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Water value, resource rent recovery and economic welfare cost of environmental protection: A water-sector model for the Steelpoort sub-basin in South Africa

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Abstract

This study developed an analytical framework and an empirical water sector model to evaluate current and alternative water allocation regimes in the Steelpoort sub-basin (SPSB) in terms of the key objectives of the national water act of South Africa. The analyses showed that bulk water is currently not only oversupplied to offstream uses in the SPSB at the expense of the ecological Reserve (instream benefits) but also underpriced. The water research levy, the only mechanism used for rent capture, recovers a negligible proportion of the water resource rent (RR) (less than 2% at best) implying that almost all RR dissipates to various offstream users in the form of indirect subsidies of about R0.42/m³ with the more realistic low-price elasticity assumption. Commercial irrigation enjoys the highest subsidy being the major consumer followed by mining and hence the most to be affected by policy change in this regard. Results also indicate that the total maximum economic value offstream users are willing to pay for increasing water yields to supply the full requirement levels currently enjoyed at the SPSB is estimated at about R2.8/ m³. Although this value does not properly measure the net social gain or loss of environmental protection, it serves as a benchmark value against which per unit costs of potential alternative water supply options can be compared. A few caveats remain as key limitations of the study call for further research work. First, this study did not generate information on instream benefits to compare with offstream values lost as a result of protecting the ecological Reserve. Second, the study can benefit from improved specification of the water sector model parameters, particularly the supply side as better information will allow estimation of an upward sloping supply (marginal cost) curve.

Keywords: water value, resource rent and subsidies, water sector model, price elasticity of demand

Introduction

Protection of basic human and ecological needs, economic efficiency and social equity are the most important pillars guiding water resource allocation and use under the new National Water Act (NWA) of South Africa (SA). The NWA promotes integrated and decentralised water resource management under a new institutional environment. New management entities (catchment management agencies – CMAs and water user associations - WUAs) are currently established at regional and local levels, emphasising a largely decentralised and participatory approach to water resource management (Hamann and O’Riordan, 2000; Perret, 2002). The decision-making process for water management in SA therefore involves dealing with a complex system of interactions between multiple biophysical and socio-economic needs co-existing in a watershed. This process must also comply with and serve the economic efficiency, social equity, and environmental sustainability objectives of the NWA. 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 involves addressing a number of key questions such as establishing priorities and appropriate

regimes for allocation of water between competing uses (Farolfi and Perret, 2002).

However, water allocation decisions are currently made on the basis of very limited information on the behavioural structure underlying the decentralised decisions of the many water users involved. Proper modelling and adequate understanding of the motivations and rules that govern the choices of individual decision makers will provide better guidance for more informed water allocation regimes and policies centrally made by water management agencies. Decision support tools that can integrate in one framework the ecological and socio-economic dimensions of water resource use are accordingly needed to facilitate the design and implementation of water management strategies. This study develops a partial equilibrium water sector model to assist water managers and policy makers in SA design and evaluate alternative water allocation strategies. The Steelpoort area, a sub-basin of the Olifants River catchment in the north-east of SA, where a water stress situation exists as total annual water requirements exceed available yield and the deficit is currently supplied at the expense of the ecological Reserve was chosen as the case study area. The sub-basin is accordingly under pressure for preparation of a water management plan that would alleviate the current stress on the Reserve component, improve the economic efficiency of water use and meet the objective of social equity in water allocation.

The developed model extends earlier work on action research and watershed analyses for resource and economic sustainability-AWARE (Farolfi and Hassan, 2003) to explore the impact of different strategies of water allocation on the key objectives of the

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TABLE 1			
Steelpoort sub-basin water resources: Supply, use and balance (2000)			
Supply sources		Demand requirements	
	10⁶ m³		10⁶ m³
MAR	396	Irrigation - large scale	65
S1. Surface water yield (10.6% of MAR)	42	Irrigation - small scale	3
S2. Groundwater	14	Mining	12
S3. Usable return flows (A+B+C)	5	Industry	5
A. Irrigation	3	Livestock	1
B. Urban water	1	Forestry	1
C. Mining and bulk	1	Domestic - urban	3
		Domestic - rural	5
WS. Total available water (S1+S2+S3)	61	WD. Total demand (requirements)	95
Balance/deficit (TWS-TWD)	-34		
Reserve (R1+R2+R3)	96.61		
R1. Ecological Reserve (in-stream flow requirements - IFR)	94		
R2. Basic human needs	2.61		
R3. Other needs (strategic, international, contingency)	ND*		
* ND means currently undetermined.			
Source: DWAF (2002)			

