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in

Hamdy A. (ed.), Lacirignola C. (ed.), Lamaddalena N. (ed.).
Water valuation and cost recovery mechanisms in the developing countries of the Mediterranean region

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 49

2002
pages 177-190

The Economics of Groundwater Use in Agriculture Under Different Water Prices and Supply Regimes in the Upland Area of Jordan

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ABSTRACT

The main objective of this paper is to manage groundwater resources in such a way that remains compatible with the safe yield of this resource. The calculations were based on information available on water supplies, areas under irrigation and market conditions. Linear programming models were used for determining solutions that maximize the total net income. Results showed that there is a potential to decrease water consumption and to reallocate it in an optimal way and to increase the net income of agriculture in the study area. The water demand from agriculture reacts to increasing water prices in a quite elastic manner over a long interval, while it was inelastic in the case of decrease the overall water supply by 15%

1. Introduction

Water scarcity is the single most important natural constraint to Jordan's economic growth and development. Rapid increase in population and industrial development has placed unprecedented demands on water resources. Jordan's population has approached 5.0 million in 2000 and growing at a very high annual rate of 3.6 percent (DOS-1, 2001).

Total demand is approaching one billion cubic meters per year, which approximates the limit of Jordan's renewable and economically developable water resources. For several years, renewable ground water resources have been withdrawn at an unsustainable rate (Table 1). Consequently, groundwater quality in some areas is deteriorating.

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Groundwater resources constitute the main source for municipal consumption and the only one in some areas. It is also the basis for the irrigated areas in the highland. The safe yield from the renewable groundwater resources has been estimated at 275.5 MCM in 1998, in addition to 143 MCM of nonrenewable groundwater resources. However, the total water use was appraised at 483.19 MCM in 1998. The estimated rate of pumping from Jafer and Azraq basins is more than twice their safe yield (Table 1).

Agricultural sector is the largest consumer of Groundwater resources, for it consumes annually 258.35 MCM (55%), and the rest is used for municipal and industrial consumption (Table 1).

Table 1. Groundwater Resources and Uses in 1998

Ground Water Basin	Safe abstraction (MCM/ year)	Ground water uses in 1998 MCM					% from safe abstraction
		Municipal Water quantity mcm/yr	Industry Water quantity mcm/yr	Agriculture Water quantity mcm/yr	Other uses Water quantity mcm/yr	Total Water Uses MCM/ year	
Yarmouk	40.00	23.49	0.17	30.77	0.37	54.80	137.00
Side Wadis	15.00	5.63	0.00	6.58	0.00	12.20	81.00
Jordan Valley	21.00	7.57	1.06	29.39	0.00	38.10	181.00
Amman –Zarqa	87.50	65.70	6.07	65.56	0.33	137.60	157.00
Dead Sea	57.00	33.79	14.57	34.39	2.17	84.92	149.00
North Wadi Araba	3.50	0.00	4.27	0.41	0.20	3.76	108.00
South Wadi Arba	5.50	1.19	3.16	3.39	0.12	4.82	88.00
Jafer	9.00	6.94	0.12	9.44	0.31	23.27	259.00
Azraq	24.00	28.10	6.59	26.86	0.54	55.79	232.00
Sirhan	5.00	0.00	0.29	1.29	0.18	1.47	29.00
Hammad	8.00	0.78	0.00	0.10	0.43	1.30	16.00
Total renewable	**275.50**	**173.18**	**36.30**	**208.17**	**4.64**	**418.02**	
Disi & Mudora	125.00	9.65	14.57	50.18	1.10	65.19	52.00
Jafer	18.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Nonrenewable	**143.00**	**9.65**	**14.57**	**50.18**	**1.10**	**65.19**	

Source: MWI, Annual Report, 1998.

Jordan Water policy is concentrated on satisfying water requirements of municipal and industrial consumption and the rest will be left for agricultural use. Thus in meeting Jordan's future demand for water, the most affected sector would be the agricultural sector. Therefore, the agricultural sector should use water resources in an efficient way to be ready to meet increasing water shortages.

As a result, it is imperative that optimal and sustainable patterns of water use be established to meet the requirements of a growing population as well as Jordan's economic development objectives and basic agricultural foodstuffs. No single action can remedy the country's water shortages; rather many actions are necessary to increase overall water availability. One strategy is to focus on increasing the usable supply of water and the amount of wastewater reuse. Another strategy is to reduce water demand by adopting water conservation programs and improving water use efficiency and water pricing policy.

