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.

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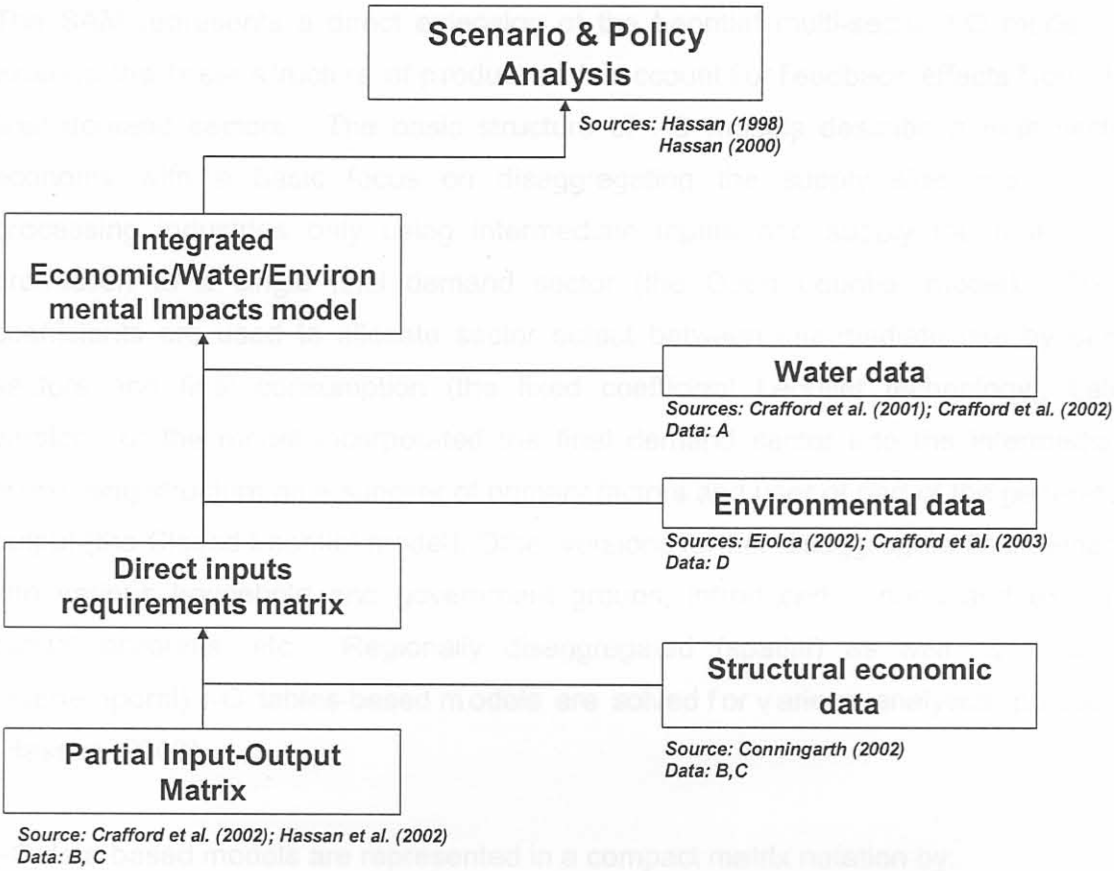
Figure 4.1: A framework showing the approach followed by the study



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:

$$X - AX = d$$

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

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

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:

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

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 $(1\text{-}A_1)^{-1}$ (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 $(1\text{-}A_1)^{-1}$ and the environmental impacts matrix (E): $(1\text{-}A_1)^{-1}.\Delta D = \Delta X_t$ 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:

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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.

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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 (V_j/X_j) 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.

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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	Tax / Subsidy	Export
	Juice factories									for		Demand
	Other food & beverages									final		
	Other food & beverages									consumption		
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).

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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