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Estimation of farmers' willingness to pay for water in the agricultural sector

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ABSTRACT

Increasing the reliability of irrigation water raises the cost of water storage and the price that farmers must pay for water. Evaluating farmers' willingness to pay (WTP) for water is key to determining the reliability of irrigation water achievable. This paper presents a probabilistic optimization method for estimating the WTP to avoid water shortage. A nonlinear programming model was formulated to model water use and estimate a single farmer's WTP when water shortage occurs. The model was subsequently expanded to include the WTP of a group of farmers relying on Monte Carlo simulation. Results show that low water prices do not have any effect on water use when there is no shortage of water. Facing water shortage, farmers employ irrigation systems with high efficiency to reduce the use and cost of irrigation water. They also change the cropping pattern to cultivate crops with low water requirements. The farmers' WTP for irrigation water during shortage is assessed probabilistically and is found to be highly variable.

1. Introduction

Determining water's economic value is a useful tool to improve water allocation, reduce wasteful use, and to achieve sustainable water management. In spite of various studies about water pricing in the agricultural sector, determining the economic value of water in the agricultural sector remains elusive for decision makers. In this respect, the farmers' willingness to pay for water reflects its value from the farmers' viewpoint. The WTP is the maximum amount that an individual agrees to pay for a product or service. It can be used for determining water price (Baghestani and Zibaei, 2010). There have been a few attempts to estimate the WTP for water in the agricultural sector. Most of these studies were empirical and applied either price elasticity or the contingent valuation method (CVM).

The CVM is applied by asking questions to farmers about their WTP for water use (Mitchell and Carson, 1989). This method requires an initial experimental survey followed by a detailed survey, both of which may be costly. Respondents (farmers) might not have a clear concept about the actual value of water, and their estimates may be more or less than the actual value. Nevertheless, the CVM has been applied by several authors. Baghestani and Zibaei (2010) estimated farmers' WTP for groundwater using the CVM and showed that farmers that use surface and ground water conjunctively have lower WTP compared with farmers that used groundwater as the only source of water. Rasekhi et al. (2012) implemented the CVM for estimating tourists' WTP for the recreational use of the Khazar coastal region (Iran). Their results showed that the educational level of tourists had a significant effect on their WTP for recreational amenities. Kwak et al. (2013) applied the CVM to determine the economic benefits of improving the quality of tap water in Pusan, Korea. Markantonis et al. (2013) used the CVM to evaluate the environmental cost of floods in the Evros river (Greece). These costs were evaluated by asking hunters, farmers, and local authorities about their WTP to avoid the effects of floods on soil and the environment. Results demonstrated the usefulness of the CVM in flood risk management. Tang et al. (2013) estimated farmers' WTP for water with the CVM. Results showed that the current price of water in the agricultural sector is low, and the

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major reason for this is that farmers are reticent to pay for irrigation water. Musavi (2015) applied the CVM to estimate the value of Khafr waterfall and recreational facilities. Results indicated that 75% of visitors agreed to pay for the use of the waterfall. Their age, education, and revenue had significant effect on the tourists' WTP.

Approaches other than the CVM have also been reported to estimate the WTP. Lund (1995) and Wilchfort and Lund (1997) introduced a two-stage optimization model to estimate households' WTP for water. Griffin and Mjelde (2000) applied the CVM for valuing water supply reliability. Salman and Al-Karablieh (2004) reported a linear programming model with an objective function of maximizing the benefits of crops' production to determine farmers' WTP for water. Chandrasekaran et al. (2009) determined water's economic value by researching the farmers' WTP for increases in the reliability of water supply. Falsafi-Zadeh and Sabouhi (2010) estimated the farmers' WTP with the choice experiments method. Results showed that farmers' WTP is between 10 to 15 percent of water charges. Hadadin et al. (2010) focused on water shortage in Jordan. They presented recommendations addressing water resource shortage in the kingdom and highlighting the importance of conservation of water and discussing the basics of sustainable solution. Medellin-Azuara et al. (2012) investigated the effect of water rationing, pricing and subsidies on water use in the agricultural sector. Policy simulation in this study included increase in subsides and water price rationing, w which indicated that subsidies may have little effect on total water use and may not promote water conservation without incentives. Adeniji et al. (2013) investigated strategies to cope with water supply shortages to households in Nigeria. Alarcon et al. (2014) investigated beneficial ways of allocating water during water shortage for irrigation. Onyango et al. (2014) researched the factors influencing farmers' WTP for water use in Kenya.

