risk;
- they may use a SAM to decide whether and where trading may be appropriate (if benefits outweigh transaction costs);
- a SAM can be used as a tool to provide valuable information about the structure of the CMA or WUA economy with which direct and indirect impacts of water management decisions may be simulated.

6.2 Limitations of the study

- SAM modelling is limited by its nature as it presents an accounting framework where the relationships between various economic and environmental sectors are represented by linear functions. This has important implications for using the model to forecast impacts of policy changes, as it does not allow for input substitution resulting from a price change in a particular sector. Also, it does not allow for changes (improvement) in technology which take place from year to year. Both these limitations are of importance as the base data used by Conningarth for their Inkomati SAM were 1993 data, and since then, South Africa has become a more open economy – therefore agriculture and forestry sectors have become exposed to international pricing policies, and export/impart competition.

- The linearity constraint of the SAM also implies that the analyses done here are static, and does not take into account the dynamic price fluctuations experienced by many of the commodity markets discussed in this study.
- Research determining marginal values of water is a necessity for proper determination of pricing and efficiency allocations.
- The SAM model developed here was based purely on the secondary data sources described in Chapter 4 and was not verified against primary data.
- Assumptions used naturally also impose limitations. The following assumptions were made during the development of the SAM modelling:
    - The structure of the Crocodile River Catchment economy in 1998 was the same as that of the Komati study area as presented in the Conningarth SAM (Conningarth, 2000). This has important implications as Nelspruit, the major economic hub in the Crocodile River Cathment, fell oustside the Komati study area.
    - The structures of the forestry, sub-tropical fruit and sugar value chains for the Crocodile River Catchment economy in 1998, were assumed to be identical to the structures of these chains in the Mpumalanga study area as presented in the Hassan WRC study (Crafford et al. 2003).
    - The elasticity values used were sourced from secondary sources. Not enough information was available on elasticities, and more research on this is required.
    - The environmental indicators and impacts (**e**) used in the study, excluding the water use impacts, were identical to those of the USA economy.
- Only a first step was made into quantifying environmental impacts. Only point source environmental impacts can be meaningfully analysed. Point source data require that the relation between economic activity and environmental impact can be quantified by a measured coefficient, and such data is in most cases not available. In addition, environmental data are often indicators data of which the actual impacts, say on ecosystem functioning or human health (e.g. probability of respiratory disease in a specific community due to air pollution) are not known.

References:

Abstract of Agricultural Statistics, (2000): Published by: Department of Agriculture, Pretoria.

Armitage, R.M.; Nieuwoudt, W.L. and Backeberg, G. (1999): Establishing tradable water rights: Case studies of two irrigation districts in South Africa. Water SA, 25 (3) : 301 – 310.

Backeberg, G. (1997): Water institutions, markets and decentralised resource management: Prospects for innovative policy reforms in irrigated agriculture. Presidential Address, 35th Annual Conference of the Agricultural Economic Association of South Africa, Osner Conference Centre, East London.

Batchelor, G. (2001): Department of Environmental Affairs, Mpumalanga – Personal communication.

Bate, R.; Tren, R. (2002): The Cost of Free Water. The Free Market Foundation. Johannesburg.

CMUGDI (Carnegie Mellon University Green Design Initiative) (2001): Economic Input-Output Life Cycle Assessment (EIO-LCA) model (Internet), Available from: www.eiolca.net [Accessed 12 Dec, 2001].

Coase, R. (1960): The problem of social cost. Journal of law and economics, Vol 3, No 1, pp 1-44.

Conningarth Consultants (2000): Socio-economic impact of the Komati River Basin development project with special reference to irrigation agriculture. Water Research Commission, WRC Report No. 888/1/00.

RSA Constitution (1996): Constitution of the Republic of South Africa 1996 (Act 108 of 1996), www.gov.za/constitution/1996/96cons.htm

Crafford, J.G.; King, N.A.; Malubane, T.G; Anderson, H.J; De Wit, M.P. (2001): Water Resource Accounts for South Africa, 1991-1998; Produced for RANESA, CSIR Document ENV-P-C 2001-050.

Crafford, J.G.; Hassan, R.M.; King, N.A.; Damon M.C.; De Wit, M.P.; Rapholo, B.M., Olbrich, B.W. (2002): *An analysis of the social, economic, and environmental direct and indirect costs and benefits of water use in the irrigated agriculture and forestry* *sectors. A case study of the Crocodile River catchment, Mpumalanga Province.* WRC Unpublished Report Project No: K5/1048/0/1.

Gush, M.B. (et al) (2002): Estimation of Streamflow Reductions Resulting from Commercial Afforestation in South Africa. WRC Report No. TT 173/22.

DBSA (1998): Mpumalanga: Development Profile 1998, Development Bank of SA.

De Wit, M.P. (2001): Economic policy making for complex and dynamic environmental problems: a conceptual framework. D.Comm Thesis, University of Pretoria, Pretoria.

DWAF (1970): Verslag van die Komissie van Ondersoek insake Wateraangeleenthede. RSA R.P. 34/1970.

DWAF (2000a): WSAM (Water Situation Assessment Model for RSA) 2000: Version 1f, Department of Water Affairs & Forestry.

DWAF (2000b): Water pricing Tables, Directorate of Water Pricing, Department of Water Affairs and Forestry.

