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**AWARE: A DECISION SUPPORT TOOL TOWARDS DECENTRALISED  
WATER MANAGEMENT IN SOUTH AFRICA**

Stefano Farolfi & Rashid M. Hassan

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# AWARE: A DECISION SUPPORT TOOL TOWARDS DECENTRALISED WATER MANAGEMENT IN SOUTH AFRICA

*Stefano Farolfi and Rashid M. Hassan* \*

## Résumé

L'objectif de cet article est de présenter un modèle de simulation pour l'aide à la décision appelé AWARE (Action-research and Watershed Analyses for Resource and Economic sustainability). Ce modèle est en cours de développement par le Centre pour l'Economie et la Politique Environnementale en Afrique (CEEPA) en collaboration avec le Ministère des Eaux et des Forêts sud africain (DWAF).

La nouvelle loi sur l'eau sud africaine (NWA, 1998) favorise la gestion intégrée et décentralisée de la ressource hydrique dans un contexte institutionnel rénové. Développement social, croissance économique, intégrité environnementale et équité dans l'accès à l'eau sont les objectifs clés du nouveau cadre juridique et réglementaire de gestion de la ressource. Des nouvelles entités (Catchment Management Agencies - CMAs, et Water Users' Associations - WUAs) sont en cours de constitution aux niveaux régional et local. Ceci souligne l'approche décentralisée et participative adoptée dans ce pays pour la gestion de la ressource hydrique. Toutefois, pour être effectifs, de tels changements radicaux demandent des temps relativement longs. La mise en œuvre du NWA doit en outre faire face à plusieurs questions sociales dans un contexte de déficit hydrique généralisé, retards et inégalités dans les infrastructures d'approvisionnement en eau. Par conséquent, la gestion et le contrôle de la demande en eau sont vus comme des tâches cruciales des nouvelles CMAs. L'approche adoptée se base sur un processus d'attribution de licences, à travers lequel des autorisations d'usage de l'eau sont allouées aux différents demandeurs. Ce processus soulève des nombreuses questions concernant les critères de priorité dans l'allocation des licences. Par exemple on peut se demander avec quelle fréquence et comment ces licences devraient être révisées, ou encore quel serait l'impact de certaines stratégies d'allocation ?

AWARE est un outil de simulation spécifiquement conçu pour modéliser des dynamiques de système au niveau du bassin versant. Le modèle évalue différents scénarios représentant des stratégies potentielles de gestion de l'eau en fonction de leur efficacité économique, viabilité environnementale et équité sociale. L'aspect central des stratégies simulées est représenté par l'attribution de priorités à certains groupes d'utilisateurs de la ressource, dans un contexte de compétition entre ceux-ci.

AWARE évalue l'impact économique (production, création d'emploi) et environnemental (préservation de la *réserve écologique*) des différents scénarios simulés qui représentent des stratégies alternatives de gestion de l'eau.

Après avoir illustré le cadre juridique et institutionnel de la gestion de l'eau en Afrique du sud, l'article présentera la structure et les principaux résultats du modèle. Dans une dernière partie, nous discuterons de l'utilité d'un modèle d'aide à la décision/négociation pour faciliter le processus de gestion décentralisée de l'eau dans le pays.

\* S. Farolfi is researcher at the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (Cirad-Tera), Montpellier and research fellow at the Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria.  
R.M. Hassan is the Director of CEEPA, University of Pretoria.

## Summary

The purpose of this paper is to illustrate a decision-support simulation model called AWARE (Action-research and Watershed Analyses for Resource and Economic sustainability). This model is being developed by the Centre for Environmental Economics and Policy in Africa (CEEPA) in collaboration with the Department of Water Affairs and Forestry (DWAF) in South Africa.

The new National Water Act of South Africa (NWA, 1998) promotes integrated and decentralised water resource management in a new institutional environment. Social development, economic growth, ecological integrity and equity of access to water are key objectives of the new water resource management regulation. New management entities (e.g. Catchment Management Agencies - CMAs, and Water Users' Associations - WUAs) are currently being established at regional and local levels, emphasizing a largely decentralized and participatory approach to water resource management. Such radical institutional changes, however, require a relatively long time frame to come into effect. The implementation of the NWA faces many social questions and economic uncertainties, within a context of water scarcity, backlogs and inequalities in infrastructure and water supply. Management and control of water demand is accordingly seen as a major task of the newly established CMAs. The approach adopted relies on a licensing process through which water use authorisations are allocated to various applicants. This process raises a number of questions as to how to prioritise between different uses and users, when and how licenses should be revised, and what the impact of certain licensing strategies might be?

AWARE is a simulation tool specifically designed for modelling system dynamics of catchment level water management. The model evaluates alternative action scenarios representing potential water management strategies for economic efficiency, environmental sustainability, and social desirability. The core emphasis of simulated water strategies is on allocation of priorities among competing groups of water users.