Recently developed statistical and optimization techniques in different field of water resources investigations (Ashofteh et al., 2013, 2015a,b,c; Beygi et al., 2014; Bozorg-Haddad et al., 2013, 2014, 2015a,b; Bolouri-Yazdeli et al., 2014; Fallah-Mehdipour et al., 2013; Orouji et al., 2013, 2014; Shokri et al., 2013, 2014; Soltanjalili et al., 2013) have not addressed the estimation of farmers' willingness to pay for water in the agricultural sector, which is the subject of the present study.

Unlike the methods that have been used to estimate farmers' WTP for water, the probabilistic optimization approach considers shortages occurring during water supply in the agricultural water sector and the determination of the water price and water rationing effects on the WTP, which sets it apart from other approaches. Furthermore, the probabilistic approach incorporates water shortage probabilities in the optimization model, which better captures actual hydrological conditions.

This study implements the method reported by Garcia-Alcubilla and Lund (2006) to estimate farmers' WTP to avoid water shortage. The latter authors applied a linear optimization model to estimate the WTP in the residential sector. This paper's nonlinear optimization model deals with the agricultural water sector. The Monte Carlo simulation method is applied to assess the uncertainty in model parameters and to derive water-demand curves of farmers.

1.1. Measuring the willingness to pay

Techniques for measuring the WTP are classified as those involving revealed preferences (RP) and those involving stated preferences (SP). The RP method derives the price of a product or service by observing individuals' behavior in markets. The SP method derives prices directly by asking individuals about their preferences. The advantage of the SP method is that it estimates 4 use and non-use values, while the RP estimates the use value of a product or service. The use value of water for residential, industrial, and agricultural customers is obvious, while its non-use value stems from its physical and cultural characteristics.

The most commonly used method for WTP estimation is the CVM, which is determined from surveys aimed at users of a good or service (water for irrigation in this case). This work relies on an indirect method for WTP estimation.

2. Materials and methods

This study applies a probabilistic optimization model to estimate farmer's WTP. Maximization of farmer's revenue from crop production is the objective function of the optimization model when there are shortages in water supply.

The goal of farmers is to maximize their income at any level of probabilistic shortage when there is water rationing for irrigation. The economic incentives for water conservation involve water pricing and rationing. Two types of decision variables are considered in the optimization model to evaluate farmers' response to incentives and derive their WTP. These decision variables include water conservation options that farmers implement to avoid shortage, such as optimizing the cropping pattern and deploying irrigation systems with high water efficiency. The first-type of variables is made of long term conservation options that must be implemented before water shortages. The second type of variables includes short-term conservation options treated as probabilistic shortage levels. The farmers responses to water prices, water rationing, and conservation options to reduce water shortage are determined in this study.

A second optimization model is herein considered that does not consider rationing policy. The results of the two optimization models, the first with water rationing and the second without it, are implemented to estimate the farmers' WTP by the difference between the values of their objective functions. The uncertainty in model parameters (such as costs, benefits,...) and its influence on farmers' WTP is addressed with Monte-Carlo simulation that generates the means and variances of uncertain model parameters.

This work's probabilistic optimization model is described by Eqs. (1)–(7) presented below. Water price is part of the model and it varies with each shortage level. In fact, a hypothetical currency price in the range of 0 through 0.2 is considered. This price range is applied to water supply costs. At low water prices there is no reduction in water consumption, because farmers' revenue is negligibly dependent on water price. As the water price increases so does the crop production cost, in which case short-term conservation options are applied. More efficient irrigation systems and changes in the cropping pattern are considered as long and short term conservation options, respectively, in this work.