This study focused on Mafraq region where agriculture depends totally on groundwater resources. The safe yield of groundwater resources is estimated at 15.77 MCM where the current use is appraised at 36.745 MCM. Mafraq region is located in the Northeast part of Jordan. This area is classified as marginal area where the annual rainfall is less than 200mm.

2. Objectives of the study

The main objective of this research is to manage groundwater resources in such a way that remains compatible with the safe yield of this resource. More specifically this research aims at:

1. Determining the optimal cropping pattern that maximizes net income under different water supply regimes and prices.
2. Estimating the price elasticity of demand for irrigation water.

3. Methodology

This study depends on data obtained from Department of Statistics (DOS) and the Ministry of Water and Irrigation (MWI). The Data obtained from DOS related to the pumping capacity of wells, fixed and operation costs of wells, as well as the area irrigated by each well and crop enterprise budgets (DOS-2, 1995-2000), whereas the data obtained from the MWI was related to groundwater supply and data related to net water requirements of crops (SHATANAWI, *et al* 1998).

In this study, a linear programming model was used. The objective of the model was to maximize the total net income of production in the irrigated areas of Mafraq by combining production activities in an optimal manner under Safe Yield conditions. The model is of static nature and considers a 12-month production period under the given investment conditions. It uses data on water requirements per unit area of land for different crops, the total land, and water available, upper limits of planted area and market capacities for the different crops. The models were formulated in such a way that water and land constraints were built-in, as well as constraints to prevent the exaggerated expansion of fruit trees, while at the same time ensuring that the market was provided with sufficient quantities of vegetable crops like potatoes and tomatoes. Water transfer activities were incorporated in order to transfer water from one month to another to get an optimal monthly water schedule.

The objective function of the models is based on the gross margins per hectare of the different production activities. These gross margins were calculated as the difference between the water-related contribution (WRC) and the costs for water, whereby WRC represents the market value of produced crops minus all other variable costs for production, such as machinery, labor, fertilizers, and other inputs. The separate handling of water costs allowed examination of the reactions in the optimal solution to changes in water prices, and derivation of a demand function for water (Salman *et al*, 2001).

3.1 model specification

The objective function of the model can be written as follows:

$$MaxZ = \sum_j x_j (wrc_j - \sum_i p_i w_i) \qquad (1)$$

where Z represents the total net income, x_j is the total land area of activity j; wrc_j is water related contribution of activity j, P_i is the price of water in month i (Oct, Nov,,Sep) and W_i is the allocated amount of irrigation water in month i:

Water constraints of the model reflect a 12-month irrigation schedule (Equation 2), these constraints can be represented as follows:

$$\sum_j a_{ij} x_j + \sum_i (-w_i^{\circ} - w_{i-1}^{+} + w_{i+1}) \leq 0 \qquad (2)$$

where a_{ij} is the water requirement in cubic meter per hectare of activity j in month i, Xj is the land area occupied by activity j, w_i° represents the total available water quantity for irrigation, which does not exceed safe abstraction in month i, w_{i-1}^{+} represents the transferred water quantity from previous month i-1, w_{i+1} represents the transferred water quantity to the month after i+1.

Land constraints considered the total available area for irrigation and distinguished between maximum portions for specific crop categories and individual crops. These constraints can be represented as follows:

$$\sum_{j}\sum_{n} x_{jn} \quad A_n \tag{3}$$

where An is the total allocated area for crop category n, where n is field crops, vegetables and fruit trees.

Moreover, individual crops are subject to market and policy constraints. The models allowed for a maximum production of vegetable crops, such as tomatoes, potatoes, cucumbers or eggplants, in such quantities that the marketing system, or alternatively processing facilities in the vicinity of the production area, are capable of handling the crops without price distortions. In addition, fruits tree were fixed in the upper bound due to the fact that the area of crops is unchanged in the short run, although in some scenarios the area of fruit trees was permitted to increase to examine the impact if increasing water supply and the prices of water. The upper limit on the corresponding acreage was based upon the maximum levels of 'historical' cultivation over the period from 1991/1992 to 1998/1999 - figures provided by DOS, this constraint could be represented as follows:

$$\sum_{j} x_j \quad B_j \tag{4}$$

where Bj is the maximum area that provides maximum market capacity of activity j.