AWARE evaluates the socio-economic (i.e. output and employment levels) and environmental (preservation of the *ecological reserve*) consequences of simulated scenarios representing alternative water management strategies.

After illustrating the legal and institutional background to water management in South Africa, the paper presents the structure and the main results of various model simulations. A discussion of the usefulness of a decision/negotiation support tool in facilitating the process of decentralised water management in the country is finally provided.

## 1. Introduction

The new National Water Act of South Africa (NWA, 1998) promotes integrated and decentralised water resource management under a new institutional environment (Hamann & O’Riordan, 2000; Perret, 2002). Social development, economic growth, ecological integrity and equity of access to water are key objectives of the new water resource management regulation. New management entities (Catchment Management Agencies – CMAs and Water Users’ Associations - WUAs) are currently established at regional and local levels, emphasizing a largely decentralized and participatory approach to water resource management. Such radical institutional changes, however, require a relatively long time-frame to come into effect. The implementation of the NWA faces many social questions and economic uncertainties, within a context of water scarcity, backlogs and inequalities in infrastructure and water supply.

Management and control of water demand has been identified as a major task of the newly established CMAs. The approach adopted for water allocation to economic uses relies on a licensing process through which water use authorisations are granted to various applicants. This process raises a number of questions (Farolfi & Perret, 2002) as to how to prioritise between different uses and users, when and how licenses should be revised, and what the impact of certain licensing strategies might be? The decision-making process for water management in South Africa deals largely with regulating a complex system of interactions between multiple biophysical and socio-economic entities co-existing in a watershed. This process must also comply with and serve the economic, social, and environmental objectives of the NWA.

Decision support tools like System Dynamic Models (SDM), which are able to take the ecological and socio-economic dynamics into account, provide a relevant framework for facilitating the design and implementation of water management strategies. SDMs use powerful simulation modelling techniques for framing, understanding, and discussing complex issues and problems (Radzicki, 1997). SDMs allow easy dynamic representations and long-term scenario-based simulations to predict outcomes of policy decisions (Costanza & Gottlieb, 1998). Where long-term studies or experimental manipulations are not possible, as in the case of evaluating the implications of CMAs’ water allocation strategies over a long period of time, simulation models can facilitate overcoming existing data and knowledge gaps (Costanza *et al.*, 1993).

This study develops an example of SDMs’ application to simulating water allocation decisions in South Africa. The developed model, called AWARE (Action research and Watershed Analyses for Resource and Economic sustainability) is a simulation model that explores the impact of different strategies of water allocation on the key objectives of the NWA at the watershed level. The Steelpoort area, a sub-basin of the Olifants river catchment in the northeast South Africa has been chosen as the case study area. The results of two versions of the model (AWARE1 and AWARE2) were simulated. AWARE1 adopts a relatively simpler structure of the model, based on restrictive assumptions about the water demand and output supply behaviour of the competing water users. The simplicity of the structure of AWARE1 is attractive to policy uses and negotiation processes and it is also less

data intensive. Some of these assumptions were relaxed in AWARE2 to show how solutions will differ under alternative, more realistic complications of the structures of water demand.

The paper is organised in six sections. The following two sections present the structure and some simulations run with AWARE1. Sections 4 and 5 illustrate the structure and show some results of AWARE2. A discussion of the usefulness of a decision/negotiation support tool in facilitating the process of decentralised water management in the country is then provided in section 6

## **2. The structure of AWARE1**

AWARE has been developed by the Water Resources Program of the Centre for Environmental Economics and Policy in Africa (CEEPA) in collaboration with the Department of Water Affairs and Forestry (DWAF) in South Africa. AWARE is a simulation tool specifically designed for modelling system dynamics of catchment level water management. It is based on a simplified representation of the Steelpoort watershed. The model evaluates alternative action scenarios, representing potential water management strategies aiming to promote economic efficiency, environmental sustainability, and social desirability in water use and allocation. The core emphasis of simulated water strategies is on allocation of priorities among competing groups of water users. In order to estimate the actual annual volume of water received by the users, the model calculates the water available in the watershed, the *yield*, corresponding to the surface plus ground water (about 25% of the natural mean annual runoff) to which the annual usable return flow from irrigation, urban uses, mining and bulk industrial activities is added (DWAF, 2002). CMA allocation strategies determine the reconciliation between yield and demand for water.