Eq. (1) denotes the objective function of the optimization model that maximizes revenue from crop production under different shortage levels. The decision variables in the objective function are the area devoted to a crop and the amount of water used.

$$MaxZ = \sum_{k=1}^{nk} f_k \left[\sum_{i=1}^{ni} \sum_{j=1}^{nj} A_{ijk} (B_i Y_{ik} - PC_i) - P_{Q_k} Q_k \right] - \sum_{j=1}^{nj} C_j SA_j \quad (1)$$

in which Z = expected value of farmer's total annual revenue; f_k = probability of shortage event k; A_{ijk} = area of crop i with irrigation system j under shortage event k; B_i = price for one unit of crop i; Y_{ik} = yield of crop i under shortage event k; P_{Qk} = price of one unit water under shortage event k; PC_i = annual cost of production inputs for crop i (excluding water charges and land lease); Q_k = amount of water use under shortage event k; C_j = annual cost of irrigation system j, and SA_j = total area under irrigation system

Table 1
Characteristic of irrigation systems.

Irrigation system (j)	units	1	2	3	4
Annual cost (C_j)	Currency	0 (0)	30 (3)	80 (8)	150 (15)
Efficiency (E_j)	–	0.6 (0.03)	0.7 (0.035)	0.8 (0.04)	0.9 (0.045)

Numbers outside (inside) the parentheses represent the mean (standard deviation) used in Monte Carlo simulation.

j; ni = number of crops and nj = number of irrigation systems and nk = number of shortage events.

Eq. (2) states that the sum of area under cultivation under each shortage level cannot exceed the area available for cultivation under shortage event k.

$$\sum_{i=1}^{ni}\sum_{j=1}^{nj}A_{ijk}\le A_{\max}\qquad \text{for all k (2)}$$

in which $Amax$ = maximum crop area.

Eq. (3) describes the amount of water use under shortage level k. Eq. (3) expresses the reduction in water use by increasing efficiency (E_j), changing the cropping pattern, and decreasing the applied water.

$$Q_k=\sum_{i=1}^{ni}\sum_{j=1}^{nj}\frac{A_{ijk}IR_{ik}}{E_j}\qquad \text{for all k (3)}$$

in which IR_{ik} = net irrigation depth of Crop i under shortage event k; E_j = efficiency of irrigation system j.

Eq. (4) represents the yield function (crop production is a function of the irrigation depth).

$$Y_{ik}=Y_i^{'}[1\text{-}Ky_i[1\text{-}\frac{IR_{ik}}{IRD_{ik}}]]\qquad \text{for all i, (4)}$$

in which Y'_i = maximum yield of area with crop i; Ky_i = crop yield coefficient, and IRD_{ik} = net irrigation requirement for crop i under shortage event k to achieve maximum crop yield.

Eq. (5) limits the available cultivation areas with irrigation system j (SA_j) under shortage event k (the area under irrigation system j is constant during shortage events and it equals 10 ha). Four irrigation systems are considered, namely furrow, surge, sprinkler and drip irrigation, each with its specific water efficiency. The furrow irrigation system is a type of surface irrigation that works well for row crops and tree crops. This irrigation system is one of oldest methods. It is cheap and low-tech making it attractive in the developing world. Surge irrigation is a type of furrow irrigation in which water is pulsed on and off at given intervals. This wetting and drying of soil can help seal the soil and encourage better water flow across the entire field instead of losing significant amounts of water to the areas of the field where the water is first applied. Sprinkler and drip irrigation are pressurized irrigation systems that can improve water efficiency and contribute substantially to food production. Sprinkler irrigation consists of applying water to the soil surface using mechanical and hydraulic devices that simulate natural rainfall. Drip irrigation systems are applied close to plants' roots so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation which involves wetting the entire soil profile. With drip irrigation water application is more frequent than with other methods and this achieves very favorable high moisture level in the soil in which plants can flourish. The most important characteristic of these four irrigation systems is their water-application efficiencies. The efficiency and annual cost of each system are listed in Table 1.

$$SA_j=\sum_{i=1}^{ni}\sum_{k=1}^{nk}A_{ijk}\qquad \text{for all j (5)}$$

Eq. (6) defines the availability of water under shortage event k:

$$0\le Q_k\le r_k\qquad \text{for all k (6)}$$

in which, r_k = the amount of available water under shortage event k.

