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The Impact of Pricing Policies on Irrigation Water for Agro-Food Farms in Ecuador

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Abstract: The institutional reform of the State established in Ecuador during the last decade has aimed at regaining control of specific sectors such as the consumptive use of water. Since 2014, regulation, consumption, and use of water, especially in agriculture, have been analyzed through policies and fiscal instruments. This research presents itself in the context of the simulation of scenarios using positive mathematical programming, to analyze the economic impact of pricing policies on agro-food farms. Policies of fixed costs, water blocks, and volumetric prices are evaluated. The results show that the existing fixed costs do not reduce water consumption. In contrast, the scenarios of water blocks and volumetric prices impact on the behavior of farmers. The tendency of water consumption to the application of volumetric prices demonstrates that banana farms have a greater tolerance to the increase of water costs. On the other hand, the response to an increase in cost in the case of cacao, sugar cane, and rice depends on the productivity of farmers. The negative effects can lead to the abandonment of agriculture. Thus, volumetric policies are more efficient in reducing water consumption as well as in recovering the costs of the irrigation system.

Keywords: agricultural policy; economic impact; irrigated agriculture; water consumption; PMP

1. Introduction

Agricultural irrigation consumes more than two-thirds of the water available at the aggregate level [1]. For this reason, it is in this sector that attention is permanently set to reduce both waste and water consumption. In addition, the low price of water is often found to be the cause of lack of proper attention from consumers regarding the improvement and modernization of the irrigation systems. Therefore, it reduces the motivation to create more efficient management and to conserve water [2]. Given the importance of irrigation to ensure food production, agricultural water management has incorporated economic instruments to reduce the consumption of irrigation water [3]. In this sense, water pricing policies are proposed to generate incentives for users to make a more efficient use of irrigation water [4]. However, the unwillingness to pay for water often results in the total avoidance of payment and the non-technical application of irrigation [5]. Therefore, the formulation of price policies requires a continuous assessment of the economic impact of the application of the stated policy on the behavior of farmers [6].

In many developing countries, regulation of consumption and use of water resources is a priority strategy in the anticipation of future water availability problems [7–9]. These efforts have been directed towards the modernization of irrigation systems [10], changes to crops with lower water consumption [11], the reduction of water waste [12], or the efficient allocation of water through markets [13]. Consequently, an instrument widely used to influence farmers' behavior is the application of water pricing policies [14]. Institutions have indeed analyzed the effects of three instruments in particular, i.e. fixed costs, volumetric prices, and water blocks, which are the most applicable means to reduce demand when water prices influence consumption [15–17]. In this regard, Kanakoudis and Tsitsifli [18–20] concluded that the application of tariffs helps to reduce water losses, as well as to reduce amounts not collected by consumption, by approximately 8%.

In the reported cases, it is observed that the loss of efficiency ranges from 10% to 35% when it comes to residential water lines [21]. In this sector, programs have been proposed to optimize the water supply systems. According to Kanakoudis [21], the application of tariffs triggers the reduction of operation costs and optimizes water consumption. These measures have contributed to the reduction of 21% of total consumption in the United States of America [21]. In Athens, Greece, restrictive measures have reduced waste levels by up to 31%. Likewise, the study of price application in the city of Kozani, Greece by Kanakoudis and Gonelas [22] demonstrates that a price increase influences water demand. In fact, the consumers' response to the marginal price entails a decrease in consumption due to the increased water demand [23]. However, in the face of an inelastic trend in the water consumption curve, a partial reduction can be achieved despite the objectives of water saving [24].

In countries with a deficient institutional presence, a price structure on irrigation water requires an analysis of the implementation capacity in certain segments of farmers in regards to the benefits involved [5]. In some cases, agricultural water prices have been applied to discourage waste [25]. Furthermore, the relationship between water costs and the reduction in consumption becomes complicated because of the irrigators' attitude toward this stated reduction [26]. Recent studies show, for example in the case of China, how the policy affects the demand for irrigation water under volumetric costs [27]. In fact, the work of Huang et al. [28] and Zhao et al. [29] demonstrates that farmers experienced a reduction in profits when water pricing was applied, leading to a change in land use. Furthermore, Galioto et al. [30] suggested, with the use of asymmetric information, the effective implementation of discriminatory water cost strategies similar to real prices, but obtaining changes in water consumption. On the other hand, in Iran, Nikouei and Ward [31] determined an inelastic demand curve for the application of additional costs to water consumption, with important impacts on the modernization of irrigation systems on the way to their improved efficiency. Liu et al. [32] conclude that water blocks can be considered an option towards water conservation in developing countries, but that, in order to be applicable, they depend on the design of the scales' levels and structure of the instrument's tariffs. An example of this is the regulation of pumped groundwater where metering of consumption is easier. However, Lika et al. [33] noted that water blocks, despite causing a reduction in water consumption, have a high impact on the financial gains of farmers. On the other hand, fixed costs are the most widespread price structure to recover partial costs of maintenance and operation [34]. In fact, Kanakoudis [35] explains how, through the assessment of tariffs on residential water consumption in Greece, fixed rates do not represent the opportunity costs with which consumer behavior is affected. These costs are not fair to consumers and they serve to cover only part of the operational costs of the system. Thus, Berbel and Gómez-Limón [36] and Woedem [37] conclude that the implementation of pricing policies can lead to a serious reduction of agricultural labor as well as a reduction in the proceeds of farmers, as a large amount of these go to the State.