### *2.1. Water supply and allocation mechanisms of AWARE1*

AWARE1 uses a water supply and allocation system that follows the CMA strategies and procedures as defined in the NWA, which are described below. Water entitlements are allocated and issued by the CMA according to the objectives emphasised in the National Water Act. Environmental objectives have been identified with the preservation of the ecological reserve<sup>1</sup>, while provision for basic human needs<sup>2</sup> are guaranteed through the equitable distribution of the resource among rural and urban households for domestic uses. After satisfying the ecological reserve requirements and basic human needs, the remaining water is to be allocated among competing economic activities according to the principles of improving the economic efficiency of water use for greater social benefits (Hassan, 2003). Economic use sectors include irrigation agriculture, livestock production, plantation forestry, industries and mines. Applications from these sectors for water licenses provide an estimate of water demanded. If the available water, after satisfaction of the ecological reserve, is higher than the indicated requirements by all the users, i.e. the case of water abundance, each user will receive an entitlement for the amount of water it has requested. However, if the

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<sup>1</sup> The ecological reserve, as specified in DWAF-IWQS (2002), p. 15, is “the quantity and quality of water required in a basin to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource”. DWAF has set the ecological reserve in Steelpoort at 95 million m<sup>3</sup>/year.

<sup>2</sup> Defined in chapter 3, part 3, of the National Water Act as an amount of water corresponding to 25 l/person/day (NWA, 1998).

water demanded exceeds the volume available to support licenses, the CMA allocates water according to one of five strategies below<sup>3</sup>:

- 1.) *No prioritisation.* All users receive licenses for a percentage of the amount of water that they have requested. This percentage is the same for all users and depends on the available resource volume.

In order to preserve the basic human needs in addition to the ecological reserve, the following water allocation strategies give priority to rural and urban domestic uses. Thereafter, one or more productive sectors are given priority:

- 2.) *Smallholders* are issued with licenses first. The rest of the users share the remaining unlicensed water proportionately, so that all users receive licenses for a percentage of what they have requested.
- 3.) *Large-scale irrigation farmers* are given priority and the rest is allocated as in strategy 2.
- 4.) *Mines* are given priority and the rest is allocated as in strategy 2.
- 5.) *Mines and industries* are given priority and the rest is allocated as in strategy 2.

Each type of user is charged a sector-dependent price per unit of water for which they receive entitlements. These entitlements' charges are then collected to constitute the annual revenue of CMA.

Each user makes an annual assessment of the amount of water it receives. If the water entitlement is less than satisfactory, a complaint of water shortage is sent to the CMA.

## 2.2. *The water demand module of AWARE1*

AWARE1 includes eight water use sectors:

1. Large-scale commercial irrigation agriculture
2. Smallholder irrigation farming
3. Livestock producers
4. Forestry farms
5. Mining
6. Industry
7. Urban households
8. Rural households

Each sector is composed by a number of users (tab. 1). The demand for water by the users of the above sectors is modelled as a function of the water price, or charge, applied by DWAF. The model was first solved using the following simple linear demand function:

$$w_{dij} = a_{ij} - b_{ij}P_j \quad [1]$$

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<sup>3</sup> This process of prioritisation corresponds to the *Compulsory Licensing* as indicated in the NWA (part 8).

Which specifies the quantity of water demanded by each user  $i$  of sector  $j$  ( $w_{dij}$ ) as a linear function of the water price faced by the sector ( $P_j$ ). The intercept and slope of the demand curve are measured by the parameters  $a$  and  $b$ , which are the same for all users of one sector. The water demand for the whole sector  $j$  is the sum of the water demand of all users belonging to this sector, as indicated in [2].

$$W_{dj} = \sum_{i=1}^n w_{dij} \quad [2]$$

Different levels of  $a$  and  $b$  have been used for the different sectors based on assumptions made about their likely elasticities to own price shifts (tab. 1). For instance, demand for water by industry, mines, large-scale farmers, and urban domestic users have been assumed to be more responsive to own price changes (i.e. larger  $b$ ) compared to the other sectors<sup>4</sup>. Rural communities are supposed to receive water (basic human needs) at 0 price.

**Table 1** – *Water users, water charges defined by DWAF, and water demand parameters per sector*

Sectors	Nb of units**	Price of the water	$a$	$b$
		licences* R/m <sup>3</sup>	in water demand function**	in water demand function**
Rural communities	20	0	0.25	0
Urban communities	5	0.0208	0.75	7.21
Smallholders irrigation farming	6,000	0.0153	0.000035	0.00013
Large-scale commercial irrigation agriculture	200	0.0153	0.4	3.92
Livestock producers	20	0.0215	0.055	0.23
Mines/quarries	20	0.0215	0.8	9.30
Forestry farms	30	0.0219	0.04	0.46
Industries	30	0.0215	0.2	1.40

Source: \* DWAF (2002), \*\* our estimations

### 2.3. Output generation and value addition in AWARE1

This version of AWARE uses very simple fixed coefficients for production technology to generate economic output and employment in the water use sectors included. Fixed ratios were used to generate Value Added (VAD) in Rand (R) and employment in men/day per m<sup>3</sup> of water. Data on the gross geographic product (GGP) and employment in the Olifants basin were obtained from Urban Econ (2000) and the National Water Resource Strategy (DWAF, 2002), which were used to calibrate the model for the Steelpoort sub-basin.