Eq. (7) states that the net irrigation depth (IR_{ik}) does not exceed the crop irrigation requirement (IRD_{ik}) and its minimum equals zero:

$$0\le IR_{ik}\le IRD_{ik}\qquad \text{for all i,k (7)}$$

Four modeling scenarios are considered for estimating the WTP and deriving the water-demand curves. The scenarios are: (1) a single farmer without water rationing, (2) groups of farmers without water rationing, (3) single farmer with rationing, and (4) rationing for groups of farmers.

2.1. *1st scenario: formulation for a single farmer without rationing*

The first scenario evaluates the effect of water prices on water consumption of an individual farmer. For this case nk is 1, because there is no rationing. Thus, Eq. (6) is omitted. The optimization model (1)–(7) is solved for different water prices. Increasing water price reduces water use because farmers apply conservation options in this instance. Conservation options are chosen based on their cost-effectiveness.

2.2. *2nd scenario: formulation for a group of farmers, without rationing*

Initial costs of cultivation and the yields of crops vary among farms. The two most important factors of inter-farm variation of cultivation practices are, however, the adopted irrigation systems and the water-use patterns. These factors affect the water consumption and can decrease or increase the cost of conservation options. One group of farmers without rationing is considered to account for inter-farm variation of cultivation practices. The Monte

Table 2
Water-shortage probability distributions.

Probabilistic distribution												
Shortage event	Shortage percent	A	B	C	D	E	F	G	H	I	J	K
I	0	1	0	0	0	0.5	0.67	0.75	0.8	0.6	0.40	0.60
II	10	0	1	0	0	0	0.00	0.00	0.0	0.0	0.00	0.10
III	20	0	0	1	0	0.5	0.00	0.00	0.0	0.0	0.00	0.10
IV	30	0	0	0	1	0	0.33	0.00	0.0	0.0	0.00	0.10
V	40	0	0	0	0	0	0.00	0.25	0.0	0.0	0.00	0.05
VI	50	0	0	0	0	0	0.00	0.00	0.2	0.4	0.60	0.05
Shortage mean		0	0.1	0.2	0.3	0.1	0.10	0.10	0.1	0.20	0.30	0.10

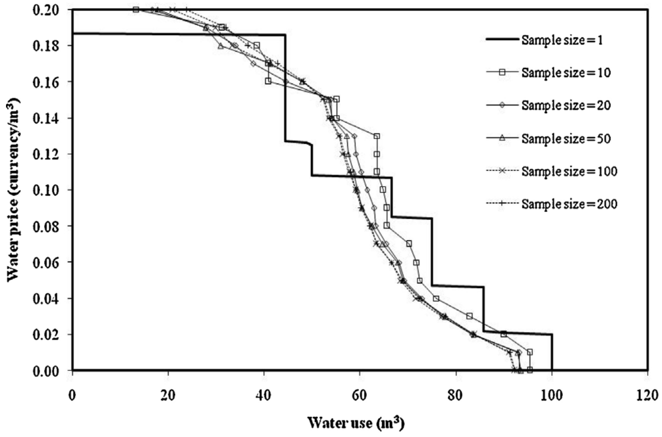

Fig. 1. Water-use curves without rationing with deterministic (sample size = 1) and probabilistic parameters (size of sample = 200).

Carlo simulation method is applied for evaluating the variation in model parameters in a group of farmers assuming that the model parameters are normally distributed with specified mean and standard deviation.

2.3. 3rd scenario: formulation for a single farmer with rationing

Shortage probability distributions for water and one farmer are considered in this scenario. The shortage probability distributions are written in Table 2, which lists 11 shortage probability distributions (A through K) and 6 shortage events (I through VI).

2.4. 4th scenario: formulation for a group of farmers with rationing

This scenario applies the probability distributions of water shortage of Scenario 3 to a group of farmers, and takes into account the inter-farm variation of cultivation practices by means of Monte Carlo simulation (see Scenario 2).