3.2 Scenarios of the study

The analysis of this investigation is based on two main scenarios. The first scenario is built on changing water supply quantity with unchanged water supply for municipal and industrial uses. The whole pumped quantity of groundwater for all purposes from four basins (Yarmouk, Azraq, Hamad, and Amman-Zarqa) is about 159.5 MCM, of which about 31.85 MCM is used for irrigation under safe yield conditions. The planted area in Mafraq represents about 49.5% of the total area irrigated from four basins. Therefore, the safe yield of water supply was estimated at 15.77 MCM per year. From this quantity the following sub-scenarios were initiated:

1. A decrease in overall water supply by 10%, results in a reduction of water available for irrigation to 7.87 MCM/year

2. A decrease in overall water supply by 15%, results in a reduction of water available for irrigation to 3.92 MCM/year. Decrease in overall water supply by more than 15%, would make no water available for irrigation.

In addition to the above scenarios the researchers consider the situation of current water use (36.75 MCM), occurrence of wet year (32.42 MCM) and the increase in overall water supply by 30% (39.46 MCM).

The second scenario is built on changing the prices of irrigation water. Changes in water prices were restricted to case of safe yield supply (15.77 MCM). To estimate the price elasticity of demand, prices parameterized systematically in the case of wet year and 15% reduction in water supply.

4. Results and discussion

4.1 The optimal use of irrigation water

The optimal cropping patterns under the assigned water supply scenarios are presented in table 2. The total irrigated area is about 1,920.6 ha under the safe yield scenario. This irrigated area constitutes mainly of vegetables and fruit trees, which accounted for 95% of the total planted area.

Reducing water supply by 10% and 15% reduced the total planted area by 46% and 75%, respectively. Decreasing water supply by 10%, affects mainly the planted area of vegetables. The planted area of vegetables decreased by 73%. The reduction in planted area of vegetables is more likely to be attributed to the low profitability of some vegetable crops. While decreasing water supply by 15% affected the planted area of both fruit trees and vegetables negatively by 45% and 95 %, respectively (Table 2).

Investigation has been carried out in the case of wet year, where water supply was estimated at 32.423 MCM, the planted increased sharply from 1920 ha to 4224 ha, which represents an increase of 120%. This increase in water supply affected positively the planted area of vegetables (Table 2). It is worthwhile mentioning that the over pumping of ground water resources beyond the safe yield in the case of the current situation is mainly used in growing vegetables.

Relative distributions of monthly water use for different water supply levels under the actual water price of $ 0.143 per m3 are presented in Table 3. The greater demand for water is extended from April up to

September this period is matched with growing vegetables in study area. Water consumption during the peak period is accounted for 90% of the total consumption.

Table 4 represents the costs and returns of water under different supply levels under the actual water price. The costs and returns of water increased and decreased analogously to increase and decrease in water use. It can be seen that as the quantity of water used increased the shadow price of water decreased accordingly. Moreover, the net income per one cubic meter as well as per unit area (hectare) decreased in the same way to water use. This can be attributed to the fact that some low profitable crops especially vegetables entered the solution of the linear programming as the available of water quantity increased.

4.2 Iimpacts of rising water prices

Table 5 indicates the optimal cropping patterns under a systematic increase of water tariffs in the case of safe yield of water supply. Cropping pattern as well as the planted area is not affected by incremental increase of water price up to the level of \$ 0.357 per m^3. This implies that water values in the region are under estimated and the decision maker can impose a price level for water up to \$ 0.357 per cubic meter without having any impact on the cropping pattern or the planted area. However, the total net income of farmers would be reduced. The government in turn can use the returns of increased tariffs for rehabilitating and conserving ground water resources in the region.

Further increases in the price of water already changed the production structure and reduced the planted area. Tomatoes, which have a relatively low gross margin, cannot cover higher variable costs and leave the optimal solution almost immediately when water price exceeded the level of \$ 0.357 per m^3. More profitable crops, but also more risky are crops such as grapes, peaches and apricots that cannot compensate for the lost area of tomatoes for an example, as they become unprofitable at higher water prices due to market constraints. Increasing water prices also lower the returns on investments, and the optimal area of fruit trees falls below the current acreage at water prices higher than about \$ 0.429 per m^3 (Table 5).

The model calculations with different water prices enable the analysis of their impact on water demand, income development, production structure and the volume of water used. Water demand under the safe yield reacts in a discrete manner to increasing prices (Figure 1). An increase in the water price from the actual of \$ 0.036 to \$ 0.214 per m^3 reduces the net returns per cubic meter from $ 0.341 down to $ 0.163. The use of all available irrigation water for agricultural activities is still justified from the economic point of view, but the total net income - as an indicator of the farmers' income - shrinks by more than 40% from $ 6.550 million down to $ 3.744 million (Table 6).