DWAF (2000c): Commercial Roundwood Survey, Department of Water Affairs and Forestry.

DWAF (2002): Private communication - Eddie Deacon, DWAF Nelspruit.

DWAF (2003): DWAF Website, www.dwaf.gov.za/documents

EPA (2002): United States Environmental Protection Agency www.epa.gov/ORD/NRMRL/lcaccess/lca101.htm

Forestry SA (2002): Abstract of South African Forestry Facts for the year 1999/2000. Published by Forestry South Africa, May 2002, www.forestry.co.za.

Government Notice No 1353 - 12 November 1999

National Water Act (Act No. 36 of 1998): Establishment of a pricing strategy for water use charges in terms of Section 56(1) of the National Water Act – 1998, www.dwaf.gov.za/documents

Haasbroek, B. (1999): Water Demand Management: South Africa Country Study. CSIR Environmentek Report Number ENV-P-C 98062

Hassan, R.M. (1998): Evaluation of the economy-wide impacts of the new water policy changes in South Africa: A SAM approach. Presented at the First World Congress of Environmental and Resource Economists, June 25-27, 1998, Venice, Italy.

Hassan, R.M. (2000): Issues in the economics of water resources management - LEK 786 Course lecturing material. Department of Agricultural Economics, University of Pretoria.

Hassan, R.M.; Olbrich, B.; Crafford, J.G. (2002): Measuring total economic benefits from water in plantation forestry: Application of quasi I-O framework to the Crocodile catchment in South Africa. South African Forestry Journal – No. 193, March 2002.

Hassan, R.M.; Blignaut, J. (2002): Policies and Practices for Financing Sustainable Development and Environmental Management in South Africa. Unpublished report.

Hassan, R.M. (2003): Economic direct and indirect costs and benefits of water use in irrigated agriculture and forestry. In: An analysis of the social, economic and environmental direct and indirect costs and benefits of water use in irrigated agriculture and forestry. Water Research Commission, WRC Project K5 1048 0 1.

Lange, G.; Hassan, R.M. (2003): Trade and the environment in Southern Africa: the impact of the 'user pays' principle for water on exports of Botswana, Namibia, and South Africa. Paper for the International Input-Output Association Conference, October 2002, Montreal, Canada.

McRae, R.N. (2000): CO2 Emissions and energy prices in the Asia-Pacific region. www.onlineopinion.com.au

Olbrich, B.; Hassan, R.M. (1999): A comparison of the economic efficiency of water use of plantations, irrigated sugar cane and sub-tropical fruits: A case study of the Crocodile River Catchment, Mpumalanga Province. WRC Report No 666/1/99, The Water Research Commission, Pretoria.

Pyatt, G; Round, J. (ed) (1985): Social Accounting Matrixes: A basis for planning. The World Bank, Washington, D.C.

SASA (2002): South African Sugar Industry Directory, 2001/2. Annual Directory produced by SASA's External Affairs Division, www.sugar.org.za.

StatsSA (2000): Supply and Use Tables.

Rosegrant, MW; Binswanger, HP (1994): Markets in Tradable Water Rights: Potential for Efficiency Gains in Developing Country Water Resource Allocation. World Development Vol. 22, No. 11, 1994.

Seckler, D. (1999): World Water Scarcity and the Challenge of increasing Water Use Efficiency and Productivity. In: Sustainable Agriculture Solutions, The Novello Press Ltd, London.

Van der Stoep, I. (2003): Private communication relating to WRC Project K5/1265 – Irrigation Water Measurement: The Application of flow meters in irrigation water management. University of Pretoria, Department of Agricultural Engineering.

Van der Merwe, M. (2002): Environmental modeller and Greenhouse effect expert; Environmentek, CSIR. Private communication.

Wilkinson, M.; Malubane, T.G.; Crafford, J.G. (2003): Guidelines for Water Management Planning. CSIR Draft Report – Unpublished.

Appendix 1: Table A1.1: Crocodile SAM – Total Input Requirements Matrix $(1\text{-}A_1)^{-1}$