### 2.4. The dynamics of AWARE1

AWARE1 employed simple growth assumptions to drive changes in demand and supply over time. The time unit is one year. The different water use sectors were assumed to grow (or

<sup>4</sup> A major CEEPA research effort is currently underway to measure water demand parameters from factual field survey data in the Steelpoort basin in order to improve this component of the model.

decrease) at annual fixed rates. This then in turn drives changes in demand for water, using sectors' fixed coefficients for production and water intake. On the other hand water supply was assumed to stay at the current yield level in the Steelpoort sub-basin of 61 million m<sup>3</sup> per year (DWAF, 2002).

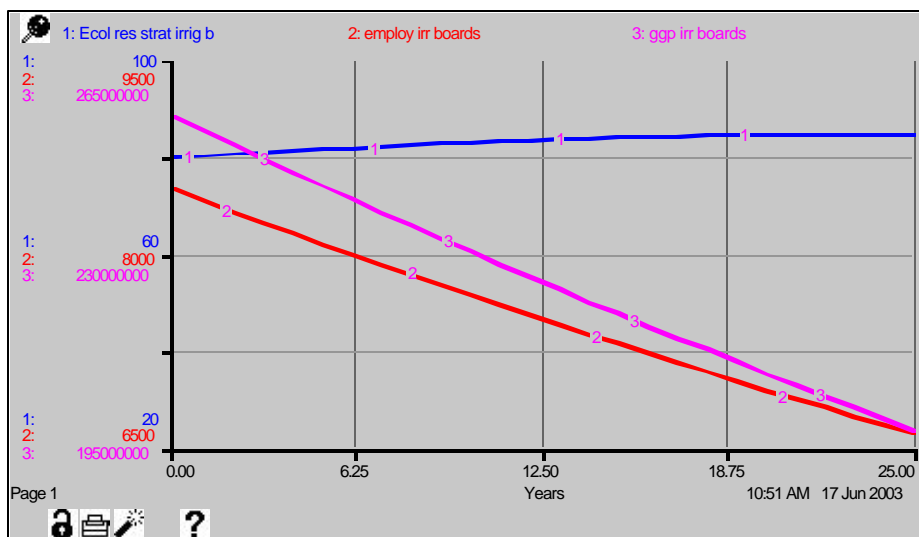
### 3. Simulations of AWARE1

AWARE1 was simulated over a 25-year period to calculate changes in a number of socio-economic indicators, namely GGP and employment in consequence of the alternative water strategies adopted.

To obtain the scenarios illustrated in this section, the following sectors' growth/decrease rates were introduced: mining and industry grow at 5%/year, commercial agriculture declines by 1% per annum, smallholder farming increases at 1%/year and domestic use grows at 4%/year and 2%/year in urban and rural areas, respectively.

Under the above assumptions of fixed water supply and the structure and scenarios of changes in water demand over time, the current negative water balance (deficit) of -34 million m<sup>3</sup> in Steelpoort increases to reach -60 million m<sup>3</sup> by year 25.

The CMA must implement in this situation a process of compulsory licensing, consisting of the adoption of one of the strategies of water allocation above illustrated. AWARE simulates the socio-economic and environmental outcomes during the analysed period according to the adopted strategy. Because the objectives of environmental sustainability (preservation of the ecological reserve) and social equity (satisfaction of domestic needs) are set as priorities in



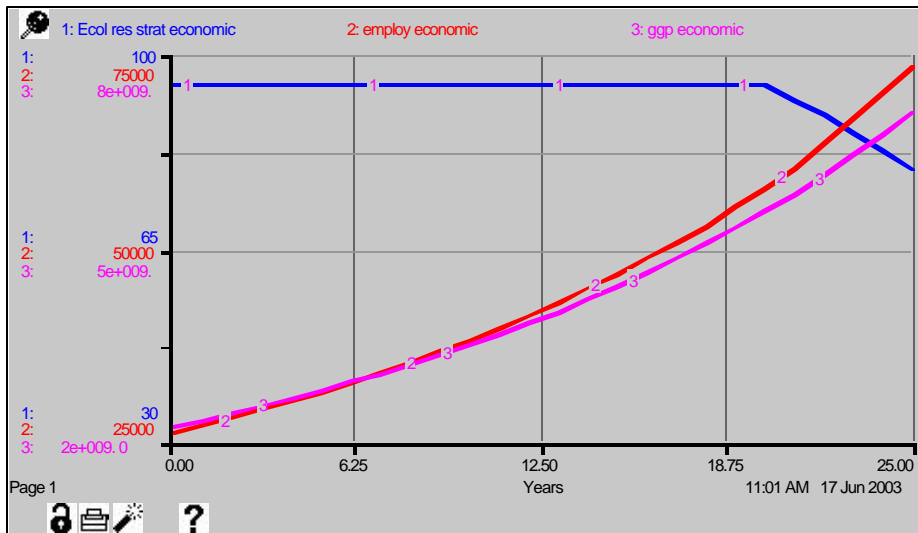
**Figure 1** – Allocating water to commercial farmers and domestic users first: impacts on the Steelpoort sub-basin GGP (R), formal employment (n. employees), and on the ecological reserve (million m<sup>3</sup>)

the simulated strategies, it is interesting to understand the changes in economic efficiency consequent to the adoption of each strategy.