NWA at the watershed level. Earlier versions of this simulation tool (AWARE) adopted a relatively simpler structure using restrictive assumptions about water demand and output supply behaviour of competing water users. The simplicity of the structure of AWARE was attractive to policy uses and negotiation processes and it is also less data intensive. The used assumptions, however, limited the ability of the model to provide more realistic representation and simulation of the actual decision-making environment. As a result, the earlier model could only evaluate regulatory command-and-control (CAC) options such as quantitative restrictions like quota allocations. Some of these assumptions were relaxed in formulating the present water sector model to show how solutions might differ under alternative, more realistic complications of the structures of water demand. This also allowed the evaluation of market-based instruments such as efficiency pricing in addition to CAC measures. The paper also uses the partial equilibrium model to derive and compare values of water and subsidies enjoyed by various uses, assess the rate of recovery of water resource rents and measure the economic welfare cost of protecting the ecological Reserve under different water pricing and allocation regimes.

The status of water resources availability and use in the Steelpoort sub-basin (SPSB) is reviewed and subsequently the analytical framework and structure of the water sector model are presented and discussed. The empirical model is then calibrated to available data to generate parameter estimates, conduct policy simulations and draw conclusions and implications of the study.

Water availability and use in the Steelpoort sub-basin

The Steelpoort region extends over 7 139 km², comprising about 13% of the Olifants water management area on the north-eastern

boundary of South Africa, with an altitude ranging between 900 to 1 200 m a.m.s.l. and rainfall between 600 and 1 000 mm/a (Stimie et al., 2001). Two main watercourses, the Steelpoort River and the Speckboom River, feed the sub-basin with their waters. Mean annual runoff (MAR) at the sub-basin is estimated at 396 x 10⁶ m³ yielding 42 x 10⁶ m³ after accounting for instream flow requirements (IFR or the ecological Reserve) of 94 x 10⁶ m³ (Table 1). Surface water yield together with groundwater and return flow supplies give an annual yield of 61 x 10⁶ m³. This annual level of water supply includes a surface storage capacity at dams totalling 26 x 10⁶ m³ from 45 different-size dams in the basin (DWAF, 2002).

On the demand side, irrigation agriculture is the major user in the SPSB, contributing to more than 70% of the total water demand in the year 2002, mainly for large commercial schemes, followed by mining (12.6%), industry and rural communities (5% each). Note that water Reserve requirements to meet basic human needs are included in the total requirements for domestic rural and urban use. Table 1 indicates the water stress situation in the SPSB where total annual water demand exceeds available yield by 34 x 10⁶ m³, a deficit that is currently supplied at the expense of the ecological Reserve. This in turn means that the ecological Reserve is not maintained at the required optimal level for proper sustenance of rivers and protection of aquatic ecosystems in the sub-basin. The various components of the water Reserve, which are given priority over all other uses in water allocation according to the National Water Resources Strategy - NWRS (DWAF, 2002), include provisions for ecological and basic human needs, international obligations and other strategic future demand needs. The Reserve is accordingly calculated based on a national water classification system that groups different water resource areas into different water management classes reflecting differences in required levels of social and environmental protection (DWAF, 2002).