	Commodity Fertilizer	Commodity Agro-chemicals & other	Commodity Petroleum	Activity Sugar cane Farming	Commodity Sugar cane	Activity Sugar mills	Activity Sugar refining	Commodity Sugar	Activity Animal Feed	Commodity Animal Feed & Molasse	Activity Sub-tropical Orchard Farming	Commodity Avoes	Commodity Mangoes	Commodity Citrus
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Fertilizer	1.0000	0.0000	0.0000	0.0569	0.0538	0.0023	0.0002	0.0002	0.0052	0.0043	0.0455	0.0231	0.0143	0.0165
2 Agrochemicals & other	0.0000	1.0000	0.0000	0.0024	0.0023	0.0021	0.0037	0.0034	0.0322	0.0268	0.0489	0.0249	0.0154	0.0177
3 Fuel	0.0000	0.0000	1.0000	0.0263	0.0249	0.0016	0.0011	0.0010	0.0100	0.0083	0.0741	0.0377	0.0234	0.0268
4 Sugar cane farming (Activity)	0.0000	0.0000	0.0000	1.0619	1.0046	0.0429	0.0032	0.0030	0.0004	0.0007	0.0000	0.0000	0.0000	0.0000
5 Sugar Cane	0.0000	0.0000	0.0000	0.0654	1.0619	0.0453	0.0034	0.0031	0.0004	0.0008	0.0000	0.0000	0.0000	0.0000
6 Sugar mills (Activity)	0.0000	0.0000	0.0000	0.0001	0.0001	1.0000	0.0745	0.0694	0.0095	0.0168	0.0004	0.0002	0.0001	0.0002
7 Sugar refining (Activity)	0.0000	0.0000	0.0000	0.0007	0.0007	0.0001	1.0002	0.9324	0.1262	0.2249	0.0017	0.0009	0.0005	0.0006
8 Sugar	0.0000	0.0000	0.0000	0.0007	0.0006	0.0001	0.0002	1.0001	0.1352	0.1108	0.0013	0.0006	0.0004	0.0005
9 Animal feed (Activity)	0.0000	0.0000	0.0000	0.0003	0.0003	0.0000	0.0001	0.0001	1.0002	0.8201	0.0004	0.0002	0.0001	0.0001
10 Animal Feed (& Molasses)	0.0000	0.0000	0.0000	0.0003	0.0003	0.0001	0.0001	0.0001	0.0003	1.0002	0.0005	0.0002	0.0001	0.0002
11 Sub-tropical orchard farming (Activity)	0.0000	0.0000	0.0000	0.0003	0.0003	0.0000	0.0001	0.0001	0.0509	0.0417	1.0501	0.5338	0.3312	0.3804
12 Avoes	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0115	0.0094	0.0266	1.0135	0.0084	0.0096
13 Mangoes	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0114	0.0094	0.0264	0.0134	1.0083	0.0096
14 Citrus	0.0000	0.0000	0.0000	0.0004	0.0003	0.0001	0.0001	0.0001	0.0975	0.0799	0.0260	0.0132	0.0082	1.0094
15 Bananas	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0152	0.0125	0.0469	0.0239	0.0148	0.0170
16 Juice factories (Activity)	0.0000	0.0000	0.0000	0.0008	0.0008	0.0001	0.0002	0.0002	0.0179	0.0147	0.0019	0.0010	0.0006	0.0007
17 Other food & beverages (Activity)	0.0000	0.0000	0.0000	0.0024	0.0023	0.0004	0.0006	0.0005	0.0552	0.0453	0.0059	0.0030	0.0019	0.0021
18 Other food & beverages	0.0000	0.0000	0.0000	0.0055	0.0052	0.0009	0.0013	0.0012	0.1236	0.1015	0.0132	0.0067	0.0042	0.0048
19 Pine Forestry (Activity)	0.0000	0.0000	0.0000	0.0013	0.0012	0.0001	0.0001	0.0001	0.0160	0.0132	0.0045	0.0023	0.0014	0.0016
20 Gum Forestry (Activity)	0.0000	0.0000	0.0000	0.0008	0.0008	0.0001	0.0001	0.0001	0.0103	0.0084	0.0029	0.0015	0.0009	0.0010
21 Roundwood	0.0000	0.0000	0.0000	0.0027	0.0026	0.0002	0.0002	0.0002	0.0335	0.0275	0.0093	0.0047	0.0029	0.0034
22 Saw milling (Activity)	0.0000	0.0000	0.0000	0.0003	0.0003	0.0000	0.0001	0.0001	0.0005	0.0005	0.0020	0.0010	0.0006	0.0007
23 Mining Timber (Activity)	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0002	0.0002	0.0009	0.0005	0.0003	0.0003
24 Poles (Activity)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
25 Charcoal (Activity)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001
26 Boards (Activity)	0.0000	0.0000	0.0000	0.0003	0.0003	0.0000	0.0001	0.0001	0.0006	0.0005	0.0021	0.0011	0.0007	0.0008
27 Wood products & Building Board	0.0000	0.0000	0.0000	0.0010	0.0009	0.0001	0.0002	0.0002	0.0018	0.0015	0.0068	0.0035	0.0022	0.0025
28 Furniture (Activity)	0.0000	0.0000	0.0000	0.0007	0.0007	0.0001	0.0002	0.0002	0.0007	0.0006	0.0012	0.0006	0.0004	0.0004
29 Furniture	0.0000	0.0000	0.0000	0.0013	0.0012	0.0002	0.0003	0.0003	0.0012	0.0011	0.0021	0.0011	0.0007	0.0008
30 Pulp&Paper	0.0000	0.0000	0.0000	0.0016	0.0016	0.0006	0.0010	0.0009	0.0099	0.0082	0.0439	0.0223	0.0139	0.0159
31 Paper products	0.0000	0.0000	0.0000	0.0028	0.0027	0.0010	0.0017	0.0016	0.0170	0.0142	0.0758	0.0385	0.0239	0.0274
32 Freight transport	0.0000	0.0000	0.0000	0.1565	0.1480	0.0084	0.0042	0.0039	0.0333	0.0278	0.0568	0.0289	0.0179	0.0206
33 Trade	0.0000	0.0000	0.0000	0.0129	0.0122	0.0054	0.0088	0.0082	0.0790	0.0659	0.0291	0.0148	0.0092	0.0106
34 Other Activities (Activity)	0.0000	0.0000	0.0000	0.1083	0.1025	0.0137	0.0173	0.0162	0.1349	0.1127	0.1689	0.0858	0.0533	0.0612
35 Other Commodities	0.0000	0.0000	0.0000	0.1362	0.1289	0.0180	0.0231	0.0216	0.1682	0.1407	0.2607	0.1325	0.0822	0.0944
36 Water (Activity)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37 Electricity (Activity)	0.0000	0.0000	0.0000	0.0046	0.0043	0.0004	0.0005	0.0005	0.0014	0.0012	0.0027	0.0014	0.0008	0.0010
38 Electricity Commodity	0.0000	0.0000	0.0000	0.0354	0.0335	0.0034	0.0037	0.0035	0.0108	0.0093	0.0205	0.0104	0.0065	0.0074
39 Labour	0.0000	0.0000	0.0000	0.0949	0.0898	0.0161	0.0225	0.0210	0.0850	0.0725	0.1353	0.0688	0.0427	0.0490
40 Capital	0.0000	0.0000	0.0000	0.0013	0.0012	0.0002	0.0003	0.0003	0.0011	0.0010	0.0018	0.0009	0.0006	0.0007
41 Large Commercial Farmers	0.0000	0.0000	0.0000	0.2635	0.2492	0.0110	0.0014	0.0013	0.0218	0.0180	0.3514	0.1786	0.1108	0.1273
42 Smallholders (Commercial)	0.0000	0.0000	0.0000	0.0069	0.0065	0.0003	0.0001	0.0001	0.0008	0.0006	0.0110	0.0056	0.0035	0.0040
43 Self Subsistant Farmers	0.0000	0.0000	0.0000	0.0002	0.0002	0.0000	0.0000	0.0000	0.0002	0.0002	0.0003	0.0002	0.0001	0.0001
44 Agro-Industries	0.0000	0.0000	0.0000	0.0001	0.0001	0.0032	0.0057	0.0053	0.0473	0.0395	0.0003	0.0002	0.0001	0.0001
45 Forestry	0.0000	0.0000	0.0000	0.0012	0.0012	0.0002	0.0002	0.0002	0.0071	0.0059	0.0073	0.0037	0.0023	0.0027
46 Other Capital (urban & other)	0.0000	0.0000	0.0000	0.0252	0.0239	0.0035	0.0046	0.0043	0.0350	0.0292	0.0375	0.0191	0.0118	0.0136
47 Households	0.0000	0.0000	0.0000	0.0524	0.0496	0.0089	0.0125	0.0116	0.0470	0.0400	0.0747	0.0380	0.0236	0.0271