Two strategies of water allocation are shown here, the one giving the highest priority to commercial agriculture (strategy 3 illustrated in section 2.1), and the other giving the highest priority to mines and industries (strategy 5 illustrated in section 2.1).

When a strategy giving the highest priority to commercial agriculture is adopted, the model produces the scenario illustrated in figure 1. Because the sum of the demand for water coming from domestic users and commercial farmers is higher than the available yield in Steelpoort, no water is allocated to other users and the ecological reserve is partially depleted. According to the model's methods for water allocation, this happens only when the sectors to which is given priority ask for a quantity of water higher than the available yield. Given the simulated decrease ratio (-1%/year) of the commercial farmers' water demand, the ecological reserve recovers over time, though not reaching the level of 95 million m<sup>3</sup> set by DWAF for Steelpoort. The figures indicating the economic efficiency of the strategy decrease (GGP from 0.25 to 0.20 billion Rand; formal employees from 8,500 to 6,500).

Figure 2 shows the impacts on the same outcomes of a strategy giving the highest priority to mines and industries, having preserved the ecological reserve and the domestic uses. Already at year 0 of the simulation, it is possible to observe a much higher economic efficiency of this strategy compared to the previous one (GGP = 2.24 billion Rand; 26,300 formal employees). The simulated development of the prioritised sectors brings an even better performance over time, but at year 20 imposes to use a portion of the ecological reserve.



**Figure 2** – Allocating water to mines, industries, and domestic users first: impacts on the Steelpoort sub-basin GGP (R), formal employment (n. employees), and on the ecological reserve (million m<sup>3</sup>)

This portion is much smaller, and appears only at year 24, if a higher user charge is applied to the mining sector and to industry (from 0.0215 to 0.04 R/m<sup>3</sup>). The adoption of economic instruments by DWAF results in a reduced economic performance (lower GGP and formal employment), but preserves the ecological reserve. The following section is dedicated to the use of economic instruments for water management.

One should analyse the above results with very critical precautions given the limitations of AWARE1. Firstly, the model assumes that supply remains fixed over time at current water yield levels, while demand steadily grows or decreases. Secondly, the model calculates trends in demand independently. It does not derive an equilibrium solution at which the water price adjusts to clear the market, causing demand to adjust to the fixed level of water supply. Subsequently, the situation could only be managed through command and control measures such as top-down allocation rules. This leaves no room for using market-based water allocation instruments such as setting water prices with the aim of re-allocating water based on economic efficiency rules at market clearing points. In addition, the above model used a very restrictive production structure that did not allow for substitution among inputs in production. Whereas using more flexible production structures that allow for input substitution will require substantial effort and data to implement, solving the model for market clearance is less demanding. The following sections adapted AWARE1 to investigate the water allocation under equilibrium conditions and associated socio-economic implications.

#### 4. The structure of AWARE2

This version of AWARE relaxed some of the restrictive assumptions of AWARE1 outlined above. More precisely, it investigates water allocation strategies under market clearing conditions. To this end, an equation for equilibrium condition has been introduced in the new version of the model:

$$W_d = W_s \quad [3]$$

Where  $W_d$  is the total water demand and  $W_s$  corresponds to the water supply (yield) in the sub basin. Under this condition, the price of water is determined endogenously, forcing demand to adjust.

To determine water demand in the basin, a simple sum of water demand for each sector has been calculated.

$$W_d = \sum_{j=1}^m W_{dj} \quad [4]$$

Where  $W_{dj}$  is the water demand for sector  $j$  as calculated in section 2.

$$W_d = a - bP \quad [5]$$

Where  $a$  and  $b$  are parameters calculated by the model by running several simulations at different levels of  $P$ .

$$W_s = Y \quad [6]$$

Where  $Y$  is a constant and corresponds to the water yield in the sub-basin.

The equilibrium price  $P$  found through equations [3], [5], and [6] can be related to the real water prices for the different sectors using price determination equations such as:

$$P_j = P(1 - S_j) \quad [7]$$

Where  $P_j$  is sector  $j$  water price as defined by DWAF,  $P$  is the equilibrium price, and  $S_j$  is then the water price subsidy applied to each sector.