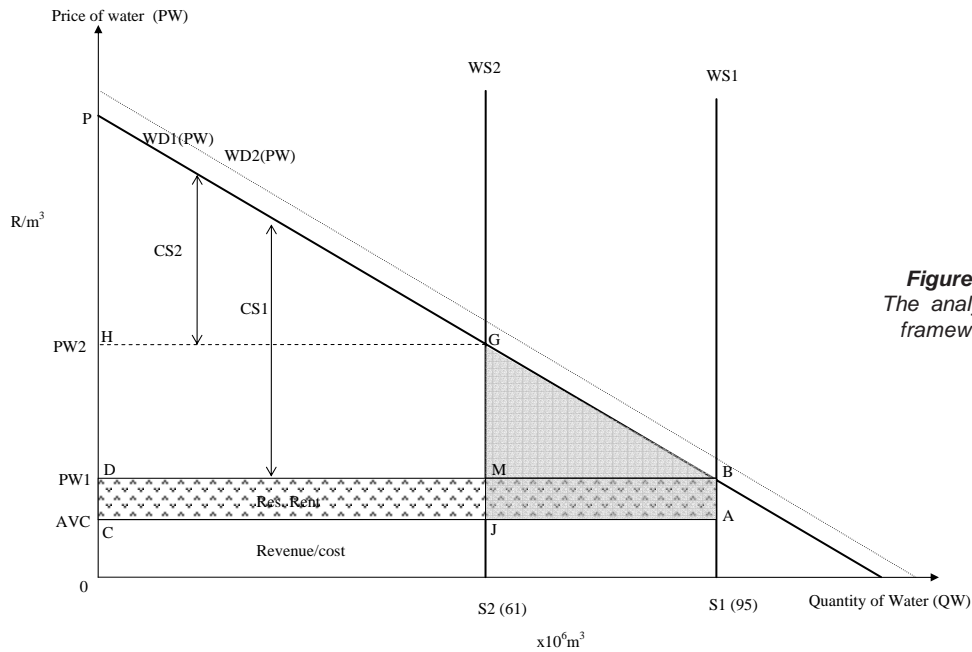


Figure 1
The analytical framework

Structure of the SPSB water sector model

A partial equilibrium water sector model was constructed to represent water supply and demand systems reflecting current water supply and use patterns shown in Table 1, which comprise eight water demand sectors. Compared to earlier efforts employing simpler structures (Farolfi and Hassan, 2003), the main feature of the present water sector model is its improved specification of the demand system. Also, market-clearing conditions were imposed to solve the model for equilibrium price and quantity levels. The model was then used to evaluate alternative water allocation regimes and determine efficiency prices. The components of the SPSB water sector model are described below.

The water supply component

In the present model total water supply (WS) was set exogenously to remain at current yield levels of $61 \times 10^6 \text{ m}^3$ (after providing for the IFR of $94 \times 10^6 \text{ m}^3$):

$$WS = QS \quad [1]$$

where:

QS a constant corresponding to the water yield in the sub-basin.

The water demand system

Water demand functions were specified for the eight economic use sectors, indicated in Table 1, which compete for water in the sub-basin. All users in the same sector were considered homogeneous in terms of their demand for water behaviour and hence have the same water demand structure:

$$WD_i = D_i(PW_i, \beta_i) \quad [2]$$

where:

WD_i defines the representative water demand function for members of sector i ($i=1,2, \dots, n$) to depend on the price of water (or water charge) they face (PW_i) and their respective water demand behaviour parameters in vector β_i .

Total demand for water (WD) in the sub-basin was then derived by aggregating water demand over the n sectors:

$$WD = \sum_{i=1}^n WD_i \quad [3]$$

Results of model simulations aggregating sectoral demands at different water prices (PW_i) were used to construct an aggregate water demand function for all uses in the sub-basin. The aggregate water demand curve $WD(PW)$ was then used to determine equilibrium water price and quantity at the sub-basin and perform the intended efficiency pricing analyses using the market clearing condition specified below.

Equilibrium in the water sector at the sub-basin

Market clearing conditions were imposed to solve the model for equilibrium water price and quantity and to enable comparative analyses of the existing and alternative water allocation regimes against economic efficiency (equilibrium price) solutions.

$$WS = QS = WD(PW, \beta) \quad [4]$$

Under this condition, an equilibrium price of water (PW) can be determined endogenously forcing demand to adjust accordingly to clear the market. This allows comparing economic efficiency regimes of water allocation with alternative options. Various scenarios of water supply and allocation strategies can also be evaluated under this analytical framework in terms of net economic welfare gains and losses. The following section presents the framework adopted for conducting the intended analyses.

The analytical approach and scenarios of the water sector model

As presented above, the SPSB water sector model was constructed to satisfy partial equilibrium conditions in the water sector at the sub-basin. Figure 1 depicts the analytical foundations of the water sector model and its potential to address specific research questions of relevance to water allocation strategies following economic

efficiency rules. As shown in Table 1 the current water supply and demand situation is represented by the *WSI* and *WDI* curves showing the total supply and demand for water at the sub-basin, respectively.