Table 7 presents the demand function and price elasticities of ground water under different supply regimes. It can be seen that water demand is elastic at midpoint in the case of safe yield (-1.044) and wet year (-1.291) water supply scenarios. This means that, starting at that price; an increase of 1% in the price of groundwater will decrease the quantity demanded by about 1.044% and 1.291%, respectively. However, the demand for ground water resources under the case of 15% reduction in water supply was inelastic (-0.506). It can be observed that own prices elasticity becomes inelastic as the available quantity of groundwater decreases (see figures 1, 2 and 3).

5. Conclusion

The water demand from agriculture reacts to increasing water prices in a quite elastic manner over a long interval, as long as the planning of cropping patterns is based on the expectation of average results only. Water prices up to $ 0.357 per cubic meter reduce farmers' incomes without any effect on the production structure; prices higher than $ 0.357 reduce the planted area and make most agricultural production alternatives unprofitable. This will reduce agricultural production and initiate negative impacts on the supply situation of markets and the living standards of the concerned rural population.

Discussions on the allocation of water between the different sectors of society on the basis of pricing mechanisms have to consider the substantial impacts on market supply in terms of quantity and variety of agricultural products.

The suggested mathematical models proved to be relatively easy to handle, and have a sufficient level of generality that would allow their use as a decision aid and prognostic tool in other locations of the region too. The model can produce insights for agricultural planners who must allocate scarce water resources among agricultural activities by time. It also generates estimates of the effects of different water prices. Indeed, we wish to stress that water pricing, aided by analyses such as this, could be an appropriate and efficient means of controlling agricultural water consumption.

Table 2. The Optimal-cropping pattern for different water supply levels under the actual water price ($ 0.143 per cubic meter)

Item	Unit	Safe Yield	Decrease 10%	Decrease 15%	Wet Year	Current situation	Increase 30%
Water supply quantity	MCM	15.770	7.868	3.920	32.423	36.745	39.459
Tomato	ha	944	54.6		2000	2000	2000
Eggplant	ha				132.4	132.4	132.4
Squash	ha	220	220		220	220	220
Cauliflower	ha						532.9
Cabbage	ha				489.4	489.4	489.4
Beans	ha	54.3	54.3	54.3	54.3	54.3	54.3
Sweet pepper	ha				78.9	78.9	78.9
Water melon	ha				546.5	1049.4	1049.4
Sweet Mellon	ha					246.3	266.2
Onion	ha	27.2	27.2	27.2	27.2	27.2	27.2
Wheat	ha						212.9
Garlic	ha	71	71	71	71	71	71
Grapes	ha	130.2	130.2		130.2	130.2	130.2
Peach	ha	261.9	261.9	123.1	261.9	261.9	261.9
Apricot	ha	212	212	212	212	212	212
Field Crops	ha	98.2	98.2	98.2	98.2	98.2	311.1
Fruit trees	ha	604.1	604.1	335.1	604.1	604.1	604.1
Vegetables	ha	1218.3	328.9	54.3	3521.5	4270.7	4823.5
Total Area	ha	1920.6	1031.2	487.6	4223.8	4973	5738.7

Table 3. Relative distribution of monthly water use for different water supply levels under the actual water price ($ 0.143 per cubic meter)

Month	Safe Yield	Decrease 10%	Decrease 15%	Wet Year	Current situation	Increase 30%
Oct	1.6	3.1	3.1	0.8	0.6	0.7
Nov	1.4	2.7	2.7	0.7	0.5	0.6
Dec	0.0	0.0	0.0	0.0	0.0	0.0
Jan	0.2	0.4	0.4	0.8	1.3	0.7
Feb	1.0	2.0	2.0	2.1	3.2	1.8
Mar	2.6	3.3	3.3	4.8	6.6	4.2
April	5.7	6.9	6.9	6.0	6.7	5.3
May	16.3	10.3	10.3	15.6	13.4	14.3
June	18.9	14.7	14.7	18.5	17.0	18.2
July	23.8	23.7	23.7	21.9	21.4	22.9
Aug	21.8	19.0	19.0	23.9	24.0	25.7
Sep	6.9	13.8	13.8	4.9	5.2	5.6
Total	100	100	100	100	100	100

Table 4. Costs and returns of water under different supply levels and according to the actual water price ($ 0.143 per cubic meter).