AWARE2 solves for the equilibrium price under the current water supply and demand, as well as production (GGP) levels, given different  $a$  and  $b$  values for the different sectors.

This new module enables AWARE2 to find the following results:

1. Calculate current water subsidies (i.e. the difference between what water users pay now and the equilibrium price  $P$ );
2. Then implement various water demand management strategies by changing  $S_j$  for some sectors (e.g. subsidise some and remove or reduce the subsidy from others). This is equivalent to using market-based instruments (the price) for water allocation, which can then be compared to the allocation regimes of the command and control measures illustrated above.

## 5. Simulations of AWARE2

The model calculates the equilibrium price  $P$  in Steeploort, under the current conditions, at 0.04896 R/m<sup>3</sup>. As a consequence,  $P_j$  for the different sectors as defined by DWAF (tab. 1) are not sufficient to force the equilibrium between  $W_d$  and  $W_s$ . This result explains the water deficit (-34 million m<sup>3</sup>) presently existing in Steeploort and the need for a compulsory licensing process.

The following table (tab. 2) indicates the levels of  $S_j$  for the different sectors. With the exception of the rural communities, that receive the amount of water corresponding to their basic human needs free of charge, all the other sectors are subjected to a subsidised water price, with respect to the calculated equilibrium price  $P$ .  $S_j$  goes from 55% of  $P$  for the forestry sector, to 69% for the commercial farmers and smallholders. Mines and industries pay 44% of the calculated equilibrium price.

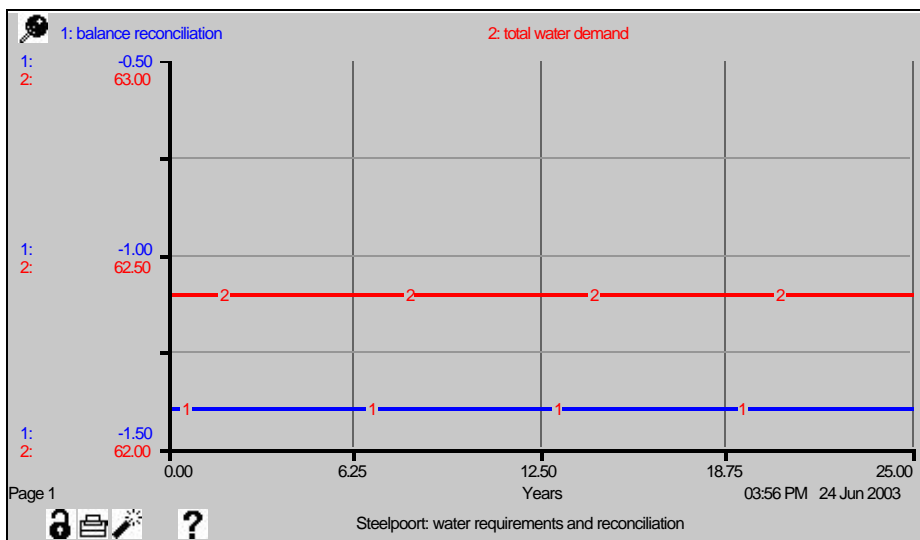
**Table 2 – Water subsidies per sector**

Sectors	$S_j$ R/m <sup>3</sup>	$S_j$ % of $P$
Rural communities	0.04896	100%
Urban communities	0.02816	58%
Smallholders irrigation farming	0.03366	69%
Large-scale commercial irrigation agriculture	0.03366	69%
Livestock producers	0.02746	56%
Mines/quarries	0.02746	56%
Forestry farms	0.02706	55%
Industries	0.02746	56%

According to this result, there is room for the adoption of market-oriented strategies in the Steelpoort water management.

The simulations below illustrate some outcomes deriving from the application of a water price  $P_j$  equal to the equilibrium price  $P$  calculated by the model to the sectors that are assumed to have higher water demand elasticity (commercial farmers, mines, industries). These sectors are also the main water users in Steelpoort. The prices for the other sectors remain at the levels indicated in table 1.

The results of the adoption of such a water management strategy are first depicted making the hypothesis that there is no change in the sectors' size over the simulated period. Then, increase and decrease rate are introduced.