Point A on Fig. 1 represents the current water allocation system in the SPSB where total water requirements of all economic uses ($95 \times 10^6 \text{ m}^3$) were supplied at an average supply cost (*AVC*) charged to users. At this point, even if one assumes that *AVC* fully recovers all supply costs (including normal profits, i.e. normal returns to capital investment), which is rarely the case, consumers are paying rates lower than the market price of water (*PWI*) and hence enjoy an indirect subsidy (area *DBAC*) on top of the consumer surplus-*CS1* (*PBD*). This subsidy value represents the water resource rent (*RR*) dissipating to water users. To provide current total requirements of all users at economic efficiency prices the water charge needs to be set at the market clearing equilibrium price *PW1*. In which case the water service provider would recover all its costs (area *C-A-SI-0*) plus the *RR* (area *DBAC*), which may be recovered by an appropriate public agency (government) on behalf of the public through some tax or royalty regime and water users remain with their *CS* (area *PBD*). This indicates that economic uses of water in the SPSB enjoy a subsidy equivalent to the total *RR* under the current water allocation system. Because different economic use sectors are charged different tariff rates, our framework allows calculation of sector specific subsidy levels employing the respective sector water demand functions specified in Eq. (2).

Moreover, the current water allocation system not only deviates from economic efficiency principles, but also introduces another social cost as total water requirements currently exceed available water supply (yield) with a deficit supplied at the expense of the ecological Reserve. The value of this social loss is not yet known and this research project did not attempt to establish values of ecological services lost as a result of the reduction in the instream flow requirements (*IFR*). Nevertheless, the analytical framework presented above allows for calculation of the opportunity cost of maintaining the ecological Reserve to fully meet *IFR*. In this case scenario of protecting the ecological Reserve, only water yield will be available for economic uses, which will shift the water supply curve leftward from *WS1* to *WS2* to supply $61 \times 10^6 \text{ m}^3$. If the available yield is to be allocated on economic efficiency basis, users will have to be charged the equilibrium price of water *PW2* at point *G* of Fig. 1. At this equilibrium point *CS* will shrink to *CS2*, water *RR* recovered will equal the area *HGJC* and the resulting net social welfare loss measured by the area *GBAJ* represents the opportunity cost of maintaining the ecological Reserve to fully meet *IFR*.

The net social welfare loss or opportunity cost of protecting the Reserve should ideally be compared to welfare gains from the economic benefits of the preserved ecological services of the Reserve. As said earlier, the present study unfortunately could not establish a value for these ecological services. Nevertheless, the total loss of economic welfare resulting from water allocation regimes that give priority to protecting the Reserve and its instream ecosystem services provides a bench-mark or baseline estimate of the potential economic benefits to be realised from increasing available water at the sub-basin, against which the cost of investment outlays to increase current water yield levels can be compared and justified. The same principle may be applied to measuring water benefits from alien-vegetation clearing programmes as those effectively shift the water supply curve to the right. This provides a more appropriate basis for calculating net social gains from such a shift to capture water-related opportunity cost of alien plant invasion compared to what is proposed in Hoskin and Du Preez (2004).

In addition to providing information on the value of investing

in additional water supplies (offstream economic benefits lost as less water is made available in order to protect instream ecosystem services), this also indicates potential economic welfare benefits from investing in technological means to improve water use efficiency as an alternative water management strategy. While increasing water yield will shift the supply curve to the right in the direction of *WS1*, technological improvements will cause the demand curve to shift outwards (*WD2*) leading to higher economic value of water (larger economic surplus and *RR*).

This study will employ the above analytical framework characterising the current decision environment of water allocation and use in the SPSB to develop an empirical water sector model and use it to analyse various water policy questions under the following scenarios and water allocation regimes:

Scenario I

In this scenario economic efficiency rules are followed as the strategy to allocate water to meet total current requirements of $95 \times 10^6 \text{ m}^3$ (*WS1*). This scenario allows performing the following analyses:

- Determine the market clearing equilibrium price *PW1*
- Use *PW1* to calculate subsidy levels enjoyed by economic uses under the current water allocation strategy and charges, i.e. how far are current tariff rates from the equilibrium price?
- Derive a measure of the water *RR*, its distribution and rate of recovery
- Calculate the total value of water to economic uses in the SPSB (the sum of *CS* and *RR*).

It is important to note that this policy does not lead to loss in economic welfare apart from the social welfare loss due to reduced ecosystem health caused by lower Reserve, which this study could not evaluate. Accordingly, it was not possible under this scenario to evaluate the trade-off between offstream and instream benefits of water. The more interesting consequence of this policy, however, is its distributional effects as it allows reallocation of economic benefits through the capture and spending of the *RR* by the appropriate public agency or government.