Available Water	Water use (MCM)	Water Expenses ($ millions)	Total income ($ millions)	Total net income ($ Million)	Shadow price ($/m3)	Net income per cubic meter ($/m3)	Net income per ha ($/ha)
Safe yield	15.770	2.253	7.124	4.871	0.234	0.314	2,536
Decrease 10%	7.868	1.124	4.141	3.017	0.234	0.386	2,926
Decrease 15%	3.920	0.560	2.261	1.701	0.359	0.429	3,490
Wet Year	32.423	4.631	12.959	8.326	0.124	0.257	1,971
Current Situation	36.745	5.250	14.059	8.810	0.087	0.243	1,771
Increase 30%	39.459	5.637	14.600	8.963	0.054	0.229	1,561

Table 5. Optimal cropping pattern at different levels of water prices in the case when water supply is 15.770 MCM

	Water price ($/cubic meter)						
Crop	0.036	0.357	0.393	0.429	0.500	0.536	0.643
Tomato	9,440	9,440					
Squash	2,200	2,200	2,200	2,200			
Beans	543	543	543	543	543	543	543
Onions	272	272	272	272	272	272	272
Garlic	710	710	710	710	710		
Grapes	1,302	1,302	1,302	1,302			
Peach	2,619	2,619	2,619	2,619	2,619		
Apricot	2,120	2,120	2,120	2,120	2,120	2,120	
Field Crops	982	982	982	982	982	272	272
Fruit trees	6,041	6,041	6,041	6,041	4,739	2,120	
Vegetables	12,183	12,183	2,743	2,743	543	543	543
Total Area	19,206	19,206	9,766	9,766	6,264	2,935	815

Table 6. Costs and returns of water at different levels of water prices in the case when water supply is 15.770 MCM

Water price ($/m^3)	Total income ($ millions)	Water Expenses ($ millions)	Total Net income ($ millions)	Shadow Price ($/m^3)	Net returns per cubic meter ($/m^3)	Net returns per ha ($/ha)	Water Use (MCM)
0.036	7.124	0.563	6.560	0.341	0.414	3415.7	15.760
0.214	7.124	3.379	3.744	0.163	0.243	1950.0	15.767
0.357	7.124	5.631	1.491	0.020	0.100	777.1	15.768
0.500	2.889	2.586	0.303	0.000	0.057	482.9	5.171
0.643	0.223	0.214	0.009	0.000	0.029	108.6	0.333
0.679	0.000	0.000	0.000	0.000	0.000	0.0	0.000

Table 7. Demand functions and price elasticities under three different scenarios of irrigation water supply.

Equation	Water Quantity	Demand Function	R^2	Price elasticity at actual price	Price elasticity at mid-point
5	Safe Yield	*Q =20.67 – 29.55 P* (16.6) (-9.67)*	84.6	-0.187	-1.044
6	Wet year	*Q =41.73 – 65.84 P* (16.0) (-10.3)*	86.2	-0.417	-1.291
7	15% reduction	*Q = 4.91 – 4.62 P* (11.8) (-4.5)*	54.7	-0.029	-0.506

Where *Q* denotes water quantity demanded and *P* denotes price of water
* Significant at = 1%