	Activity Charcoal	Activity Boards	Commodity Wood products & building	Activity Furniture	Commodity Furniture	Activity Pulp& Paper	Commodity Paper products	Commodity Freight transport	Commodity Trade	Activity Other Activities	Commodity Other Commodities	Activity Water	Activity Electricity	Commodity Electricity
	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1 Fertilizer	0.0005	0.0005	0.0005	0.0007	0.0011	0.0007	0.0011	0.0010	0.0024	0.0047	0.0023	0.0015	0.0006	0.0001
2 Agrochemicals & other	0.0107	0.0129	0.0107	0.0164	0.0121	0.0162	0.0120	0.0036	0.0089	0.0170	0.0085	0.0189	0.0024	0.0003
3 Fuel	0.0068	0.0082	0.0068	0.0105	0.0114	0.0104	0.0113	0.0074	0.0183	0.0350	0.0174	0.0123	0.0122	0.0016
4 Sugar cane farming (Activity)	0.0000	0.0000	0.0002	0.0000	0.0000	0.0003	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5 Sugar Cane	0.0000	0.0000	0.0003	0.0000	0.0000	0.0003	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6 Sugar mills (Activity)	0.0003	0.0003	0.0056	0.0004	0.0003	0.0074	0.0044	0.0001	0.0002	0.0003	0.0001	0.0001	0.0001	0.0000
7 Sugar refining (Activity)	0.0034	0.0041	0.0743	0.0052	0.0035	0.0052	0.0034	0.0005	0.0014	0.0026	0.0013	0.0009	0.0011	0.0001
8 Sugar	0.0007	0.0008	0.0007	0.0010	0.0009	0.0010	0.0009	0.0005	0.0012	0.0022	0.0011	0.0008	0.0011	0.0001
9 Animal feed (Activity)	0.0003	0.0003	0.0003	0.0004	0.0004	0.0004	0.0004	0.0002	0.0004	0.0008	0.0004	0.0003	0.0004	0.0000
10 Animal Feed (& Molasses)	0.0003	0.0004	0.0003	0.0005	0.0005	0.0005	0.0005	0.0002	0.0005	0.0010	0.0005	0.0004	0.0005	0.0001
11 Sub-tropical orchard farming (Activity)	0.0003	0.0003	0.0003	0.0004	0.0004	0.0004	0.0004	0.0002	0.0005	0.0010	0.0005	0.0003	0.0004	0.0001
12 Avoes	0.0001	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0005	0.0002	0.0002	0.0002	0.0000
13 Mangoes	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000
14 Citrus	0.0004	0.0005	0.0004	0.0006	0.0005	0.0006	0.0005	0.0003	0.0007	0.0013	0.0006	0.0005	0.0006	0.0001
15 Bananas	0.0001	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0003	0.0006	0.0003	0.0002	0.0002	0.0000
16 Juice factories (Activity)	0.0008	0.0010	0.0008	0.0013	0.0012	0.0012	0.0012	0.0006	0.0015	0.0029	0.0015	0.0010	0.0015	0.0002
17 Other food & beverages (Activity)	0.0025	0.0030	0.0025	0.0039	0.0036	0.0038	0.0036	0.0019	0.0047	0.0091	0.0045	0.0031	0.0046	0.0006
18 Other food & beverages	0.0057	0.0068	0.0056	0.0087	0.0081	0.0086	0.0080	0.0043	0.0106	0.0203	0.0101	0.0070	0.0103	0.0013
19 Pine Forestry (Activity)	0.0266	0.0320	0.0261	0.0407	0.0239	0.0369	0.0216	0.0002	0.0005	0.0010	0.0005	0.0002	0.0002	0.0000
20 Gum Forestry (Activity)	0.0170	0.0205	0.0167	0.0260	0.0153	0.0236	0.0138	0.0001	0.0003	0.0007	0.0003	0.0001	0.0001	0.0000
21 Roundwood	0.0557	0.0669	0.0545	0.0851	0.0500	0.0772	0.0451	0.0005	0.0011	0.0021	0.0011	0.0004	0.0005	0.0001
22 Saw milling (Activity)	0.0116	0.0139	0.3100	0.0177	0.0106	0.0176	0.0105	0.0004	0.0009	0.0018	0.0009	0.0003	0.0002	0.0000