Scenario II

The strategy of this scenario gives priority to protecting the ecological Reserve and hence allocates only water yield (*WS2*) among competing economic uses, again guided by the principles of economic efficiency. While preserving instream ecological values, this strategy leads to lower economic welfare as explained earlier. This welfare loss represents the opportunity cost of protecting freshwater ecosystems in the SPSB. Under this strategy the following analyses will be performed:

- Determination of the equilibrium price *PW2* that establishes economic efficiency in water allocation
- Evaluation of how far current water tariffs are from economic efficiency (subsidy levels) under ecologically sustainable water allocation regimes
- Calculation of the welfare loss caused by environmental protection as the opportunity cost of maintaining the ecological Reserve
- Evaluation of the change in water *RR*, its recovery and distribution under this strategy

Results from the first two scenario analyses will be used to evaluate the costs and benefits and hence social desirability and attractiveness of these two alternative water management regimes in the sub-basin.

The empirical water sector model of the SPSB

This section specifies sectoral water demand functions, then calibrates the specified empirical model to available data to determine the water demand system parameters for the various use sectors. An aggregate water demand function for the SPSB is then derived by aggregating sectoral water demands.

The SPSB model includes eight water use sectors, as indicated in Table 1. The demand for water by these sectors is modelled as a function of the water price assuming the following linear demand function:

$$WD_i = a_i - b_i PW_i \quad [5]$$

where:

WD_i determines the quantity of water demanded by sector i as a linear function of the water price faced by the sector (PW_i). a_i and b_i , respectively, measure the intercept and slope of the demand curves.

Calibration of the demand system to available data

The following data sources were used to conduct the empirical analyses and simulations:

- Levels of water use and charges (Table 1 and **Appendix**). Information on current levels of water use and charges by sector was compiled from surveys of primary and secondary sources, i.e. water users and water management agencies at the sub-basin
- The surveys also generated information on domestic water use by urban and rural households, which allowed estimation of water demand parameters for domestic users
- Estimates of water demand parameters generated by a number of recent water demand studies in the country and elsewhere (see ranges reported in **Appendix**) were used in the sense of "benefit transfer" to complement this study's efforts to specify the demand behaviour of water users at the SPSB (Dockel, 1973; Hassan et al., 1996; Amir and Fisher, 1999; Veck and Bill, 2000; King, 2004; Tewari, 2003; Mirrilees et al., 2003; Veck and Williams, 2004; Van Vuuren et al., 2004).

Data on current costs of water to various users were compiled for the SPSB. There is a wide range among use sectors in terms of the cost of water. Some users are provided with water from a public network or from a dam (government schemes). On the other hand, other users are self-providers. Government water tariffs/charges levied by DWAF on bulk water supplies to different use sectors were used as water prices (PW). Details of the structure of water charges in the SPSB for sectors abstracting water for commercial use are found in the **Appendix** and consist of the following components (DWAF, 2003):

- The consumptive (use) charge, which applies only to users receiving water from government water schemes. This charge recovers costs associated with maintenance and operation of the water supply schemes
- The water resource management charge (WRMC), which applies to all users except Schedule 1 users. Schedule 1 users as defined in the NWA are those abstracting water directly from a natural source (including storage and use of rainwater) for non-commercial purposes such as household consumption, gardening and subsistence stock watering, (DWAF, 2003). This charge is introduced to recover actual costs of water resource management activities (e.g. planning and control of water allocations

and use, monitoring and control of pollution and invasive alien plants, water conservation and demand management, etc.). Note that this charge also applies to streamflow reduction activities such as cultivated forests (plantations) and commercial dry-land agriculture

- The water research levy, which is collected from users, supplied with water from government schemes and water service providers (i.e. municipalities and WUAs including irrigation boards)

While the first two represent recovery of actual water supply costs, the water research levy is treated as a royalty recovering part of the resource rent.

The SPSB water demand system model was calibrated to data on estimates of price elasticity of water demand obtained from a number of sources at observed current levels of water use and price charges to generate the demand system parameters (slope b and intercept a). Details of the calibration process are presented in the **Appendix**.

Using the specified sectoral water demands, a total water demand function for the SPSB was then derived by aggregating over all sectors:

$$WD = a - b PW = \sum_i WD_i = \sum_i (a_i - b_i PW_i) \quad [6]$$

Simulation of quantities of water demanded by the various sectors WD_i at different price levels PW_i , aggregated over all sectors gives total demand by all sectors WD_g . Simulated values of WD_g and PW_g were then used to fit an aggregate water demand curve and derive its parameters a and b . Since specification of the aggregate water demand curve is sensitive to the chosen sectoral elasticity parameters, this method resulted in the total water demand functions given in the **Appendix** for the SPSB.