2.5. Case study

The case study involves two crops planted in distinct areas of each farm. The data pertinent to these two crops are maximum cultivable area (10 ha), market price of crop, and annual cost of production. Furthermore, four irrigation systems with different efficiencies are considered in this paper's model. These four irrigation systems are decision variables that must be determined by farmers before shortage events. The mathematical model calculates farmer(s) WTP to investigate the effects of shortage and unit price of water considering several conservation options which are divided into short-term and long-term options. Data input to the model are listed in Tables 1, 2, and 3.

3. Results and discussion

Single farmer's and group of farmers' water-use were derived for Scenarios 1 through 3. Fig. 1 presents the water-use curves without rationing calculated with the Monte Carlo method. It is seen in Fig. 1 that increasing the water price reduces water use for one farmer (sample size 1) and for groups of farmers (sample size larger than 1). Notice that the water-use curves become nearly identical for 50 or more farmers. The water-use curves can be used to estimate the price elasticity of irrigation water. The water-use curves for single and groups of farmers show that at low water prices the effect of water use on farmers' income is negligible and, therefore, water use is not responsive to water price. In other words, the price elasticity of irrigation water is low. Increasing water price makes the water use more elastic because irrigated agriculture becomes expensive, and, as the water price becomes very high the water use becomes nil.

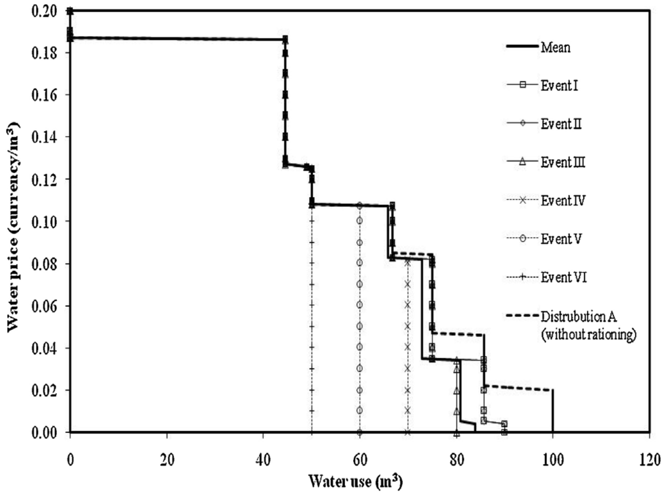

Fig. 2. Water-use curves for different levels of shortage prescribed by distribution K (one farmer).

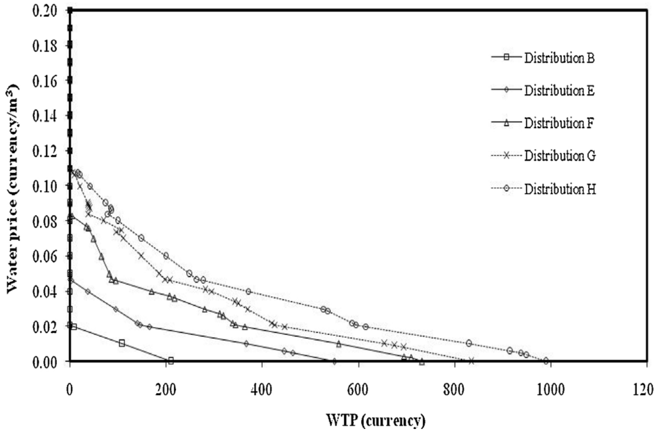

Fig. 3. Farmer's WTP for irrigation water corresponding to several probability distributions of water shortage with the same mean (one farmer).

The effects of water rationing on one farmer corresponding to Scenario 2 were explored with water-shortage probability distribution K, which features a 60% probability of no shortage (Event I), and with probabilities of water shortages equal to 10, 20, 30, 40, and 50% named events II, III, IV, V, and VI, respectively (see Table 2). The results are depicted in Fig. 2, which shows that for low prices rationing induces the adoption of conservation options, which are cost effective to implement at low prices. In fact, conservation is not implemented when there is no rationing and water price is low. In contrast, as the water price increases conservation options become cost-effective and they are implemented even without rationing. The results of Fig. 2 show that a farmer's WTP for water to avoid shortages decreases as the water price increases.