23 Mining Timber (Activity)	0.0052	0.0062	0.1387	0.0079	0.0047	0.0079	0.0047	0.0002	0.0004	0.0008	0.0004	0.0001	0.0001	0.0000
24 Poles (Activity)	0.0003	0.0004	0.0082	0.0005	0.0003	0.0005	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25 Charcoal (Activity)	1.0015	0.0018	0.0408	0.0023	0.0014	0.0023	0.0014	0.0000	0.0001	0.0002	0.0001	0.0000	0.0000	0.0000
26 Boards (Activity)	0.0119	1.0143	0.3181	0.0182	0.0109	0.0181	0.0108	0.0004	0.0010	0.0018	0.0009	0.0003	0.0002	0.0000
27 Wood products & Building Board	0.0388	0.0467	1.0380	0.0593	0.0355	0.0590	0.0351	0.0013	0.0031	0.0059	0.0029	0.0010	0.0008	0.0001
28 Furniture (Activity)	0.0032	0.0038	0.0031	1.0048	0.5868	0.0048	0.0033	0.0007	0.0017	0.0033	0.0016	0.0010	0.0010	0.0001
29 Furniture	0.0054	0.0065	0.0053	0.0083	1.0057	0.0082	0.0056	0.0012	0.0029	0.0056	0.0028	0.0017	0.0018	0.0002
30 Pulp&Paper	0.0050	0.0061	0.0050	0.0077	0.0068	1.0076	0.5867	0.0031	0.0078	0.0149	0.0074	0.0018	0.0020	0.0003
31 Paper products	0.0087	0.0105	0.0086	0.0133	0.0117	0.0132	1.0115	0.0054	0.0135	0.0257	0.0128	0.0031	0.0035	0.0004
32 Freight transport	0.0140	0.0168	0.0140	0.0214	0.0211	0.0211	0.0209	1.0120	0.0298	0.0569	0.0283	0.0152	0.0146	0.0019
33 Trade	0.0104	0.0125	0.0108	0.0159	0.0133	0.0158	0.0132	0.0056	1.0138	0.0264	0.0131	0.0031	0.0042	0.0005
34 Other Activities (Activity)	0.0872	0.1048	0.0865	0.1333	0.2795	0.1318	0.2781	0.2813	0.6972	1.3312	0.6628	0.0934	0.1455	0.0188
35 Other Commodities	0.1540	0.1851	0.1522	0.2354	0.2288	0.2326	0.2264	0.1276	0.3162	0.6038	1.3006	0.1763	0.2799	0.0362
36 Water (Activity)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
37 Electricity (Activity)	0.0009	0.0011	0.0010	0.0014	0.0013	0.0014	0.0013	0.0006	0.0016	0.0031	0.0015	0.0055	1.0232	0.1325
38 Electricity Commodity	0.0073	0.0088	0.0074	0.0112	0.0101	0.0111	0.0100	0.0050	0.0124	0.0236	0.0117	0.0423	0.1789	1.0232
39 Labour	0.0997	0.1198	0.0991	0.1523	0.1330	0.1503	0.1313	0.0615	0.1525	0.2911	0.1450	0.1236	0.1335	0.0173
40 Capital	0.0013	0.0016	0.0013	0.0020	0.0018	0.0020	0.0018	0.0008	0.0020	0.0039	0.0019	0.0017	0.0018	0.0002
41 Large Commercial Farmers	0.0033	0.0040	0.0033	0.0051	0.0104	0.0051	0.0104	0.0104	0.0258	0.0493	0.0246	0.0035	0.0055	0.0007
42 Smallholders (Commercial)	0.0002	0.0002	0.0002	0.0003	0.0005	0.0003	0.0005	0.0006	0.0014	0.0026	0.0013	0.0002	0.0003	0.0000
43 Self Subsistant Farmers	0.0002	0.0002	0.0002	0.0002	0.0005	0.0002	0.0005	0.0005	0.0012	0.0024	0.0012	0.0002	0.0003	0.0000
44 Agro-Industries	0.0002	0.0002	0.0006	0.0002	0.0002	0.0003	0.0002	0.0001	0.0003	0.0005	0.0002	0.0002	0.0002	0.0000
45 Forestry	0.0797	0.0958	0.0780	0.1218	0.0724	0.1200	0.0709	0.0019	0.0046	0.0089	0.0044	0.0009	0.0011	0.0001
46 Other Capital (urban & other)	0.0275	0.0331	0.0273	0.0421	0.0672	0.0417	0.0668	0.0595	0.1474	0.2815	0.1402	0.5684	0.5714	0.0740
47 Households	0.0551	0.0662	0.0547	0.0842	0.0735	0.0830	0.0725	0.0340	0.0842	0.1608	0.0801	0.0683	0.0738	0.0095

