# 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 socioeconomic 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.