Fig. 3 depicts the calculated WTP for irrigation water by one farmer corresponding to several shortage probability distributions with the same mean. The WTP for a single farmer was calculated based on Scenarios 1 and 2 as the difference between the benefits accruing from crop production with and without water rationing (i.e., the difference between the values of the objective functions of Scenarios 1 and 2). Fig. 3 indicates that the farmer's WTP for

Table 3
Characteristics of crops under cultivation.

Characteristics	units	Crop 1	Crop 2
Net irrigation requirement (*IRD*)	mm/day	0.6 (0)	0.4 (0)
Maximum yield of Crop (*Y'*)	Ton/hectare	9 (0.9)	3.5 (0.35)
yield coefficient of Crop (*ky*)	–	1 (0.1)	0.7 (0.07)
Price of Crop (*B*)	Currency	200 (20)	400 (40)
Annual cost of production inputs of Crop (*PC*)	Currency	300 (30)	150 (15)

Numbers outside (inside) the parentheses represent the mean (standard deviation) used in Monte Carlo simulation.

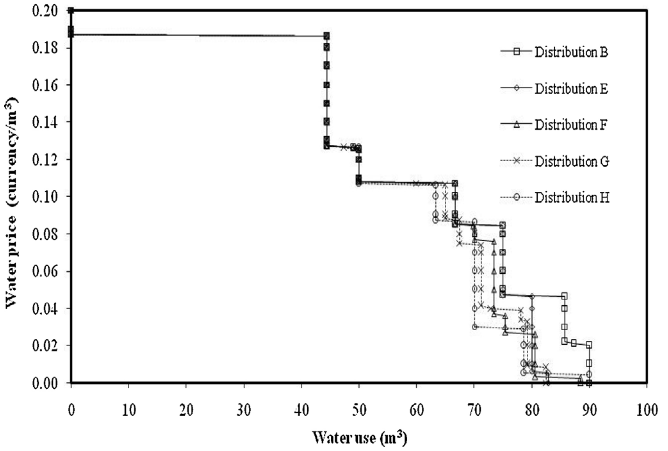

Fig. 4. Water-use curves for probability distributions of water shortage with the same mean (one farmer).

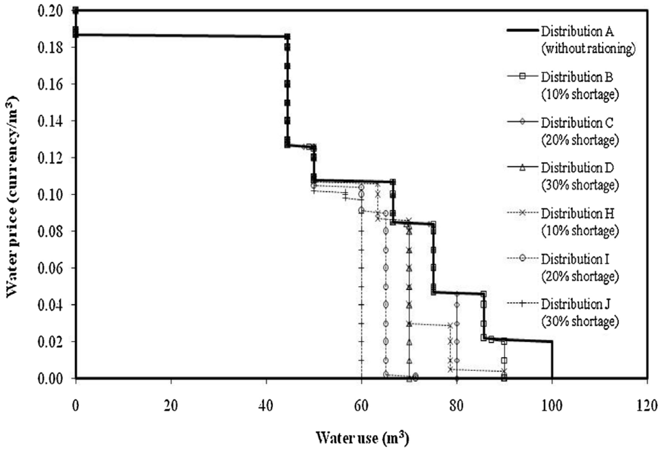

Fig. 6. Water-use curves for probability distributions of water shortage with different means (one farmer).

water is larger for distributions whose shortage has a wide range (probability distribution H) than for those whose shortage falls in a narrow range (such as probability distribution B). Fig. 4 graphs the water-use curves for one farmer corresponding to several shortage probabilities with the same mean based on Scenario 2. It is evident from Fig. 4 that the water use decreases with increasing price for all probability distributions of water shortage. The narrow-ranged shortage distribution B exhibits the larger water use for a given water price compared to the other, broader-ranged distribution functions.

Fig. 5 depicts the results corresponding to Scenario 2 for a farmer's WTP corresponding to two groups of shortage probability distributions. Probability distributions in the first group (B–D) have narrow ranges of water shortage. The second-group probability distributions (H, I, J) have broad ranges of water shortage. The graphs in Fig. 5 indicate that a farmer's WTP is higher for broad-ranged probability distributions H–J than for the narrow-ranged probability distributions B–D.