Table A1.2: Crocodile SAM – Environmental Impacts Matrix (E)

				Commodity Fertilizer	Commodity Agro-chemicals & other	Commodity Petroleum	Activity Sugar cane Farming	Commodity Sugar cane	Activity Sugar mills	Activity Sugar refining	Commodity Sugar	Activity Animal Feed	Commodity Animal Feed & Molasse	Activity Sub-tropica Orchard Farming	Commodity Avoes
				1	2	3	4	5	6	7	8	9	10	11	12
Source	Water	Intake	m3/R	0.004292	0.0010415	0.00044	0	0.543478	0	0	0.149142	0	0.54013	0	0.130072
		Electricity	Mkw-hr/milR	0.000271	3.43E-05	4.51E-05	0	2.57E-05	0	0	1.73E-05	0	2.37E-05	0	1.45E-05
		Energy	TJ/milR	0.003377	0.0003813	0.002159	0	0.00058	0	0	0.000951	0	0.000183	0	0.000135
		Bitum	mt/milR	0.066299	0.0066043	0.000365	0	0	0	0	0.020436	0	0.002873	0	0
		Anth	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		NatGas	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		LNG	mt/milR	0	0	0.011344	0	0	0	0	0	0	0	0	0
		LPG	mt/milR	0.003775	0.0015554	0.027612	0	0.002464	0	0	0.000646	0	6.44E-05	0	0
		MotGas	mt/milR	0.00999	0.0006119	0.000206	0	0.007367	0	0	0.001909	0	0.000608	0	0.001934
		Kero	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0.000235
		AvFuel	mt/milR	0	0	5.38E-06	0	0	0	0	0	0	0	0	0.000223
		JetFuel	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0.000148
		LFO	mt/milR	0.009877	0.0007718	0.000788	0	0.001957	0	0	0.003692	0	0.000768	0	0
		HFO	mt/milR	0.005001	0.0006071	0.000671	0	0	0	0	0.002358	0	0.000352	0	0
	Soil	Nitrogenous	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	1.39E-08
		Ammonium Nitrate	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	1.42E-06
		Ammonium Sulfate	Rmill/milR	0	0	0	0	3.29E-07	0	0	0	0	0	0	2.07E-06
		Organic	Rmill/milR	0	0	0	0	8.22E-08	0	0	0	0	0	0	3.33E-06
		Phosphatic	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	4.17E-08
		Super Phosphates	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	3.98E-06
		Mixed	Rmill/milR	0	0	0	0	6.58E-07	0	0	0	0	0	0	5.06E-06
Sink	Air	SO2	mt/milR	0.000201	0.0001622	0.000581	0	4.05E-06	0	0	0.000446	0	1.25E-05	0	4.35E-06
		CO	mt/milR	0.001784	0.0003462	0.000312	0	0.001604	0	0	0.000627	0	1.21E-06	0	2.33E-07
		NO2	mt/milR	0.000509	0.000111	0.000385	0	0.001792	0	0	0.000475	0	7.06E-06	0	2.2E-06
		VOC	mt/milR	0.000381	0.0001059	0.000299	0	0.000283	0	0	9.66E-05	0	1.84E-05	0	1.42E-06
		Lead	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		PM10	mt/milR	0.000286	9.475E-06	2.86E-05	0	0	0	0	0.000119	0	2.27E-05	0	2.55E-06
		Non-Point Air	mt/milR	0	1.099E-05	2.22E-05	0	0	0	0	2.48E-06	0	2.65E-06	0	0
		Point Air	mt/milR	0	2.141E-05	1.43E-05	0	0	0	0	7.43E-05	0	1.17E-05	0	0
		Air Releases	mt/milR	0	3.221E-05	3.66E-05	0	0	0	0	7.43E-05	0	1.43E-05	0	0
		CO2	MTCO2E/milR	0.252438	0.0271141	0.116108	0	0.036132	0	0	0.077262	0	0.012682	0	0.007938
		CH4	MTCO2E/milR	0.000181	1.364E-05	3.85E-05	0	0.000109	0	0	4.21E-05	0	1.09E-05	0	3.49E-05
		N2O	MTCO2E/milR	0.001476	0.000322	0.001117	0	0.005197	0	0	0.001377	0	2.05E-05	0	6.38E-06
		CFCs	MTCO2E/milR	0	0.0111412	0.000366	0	0	0	0	0	0	0	0	0
		Non-Point Air	mt/milR	0	3.6E-06	1.51E-06	0	0	0	0	0	0	1.21E-06	0	0
		Point Air	mt/milR	0	4.169E-06	1.66E-06	0	0	0	0	4.95E-06	0	1.1E-06	0	0
	Water	Recycled/Reused	m3/R`000	0	2.8689748	29.13669	0	0	0	0	18.74659	0	0	0	0
		Discharged Untreated	m3/R`000	0	0	1.751386	0	0	0	0	9.373294	0	0	0	0
		Discharged Treated	m3/R`000	0	0	2.037976	0	0	0	0	9.373294	0	0	0	0
Soil	Waste	Generated	mt/milR	7.7E-06	0.013077	0.073078	0	0	0	0	0	0	1.1E-07	0	0
		Managed	mt/milR	0	0.0019128	0.068877	0	0	0	0	0	0	0	0	0
		Shipped	mt/milR	7.7E-06	0.0005988	0.000702	0	0	0	0	0	0	1.1E-07	0	0