The area under this demand curve is equal to the sum of the areas of all sector demand curves:

$$\int_0^{QW} PW(QW) dQW = \sum_{i=1}^n \int_0^{QW_i} PW_i(QW_i) dQW_i \quad [7]$$

where:

QW refers to quantity of water demanded.

Results of the empirical model under alternative water allocation regimes

The two above discussed scenarios (efficiency pricing at current levels of water use of $95 \times 10^6 \text{ m}^3$ and at the maximum yield of $61 \times 10^6 \text{ m}^3$) were evaluated using the estimated water sector model. The model was used to determine equilibrium prices at the two levels of total water allocation and in turn calculate the various values depicted in Fig. 1 under each scenario (e.g. RR , CS and water subsidies).

For simplicity of notation we will use Q in place of QW , P for PW and C in place of AVC . According to the analytical framework depicted in Fig. 1, we derive consumer surplus (CS) measures as follows:

$$CS(Q) = \int_0^Q (P(Q) - C) dQ = \left|_0^Q \frac{1}{2b} Q^2 \right. \quad [8]$$

For Scenario I, where $Q = 95$ the integral in Eq. (8) will be evaluated between 0 and 95 to calculate the CS (similarly between 0 and 61 for Scenario II, where $Q = 61$). On the other hand, the resource rent (RR) is derived as the difference between the equilibrium price at Q level of 95 (61 for Scenario II) and costs paid by each user per m^3 of water used, which when multiplied by the quantity of water used

	High elasticity		Low elasticity	
	Scenario I	Scenario II	Scenario I	Scenario II
Equilibrium price (R/m ³)	0.843	4.266	0.512	5.322
Subsidy (R m.) R/m ³	70.85 0.74	253.56 4.16	39.48 0.42	317.25 5.20
Resource rent-RR (R m.) R/m ³	71.49 0.75	254.07 4.16	40.12 0.42	317.82 5.21
% of RR recovered	0.90%	0.20%	1.61%	0.18%
Consumer surplus (R m.) R/m ³	454.42 4.78	187.36 3.07	638.38 6.72	263.20 4.31
Welfare cost (R m.) R/m ³	- -	83.82 2.46	- -	96.13 2.83
Price elasticity of demand	-0.09	-0.69	-0.04	-0.62

by each sector gives the total subsidy enjoyed by that sector and when summed over all sectors gives an estimate of the total subsidy at the sub-basin. Results of the above calculations for the two scenarios are summarised in Tables 2 and 3 under the two scenarios described above. Tables 2 and 3 also report results under two elasticity assumptions: a high elasticity (HES) using the upper bound and low elasticity (LES) based on the lower bound of elasticity ranges given in the **Appendix**.

The simulation results reported in Table 2 indicate that at current water allocation levels (95 x 10⁶ m³) the market value of bulk water in the SPSB is about R0.84 under the HES assumption, generating more than R70 m. of resource rents (RRs), almost all dissipating to various water users. At this market-clearing price an economic surplus (CS) of more than R450 m. is generated giving an average of R4.78/m³ welfare water value. When water supply was limited to the available yield of 61 x 10⁶ m³ in order to protect the ecological Reserve, a much higher market price of R4.27/m³ was achieved, leading to a much higher subsidy of R4.16/m³. This, however, reduced the economic surplus to R3.07/m³, causing a deadweight loss in the economic welfare value of water of more than R58 m. This amounts to an opportunity cost of R1.71 for every m³ of water withdrawn from economic activity for environmental