Fig. 6 graphs the water-use curves for one farmer corresponding to several shortage probabilities with different means. It is evident from Fig. 6 that the water use decreases with increasing price for all probability distributions of water shortage. The narrow-ranged shortage distributions B–D exhibit larger water use for a give water price than the broad-ranged shortage distributions H–J, respectively. Also, for narrow-ranged distributions (B–D) and broad-ranged distributions (H–J) the water use decreases for a given price of water as the percentage of water shortage increases.

Fig. 7 shows the calculated the water-use curves corresponding to Scenario 4 for a group of farmers using probability distribution E for shortage of irrigation water (see Table 2) and Monte Carlo simulation. It is seen is Fig. 7 that the water-use decreases for increasing

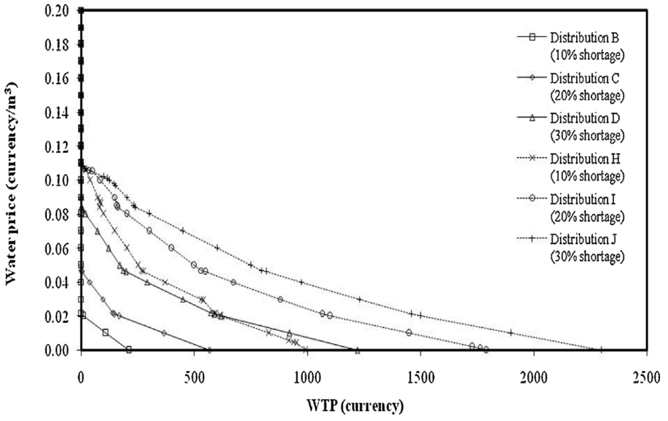

Fig. 5. Farmer's WTP for irrigation water for probability distributions of water shortage with different means (one farmer).

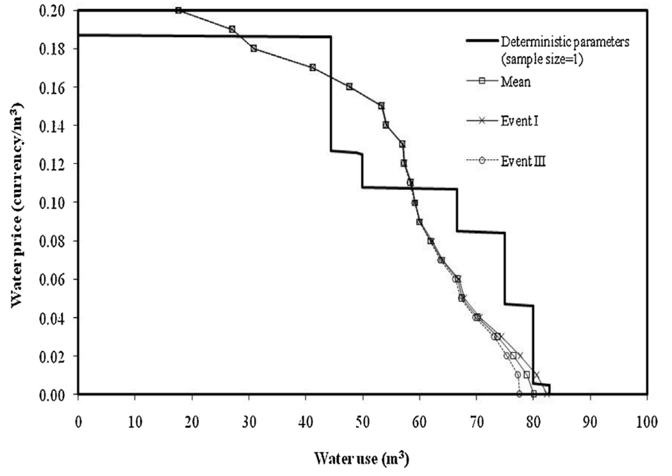

Fig. 7. Water-use curves for distribution E with probabilistic parameters (sample size = 1 is one farmer without rationing; other graphs represent groups of farmers).

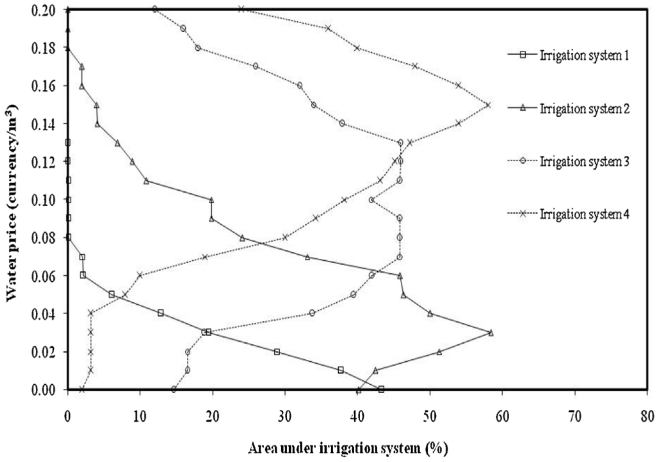

Fig. 8. Area under irrigation (in hectares) for distribution E. The efficiency of an irrigation system increases with its designation number.