				Activity Charcoal	Activity Boards	Commodity Wood products & building	Activity Furniture	Commodity Furniture	Activity Pulp& Pap	Commodity Paper products	Commodity Freight transport	Commodity Trade	Activity Other Activities	Commodity Other Commodities	Activity Water
				25	26	27	28	29	30	31	32	33	34	35	36
Source	Water	Intake	m3/R	0.247633	0.0326591	0	0	0.011954	0	0.015144	0.005287	0.002881	0	0	2.405454
		Electricity	Mkw-hr/milR	0.000208	0.0001876	0	0	1.91E-05	0	0.000188	1.34E-05	7.89E-05	0	0	4.36E-05
		Energy	TJ/milR	0.000547	0.0006957	0	0	0.000324	0	0.002181	0.000316	0.000523	0	0	0.000257
		Bitum	mt/milR	0.006381	0.0020458	0	0	0.003501	0	0.051455	0	0	0	0	0
		Anth	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		NatGas	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		LNG	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		LPG	mt/milR	0.000859	0.0013753	0	0	0.000471	0	0.000551	0.000164	0.000549	0	0	0.000582
		MotGas	mt/milR	0	0.0019474	0	0	0.001853	0	0.000659	0.004001	0.002939	0	0	0.002521
		Kero	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		AvFuel	mt/milR	0	0	0	0	0	0	0	5.39E-05	0	0	0	0
		JetFuel	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		LFO	mt/milR	0.000852	0.0060092	0	0	0.002338	0	0.001204	0.002442	0.006434	0	0	0.001446
		HFO	mt/milR	0.001565	0.0005011	0	0	0	0	0.011047	0	0	0	0	0
	Soil	Nitrogenous	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	0
		Ammonium Nitrate	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	0
		Ammonium Sulfate	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	0
		Organic	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	0
		Phosphatic	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	0
		Super Phosphates	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	0
		Mixed	Rmill/milR	0	0	0	0	0	0	0	0	0	0	0	0
Sink	Air	SO2	mt/milR	0.000305	8.009E-05	0	0	0.000127	0	0.001216	0	2.14E-05	0	0	5.93E-05
		CO	mt/milR	0.003395	0.0006179	0	0	1.43E-07	0	0.001173	0.000475	4.85E-06	0	0	0.000198
		NO2	mt/milR	6.19E-05	0.0003524	0	0	5.72E-07	0	0.000862	9.39E-06	1.5E-05	0	0	0.000277
		VOC	mt/milR	0.000117	0.0006888	0	0	1.1E-05	0	0.000237	0.000157	0.00022	0	0	0.00016
		Lead	mt/milR	0	0	0	0	0	0	0	0	0	0	0	0
		PM10	mt/milR	8.03E-05	0.0002609	0	0	7.97E-08	0	7.46E-05	5.21E-07	3.74E-06	0	0	1.71E-05
		Non-Point Air	mt/milR	6.7E-06	4.577E-06	0	0	7.52E-06	0	1.07E-05	0	0	0	0	0
		Point Air	mt/milR	1.34E-05	0.0001465	0	0	2.69E-05	0	0.00017	0	0	0	0	0
		Air Releases	mt/milR	2.01E-05	0.000151	0	0	3.44E-05	0	0.00018	0	0	0	0	0
		CO2	MTCO2E/milR	0.025828	0.0357326	0	0	0.023166	0	0.168623	0.020725	0.031095	0	0	0.014058
		CH4	MTCO2E/milR	6.7E-06	3.89E-05	0	0	3.05E-05	0	4.24E-05	6.15E-05	5.04E-05	0	0	3.79E-05
		N2O	MTCO2E/milR	0.000179	0.0010229	0	0	1.66E-06	0	0.0025	2.73E-05	4.33E-05	0	0	0.000802
		CFCs	MTCO2E/milR	0	0	0	0	0	0	0	0	0	0	0	0
		Non-Point Air	mt/milR	1.67E-06	2.288E-06	0	0	3.17E-08	0	2.51E-07	0	0	0	0	0
		Point Air	mt/milR	3.35E-06	6.636E-05	0	0	1.14E-07	0	2.33E-05	0	0	0	0	0
	Water	Recycled/Reused	m3/R`000	6.335653	0	0	0	0	0	75.81635	0	0	0	0	0
		Discharged Untreated	m3/R`000	0	0	0	0	0	0	6.344464	0	0	0	0	0
		Discharged Treated	m3/R`000	0	0	0	0	0	0	16.49561	0	0	0	0	0
Soil	Waste	Generated	mt/milR	6.19E-05	6.865E-06	0	0	1.81E-05	0	4.53E-05	8.17E-06	0.006772	0	0	0.00097
		Managed	mt/milR	0	0	0	0	0	0	0	1.74E-07	0.004116	0	0	0.000947
		Shipped	mt/milR	6.19E-05	4.577E-06	0	0	1.8E-05	0	4.19E-06	7.3E-06	0.005333	0	0	2.86E-05