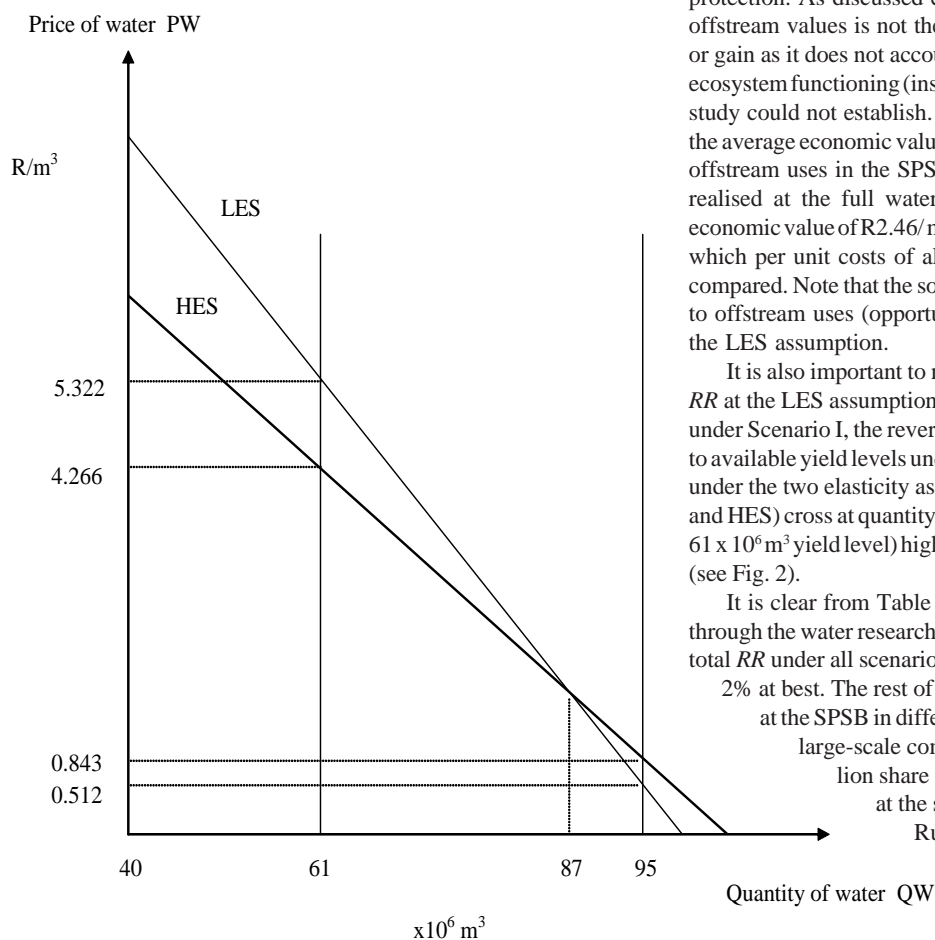


Figure 2
Water demand in the Steelpoort sub-basin for different levels of price elasticity

protection. As discussed earlier, this measure of loss in CS from offstream values is not the appropriate measure of net social loss or gain as it does not account for the welfare gains from improved ecosystem functioning (instream values of water), which the present study could not establish. Nevertheless, these results suggest that the average economic value from increasing water supply (yield) to offstream uses in the SPSB amounts to R1.7/m³. Adding the RR realised at the full water supply scenario to this gives a total economic value of R2.46/m³ that can be used as a benchmark against which per unit costs of alternative water supply options may be compared. Note that the social benefit from increased water supply to offstream uses (opportunity cost) increases to R2.83/m³ under the LES assumption.

It is also important to note that while the equilibrium price and RR at the LES assumption are lower than those realised with HES under Scenario I, the reverse is true when water supply was limited to available yield levels under Scenario II. This is due to the fact that under the two elasticity assumptions the two demand curves (LES and HES) cross at quantity $QW = 87 \times 10^6 \text{ m}^3$, below which (e.g. the $61 \times 10^6 \text{ m}^3$ yield level) higher price levels obtain with the LES curve (see Fig. 2).

It is clear from Table 2 that the only part of the RR collected through the water research levy captures a very small portion of the total RR under all scenarios and elasticity assumptions of less than 2% at best. The rest of the RR dissipates to various water users at the SPSB in different shares as shown in Table 3. Clearly,

large-scale commercial irrigation agriculture reaps the lion share of the RR as it is the major user of water at the sub-basin followed by mining activities.

Rural households and small irrigation farmers are currently subsidized as Schedule 1 users. The per unit subsidy is highest for irrigation farmers while mining, industry and urban households are charged for bulk water at relatively lower subsidy rates.

	High elasticity		Low elasticity	
	Scenario I	Scenario II	Scenario I	Scenario II
Rural households	5.95	8.41	6.49	8.39
Urban households	2.16	3.69	1.37	3.46
Irrigation-small	3.57	4.69	3.89	4.59
Irrigation-commercial	73.77	59.22	78.02	55.31
Livestock	1.13	1.60	1.20	1.58
Mines	8.64	14.80	5.47	17.88
Forestry	1.18	1.41	1.28	1.34
Industry	3.60	6.17	2.28	7.45
Total (R m.)	70.85	253.56	39.48	317.25
	100%	100%	100%	100%

Conclusions and limitations of the study

The preceding analyses showed that bulk water is currently over-supplied to offstream uses in the SPSB at the expense of the ecological Reserve (instream benefits). The study also indicated that bulk water is currently underpriced and the only rent capture instrument used, the water research levy, recovers a negligible proportion of the *RR*. The consequence is dissipation of almost all the *RR* to various offstream users of water in the form of indirect subsidies of about R0.75 or R0.42/m³ with the HES and LES assumptions, respectively. Commercial irrigation enjoys the highest subsidy being the major consumer followed by mining. Results of the simulation analysis also indicate that the opportunity cost in terms of economic surplus lost to offstream uses as a result of limiting water supply to protect the ecological Reserve is R2.83/m³. This value, while it does not properly reflect the net social gain or loss of environmental protection, serves as a benchmark value against which per unit costs of potential alternative water supply options can be compared.