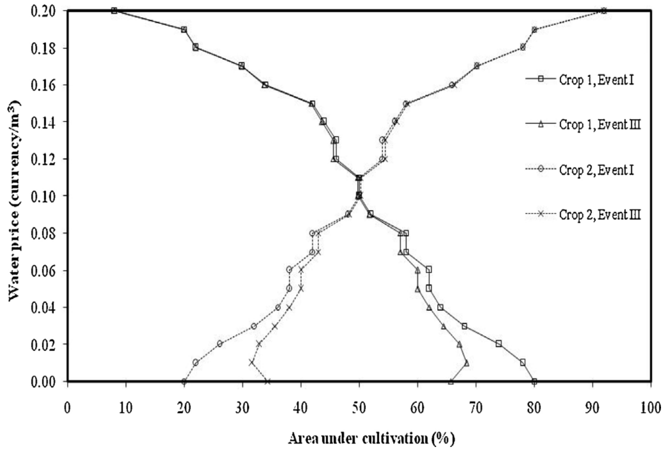

Fig. 9. Average area under cultivation of crops 1 and 2 for different shortage events in distribution E. Crop 1 has a larger water requirement than crop 2.

water price, and it does so in very similar fashion for the mean shortage of distribution E and its events I and III (see Table 2 for a description of events I and III and the mean of distribution E), except at very low price of water, when the water use increases with decreasing water shortage.

Fig. 8 depicts the average area under irrigation corresponding to Scenario 4 calculated with probability distribution E. Fig. 8 shows that as the water price increases farmers deploy more efficient irrigation systems (such as system 4 in Fig. 8) to decrease water use. As the water price becomes very high, because farmers have to pay more for water use the cultivation is not cost-effective so they restrict cultivation and it results in area under irrigation systems reduction. In this case there is an economic incentive for farmers to decrease water use.

Fig. 9 graphs the area under cultivation crops 1 and 2 are under different water-shortage events. The area cultivated with crops 1 and 2 decrease with increasing water price, but the decrease is more pronounced for crop 1, which has the higher water requirement of the two crops. The crop pattern shifts with increasing water price.

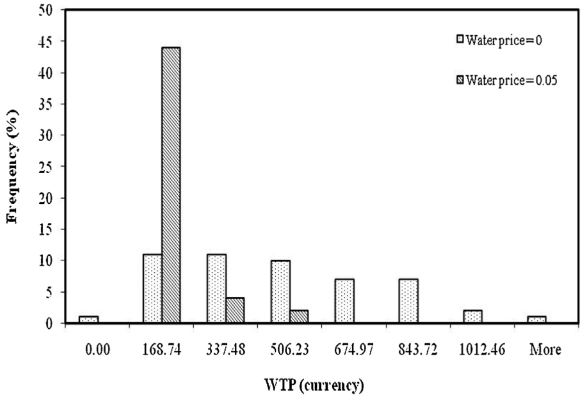

Fig. 10. Histogram of Monte Carlo simulation results for two water prices.

Monte Carlo simulation was implemented considering model parameters' uncertainty to assess the variation of farmers' WTP and avoid water shortage. The results are presented in Fig. 10, which shows the WTPs corresponding to water prices equal 0 and 0.5 and probability distributions A–E. It is seen in Fig. 10 that the WTP of farmers is variable for a water price equal to 1, while for water price equal to 0.5. 45% of the farmers exhibited a WTP equal to 0.168 currency units per cubic meter.

4. Concluding remarks

This paper presented a probabilistic optimization model estimate farmers WTP for irrigation water under various water-shortage scenarios. A nonlinear model was first formulated to model water use and subsequently this model was applied to estimate a single farmer's and a group of farmers' WTP corresponding to various water prices. The probabilistic optimization of this study calculates water-use curves.

Results showed that without water rationing increasing water price reduces water use. In fact, farmers want to reduce water use to cut the cost of water supply. With water rationing, farmers' WTP and water use are affected by the price of water, the distribution of water shortage, the type of irrigation system, and the crop type.

This paper has demonstrated how water pricing in the agricultural sector based on farmers' WTP can be derived and for evaluating agricultural management strategies that involve water allocation policies, conservation options, and irrigation practices.

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