Source: See Section 4.4

Appendix 2: Table 5.4.1

All values given in R'000		Xt					
Sectors		1998	2000	2005	2010	2015	2020
1	Fertilizer	36,061	37,886	42,865	48,498	54,871	62,081
2	Agrochemicals & other	66,211	69,563	78,704	89,046	100,747	113,986
3	Fuel	132,532	139,241	157,538	178,240	201,662	228,163
4	Sugar cane farming (Activity)	384,212	403,663	456,708	516,723	584,625	661,449
5	Sugar Cane	406,019	426,574	482,629	546,050	617,806	698,991
6	Sugar mills (Activity)	10,941	11,495	13,006	14,715	16,648	18,836
7	Sugar refining (Activity)	46,741	49,108	55,561	62,862	71,123	80,469
8	Sugar	51,616	54,229	61,355	69,418	78,540	88,861
9	Animal feed (Activity)	22,062	23,179	26,224	29,670	33,569	37,981
10	Animal Feed (& Molasses)	26,900	28,262	31,975	36,177	40,931	46,310
11	Sub-tropical orchard farming (Activity)	235,736	247,670	280,216	317,038	358,700	405,836
12	Avoes	75,316	79,129	89,527	101,292	114,602	129,662
13	Mangoes	26,765	28,120	31,815	35,996	40,726	46,078
14	Citrus	186,788	196,244	222,032	251,209	284,220	321,569
15	Bananas	159,709	167,794	189,844	214,791	243,016	274,951
16	Juice factories (Activity)	71,879	75,518	85,442	96,670	109,373	123,745
17	Other food & beverages (Activity)	292,217	307,010	347,354	392,999	444,643	503,072
18	Other food & beverages	654,341	687,467	777,806	880,016	995,658	1,126,495
19	Pine Forestry (Activity)	33,884	35,599	40,277	45,570	51,558	58,333
20	Gum Forestry (Activity)	21,663	22,760	25,751	29,135	32,963	37,295
21	Roundwood	70,681	74,259	84,017	95,058	107,549	121,682
22	Saw milling (Activity)	400,717	421,003	476,327	538,920	609,738	689,863
23	Mining Timber (Activity)	156,039	163,939	185,482	209,856	237,432	268,633
24	Poles (Activity)	23,496	24,686	27,929	31,600	35,752	40,450
25	Charcoal (Activity)	10,566	11,100	12,559	14,209	16,077	18,189
26	Boards (Activity)	167,657	176,145	199,292	225,481	255,111	288,634
27	Wood products & Building Board	772,054	811,139	917,729	1,038,327	1,174,771	1,329,146
28	Furniture (Activity)	339,777	356,979	403,889	456,963	517,012	584,951
29	Furniture	33,681	35,386	40,037	45,298	51,250	57,985
30	Pulp&Paper	1,386,742	1,456,946	1,648,401	1,865,014	2,110,092	2,387,376
31	Paper products	448,676	471,391	533,335	603,420	682,714	772,428
32	Freight transport	226,913	238,400	269,728	305,173	345,275	390,647
33	Trade	203,459	213,759	241,849	273,629	309,587	350,269
34	Other Activities (Activity)	1,730,476	1,818,081	2,056,992	2,327,298	2,633,124	2,979,138
35	Other Commodities	3,135,500	3,294,235	3,727,125	4,216,899	4,771,035	5,397,988
36	Water (Activity)	30,086	31,609	35,762	40,462	45,779	51,794
37	Electricity (Activity)	15,866	16,669	18,860	21,338	24,142	27,315
38	Electricity Commodity	122,555	128,759	145,679	164,823	186,482	210,987
39	Labour	1,147,513	1,205,606	1,364,033	1,543,278	1,746,077	1,975,526
40	Capital	121,145	127,278	144,003	162,926	184,336	208,559
41	Large Commercial Farmers	215,186	226,080	255,789	289,401	327,431	370,458
42	Smallholders (Commercial)	11,011	11,569	13,089	14,809	16,755	18,957
43	Self Subsistant Farmers	1,723	1,810	2,048	2,317	2,621	2,966
44	Agro-Industries	42,102	44,234	50,046	56,623	64,063	72,482
45	Forestry	64,487	67,752	76,655	86,728	98,125	111,020
46	Other Capital (urban & other)	250,488	263,169	297,751	336,878	381,147	431,233
47	Households	1,452,340	1,525,864	1,726,376	1,953,235	2,209,907	2,500,307
	Total (excluding Activities where duplicate commodity exists)	11,630,479	12,219,272	13,824,985	15,641,701	17,697,149	20,022,700
		E					
	Water Use	623,152	654,699	740,732	838,070	948,199	1,072,801
	Water Use / Mean Annual Runoff (%)	49%	52%	59%	66%	75%	85%