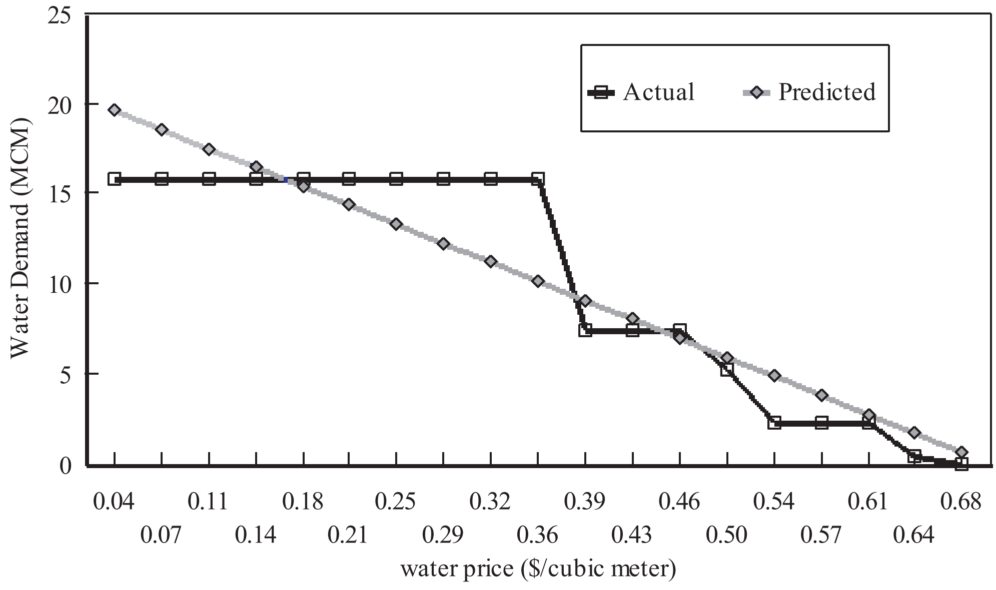

Figure 1. Demand Curve in the Case of Safe Yield Water Supply (15.770 MCM)

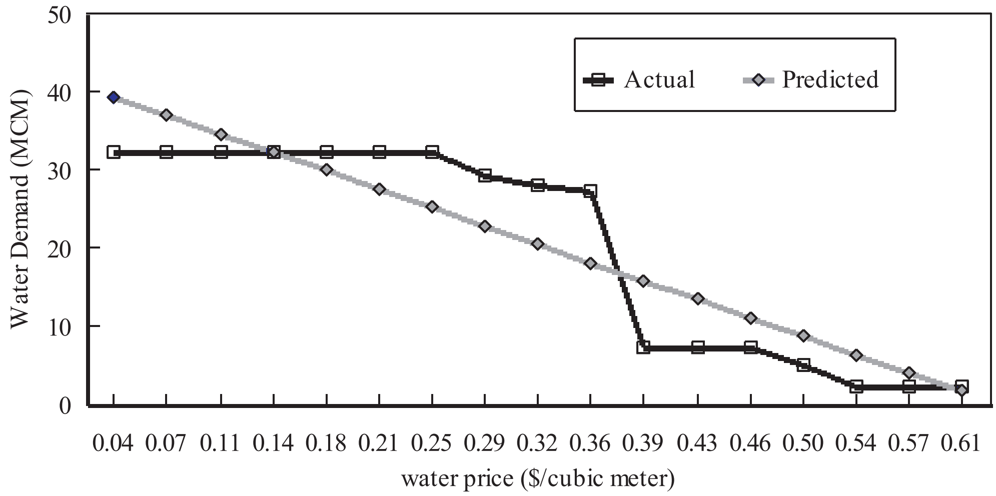

Figure 2. Demand Curve in the case of wet year (32.423 MCM)

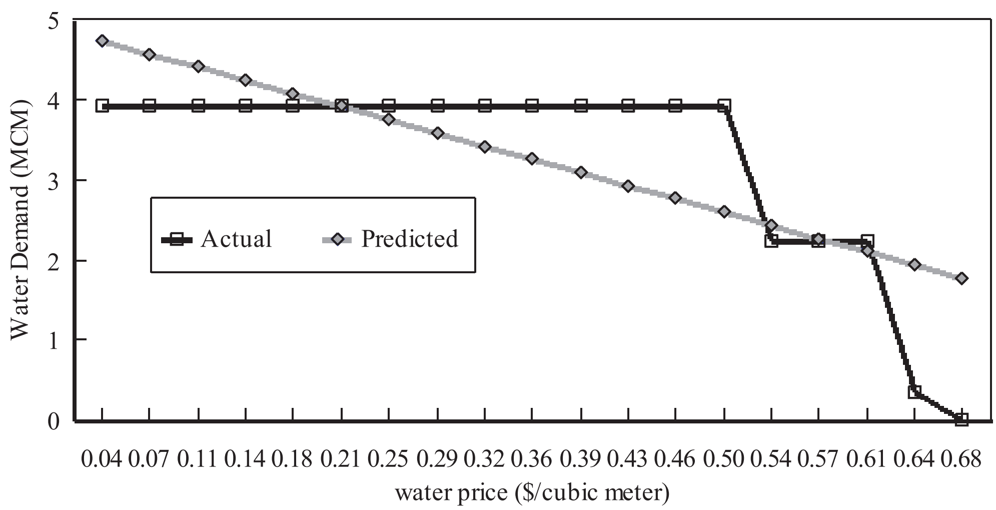

Figure 3. Demand Curve in the case of wet year (3.920 MCM)

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