These results, however, should be viewed with caution. In spite of the relative robustness of the derived results under alternative price elasticity scenarios, the following caveats remain as key limitations of the study that call for further research work:

- An important deficiency of the study is the lack of information on instream benefits to compare with benefits lost to offstream uses and enable calculation of net social gains or loss of environmental protection through conserving the ecological Reserve
- Current specification of the supply side of the water sector model can be improved with better information to allow estimation of upward-sloping supply (marginal cost) curves rather than the fixed total supply currently used. This may not significantly alter the empirical findings but will certainly be more appropriate especially for users of delivered (processed) water such as municipal supplies to industry and domestic sectors
- The water demand side of the model can also benefit from improved parameter estimates for the mining, industry and irrigation sectors.

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Appendix

Calibration of demand system model parameters

The following procedure was employed to estimate the SPSB water demand system parameters. Given the linear water demand system specification:

$$Q_i = a_i - b_i * P_i$$

and the definition of price elasticity e_i :

$$e_i = (\partial Q_i / \partial P_i) (P_i / Q_i)$$

one can compute demand function parameters a_i and b_i using information on Q_i , P_i and e_i as follows:

Since $e_i = (\partial Q_i / \partial P_i) (P_i / Q_i)$

which means, using the linear demand function:

$$e_i = b_i * (P_i / Q_i)$$

solving for: $b_i = e_i * (Q_i / P_i)$

and hence: $a_i = Q_i + b_i * P_i$

Using our knowledge of current water use levels (Q_i), prices (P_i) and elasticity estimates (e_i) we can then calculate the values of a_i and b_i for the various demand sectors at the SPSB (Table A.1).

An alternative method was used to derive parameters a and b of total water demand. In this method, the value of a (intercept at $PW = 0$) was calculated to be

$$a = \sum_{i=1}^n a_i = 103.37 \text{ (according to Eq. 6).}$$

Parameter b was then derived using a weighted average of sectoral demand elasticities such that:

$$e = \frac{\sum_{i=1}^n e_i * QW_i}{\sum_{i=1}^n QW_i}$$

Then the value of b was derived using the estimated total demand elasticity e and the equilibrium price (PW) at current water use levels ($WD = 95$). The two methods gave very close values of a , b and e .

TABLE A.1 Elasticity and water demand parameters= estimates and water charges in the SPSB								
Sector	Range of elasticity estimates (e_i) ¹	Intercept (a)		Slope (b)		Bulk water charges 2002/3 (C/m ³)		
		High e_i	Low e_i	High e_i	Low e_i	Use charge	WRMC	Total ³
Rural households	0.29	6.45	6.45	6.04	6.04	0	0	0
Urban households	0.17 - 0.81	5.43	4.41	0.71	0.41	29	2.08	33
Irrigation-small	0.00001 - 0.06	3.00	3.00	0.05	0.05	0	0	0
Irrigation-Large	0.00001 - 0.06	65.39	65.065	1.30	0.22	2.9	0.9	3.8
Livestock ²	-	1.001	1.001	0.01	0.01	2.9	0	3.8
Mines	0.04 - 0.24	14.88	12.48	1.25	0.21	29	2.08	33
Forestry	0.012	1.012	1.012	0.04	0.04	0	0.8	1
Industry	0.04 - 0.24	6.2	5.2	0.52	0.09	30	2.08	33
<i>Aggregate demand</i>	<i>0.04 - 0.09</i>	<i>10.337</i>	<i>98.62</i>	<i>9.93</i>	<i>7.07</i>			

1. Note that in calibrating the empirical water sector model we have used lower bounds of 0.47 and 0.001 as averages instead of the very low tail values of 0.17 and 0.00001 for urban household and irrigation agriculture elasticity, respectively.

2. As no source was available for the livestock sector, the same range of elasticities used for the irrigation-small sector was adopted.

3. The difference between the total and the sum of user charge and WRMC represents the water research levy.