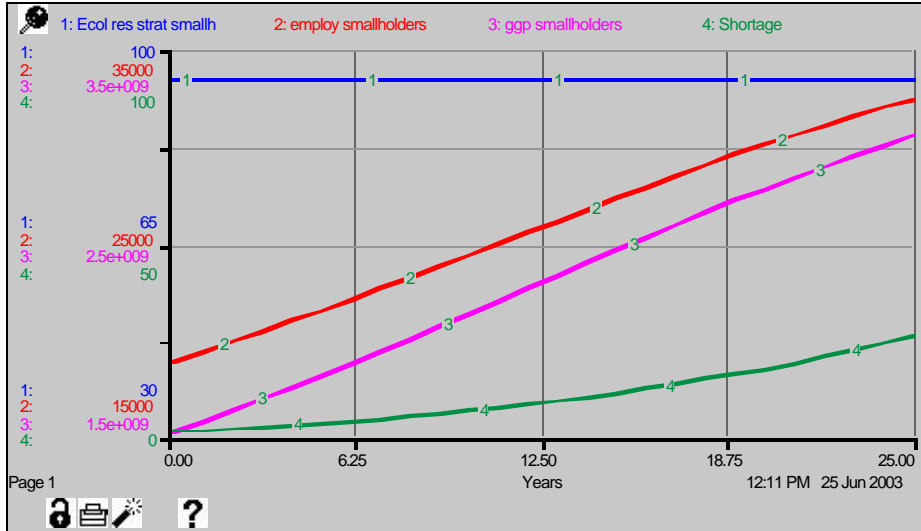
**Figure 3** – Applying  $P_j = P$  to industries, mines, and commercial farmers: water demand (million  $m^3$ ) and balance reconciliation (million  $m^3$ ) in the Steelpoort sub-basin

Figure 3 shows that, if there is no change in the size of the sectors over the studied period, applying  $P_j = P$  to industries, mines, and commercial farmers influence their water demand so that the equilibrium between  $W_s$  and  $W_d$  in Steelpoort is almost reached. In other words, it is an effective strategy for reaching the equilibrium between water demand and supply.

The following simulation (figure 4) employs the same sectors' growth/decrease rates used in section 3, and applies  $P_j = P$  to industries, mines, and commercial farmers, where  $P$  is the equilibrium price at year 0.

Giving priority to smallholders and domestic uses (strategy 2 in section 2.1), the other sectors receive entitlements proportionally to the ratio  $W_s / W_d$ . Because smallholders represent a minor quota of water demand in Steelpoort, this strategy can be considered as a market-oriented water allocation strategy. In fact it gives priority under a command and control criterion to the most socially sensitive sectors (domestic uses and smallholding farmers), then it allocates water according to the response of the remaining sectors to the fixed water prices.

The model in its present form does not consider sectors' responses in terms of improvement of the efficiency in water use, or exchange of entitlements among users. Nevertheless, some relevant considerations can be made.



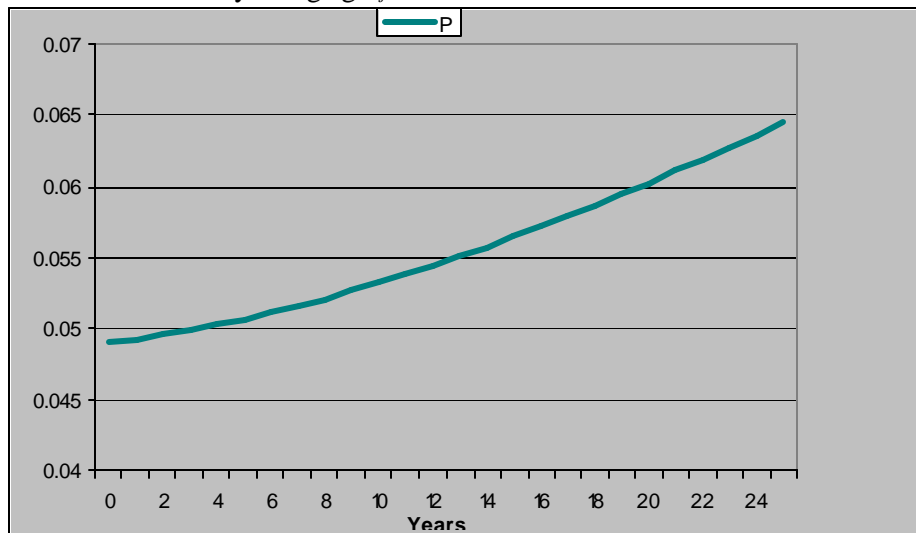
**Figure 4** – Allocating water to smallholders and domestic users first,  $P_j = P$  for commercial farmers, mines and industries: impacts on the Steelpoort sub-basin GGP ( $R$ ), formal employment ( $n$ . employees), the ecological reserve (million  $m^3$ ), and on water shortage (million  $m^3$ )

Firstly, the ecological reserve is preserved over the whole simulated period. Secondly, water shortage ( $W_d$  not satisfied) is maintained at a reasonable level (24 million  $m^3$ /year) at year 25, if compared to the 60 million  $m^3$  of the scenarios illustrated in section 2, where water prices were those indicated in table 1. Thirdly, the economic indicators (GGP and formal employment) at year 0 are relatively close to the levels of the above-mentioned scenarios. Instead, over time they suffer the limitation in water demand by the sectors that have the highest water productivity (mines and industries) due to a higher water price. This triggers GGP and employment levels at year 25 corresponding to 50% of the levels in the strategies that give priority to the most productive sectors.

The reduced economic performance in the sub-basin can be interpreted as the opportunity cost of environmental preservation and of social equity achievement.

On the other hand, the increased water price for some users has a positive effect on the CMA revenue (the latter passes from 1.4 million R/year at year 25 for the strategy 5 at current prices to 2.3 million R/year for the strategy 2 imposing  $P_j = P$  for the above mentioned sectors). The additional amount of money coming from the adoption of an economic-oriented strategy could be used by the public sector for creating a fund aimed at subsidising those users willing to improve their water-use efficiency through managerial or technical investments. A “stick and carrot” system would be put in place in this case, where the price for water entitlements represents the negative incentive to the over-use of the resource, and the subsidies facilitate pro-active attitudes towards improved water use. Market-oriented tools like water prices and subsidies are in fact likely to induce users to increase their efficiency in water use. This issue will be explored in future versions of AWARE.

Moreover, the model calculates the equilibrium price  $P$  dynamically in function of the increase/decrease rates assumed for the different sectors. Figure 5 shows the trend of  $P$  for the sectors' growth/decrease rates used in section 3. This result allows adjusting overtime  $P_j$  for the various sectors by changing  $S_j$ .



**Figure 5** – Equilibrium price ( $R/m^3$ ) dynamics for given increase/decrease rate in the different sectors

## 6. Discussion and perspectives

The model presented in this paper looks at the impacts on socio-economic and environmental indicators of different water management strategies adoptable in Steelpoort, a sub-basin of the Olifants river basin in South Africa. It is an attempt to analyse water policy implementation at the local level and from an integrated viewpoint. Because of the complex nature of the problem, the modelling choice consisted of a system dynamic model (SDM) called AWARE.

The simulations presented show the relevance of such a tool for the interpretation of possible scenarios consequent to the adoption of different water allocation strategies among the various stakeholder groups in the basin. The peculiarity of the model lies in its multi-objective character that corresponds to the multiple criteria of the South African National Water Act. Socio-economic outputs, as well as the preservation of the ecological reserve are explored for several water management strategies.

The two sub-models illustrated (AWARE1 and AWARE2) look at the problem from different perspectives: the first sub-model focuses on the allocation of water entitlements among sectors potentially in conflict for the scarce resource through command and control strategies. The second sub-model investigates water allocation strategies under market clearing conditions

A third version of the model (AWARE EE) is presently under construction. It is an adaptation to the studied reality of a simulation model to illustrate feedbacks among resource consumption, production and factors of production in ecological-economic systems (Woodwell, 1998). The model employs a Cobb-Douglas production function of the form

$Y = a * L^b K^c W^d$ , where  $Y$  is the output,  $L$  is human capital input,  $K$  is the services of man-made capital,  $a$  is the level of technology in production, and  $W$  is water available for production.  $b$ ,  $c$ , and  $d$  are constant, and sum to one, indicating constant returns to scale.

The significant variations in the output of the model runs illustrate the sensitivity of these models to even small changes in specifications. Only once data from current field surveys is available, can the model be satisfactorily calibrated. Until then, the greatest value of the tool is not prediction or forecasting, but revealing the interconnections between strategic decisions and ecological and socio-economic elements of the system. To that end, AWARE helps understanding the concept of conflict in the use of a scarce resource and provides a basis for discussion among different groups of interest.

At its present stage of development, AWARE can be of relevant interest as a negotiation support tool, facilitating discussions and dialogue among stakeholders. Once in place, CMAs can use tools such as AWARE for fulfilling their role as facilitators within the participatory process leading to water entitlements for different groups of stakeholders. Guidelines on how to use AWARE to this purpose and a game role derived from the model are in preparation.

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### **Biography of the authors**

**Stefano Farolfi**, MSc in Agricultural Sciences (University of Bologna - Italy), MSc in Agricultural and Food Economics (CIHEAM, Paris - France), PhD in Environmental Economics (University of Padova - Italy).

Environmental economist at CIRAD, the French organisation specializing in agricultural research for the tropics and subtropics of the world, research fellow at CEEPA and senior lecturer at University of Pretoria. He has conducted research and development programmes within the following institutions: FAO, French National Institute for Agronomic Research (INRA), Washington State University, and University of Bologna.

**Rashid M. Hassan**, BSc (77) and MSc (83) in Agric. Economics, University of Khartoum, Sudan; MSc (88) and PhD (89) in Economics, Iowa State University, USA.

Professor and Director of the Centre for Environmental Economics and Policy in Africa (CEEPA). His research fields are: Natural resource and environmental economics; agricultural production and policy analysis; Optimisation and economic systems modelling.