In Ecuador, during the past decade an institutional reform restored a centralized management system [38,39]. This resulted in a growing interest in reducing water consumption in agriculture, as this helps in its conservation, as well as benefiting the wellbeing of other consumers [40]. Institutions such as the Water Regulation and Control Agency (WRCA) and the Public Water Company (PWC) dictate the regulatory framework for water resources [41]. Since 2014, these water authorities have worked to improve their institutionalism, regulation, and inventory [42]. This policy is guided toward the application of rates to the use of irrigation water aiming at recovering investment costs and reducing water consumption in agriculture [43]. In fact, current water policy has been formulated following the principles of governance and Integral Water Resources Management (IWRM) [44]. In addition, three distinct points can be identified in the current legislation: (1) prohibition of the establishment of a water market; (2) recognition of community organizations as managers of irrigation systems; and (3) access to water as a universal human right [45].

Ecuador now demonstrates progress in the development of its irrigation infrastructure as currently some institutions are working alongside farmers to recognize the economic value of water consumption [46]. Prior to the reform, the State had lost its role in water resource management [47]. However, recent public investment has increased the irrigation capacities of coastal agro-food systems, as well as assisted in the reduction in the negative impacts of climate change, focusing its attention on the conservation of water resources [48]. In addition, in most public and private irrigation systems, fixed rates are applied to cover operation and management (O&M) costs, without encouraging water use reduction [49]. Likewise, heterogeneous farmers determine unequal competition for "common" resources where regulation is weak [50].

In this regard, the present study evaluates three water pricing policies and analyzes the most efficient respective instrument in the reduction of irrigation water use, while paying attention to the profitability of farmers. For that, the case study of the Manuel de Jesus Calle irrigation system (MJCS) was performed. The current paper analyzes the behavior of farmers in the face of rising irrigation water costs. To reach this objective, a baseline scenario was evaluated for banana, cacao, sugar cane, and rice farms, all subject to three pricing policies: fixed, volumetric, and water block rates. One problem discovered in this research is the need to regulate water consumption through policy instruments that increase the price of irrigation water in crop sectors, which are of great importance to Ecuador's economy and food security. Therefore, through the Agro-Food System Analysis Model (AFSAM), the simulation of the effects of a water pricing policy characterized by monocultures is proposed. The hypothesis suggests that the current volumetric price is the most applicable instrument with the ability to reduce the use of irrigation water [16,51].

2. Case Study

Ecuador's per-capita water availability is equivalent to 22,000 m^3/year [52]. Agriculture consumes approximately 80% of the total available water [53]. Therefore, low irrigation technology (95% of the area under flood irrigation) on farms is offset by the use of a large amount of wage labor [54,55]. In addition, an estimated 1.2 million hectares are irrigated by public or private systems [56], equivalent to 34% of total arable land [57].

This case study focuses on the Manuel de Jesus Calle (MJCS) irrigation system located in La Troncal canton, in the coastal region of Ecuador. MJCS is the largest public irrigation system in the country [57], the main channel of which is more than 50 years old. It irrigates a land area of 16,000 hectares of sugar cane crops and about 14,000 hectares of rice, banana, and cacao. Since 2000, the system has been administered by an Irrigation System Users Board (ISUB) that comprises over 1000 landowners of small, medium-sized, and large properties [58].

Land in the MJCS is divided into 30% small-sized farms (1–50 ha), 20% medium-sized farms (50–100 ha), and 50% large farms (over 100 hectares) [49,59]. MCJS's cultivation area is composed of monocultures, namely: 6% cacao, 52% sugar cane, 38% banana and 4% rice. Approximately 90% of labor in the sector is salaried, fixed, or temporary, and 10% is family labor [60]. The use of technical irrigation depends highly on the investment capacity of each farmer; banana farms are characterized by high incomes and high demand for seasonal labor. In addition, the profitability of sugar cane and rice depends greatly on market demand. Moreover, many farms have replaced banana with cacao considering the high price of the latter in international markets [61].

Baseline Scenario

The cost of irrigation water at MJCS is 22 USD/ha per year. The system is operated manually, and the valves are opened and closed daily. Seventy percent of the main channel is concrete [45], and due to deterioration, all secondary lines provide poor distribution of water. The farms analyzed have the infrastructure already installed for each type of irrigation system. Approximately 95% of the irrigation system of MJCS works through gravity. In the remaining 5% a technical irrigation system is being used [60]. Irrigation shifts employ 100 L/s/ha and are delivered every 14 days, with a duration of 3 h/ha, except for rice and banana crops, the periodicity of which is seven days per farm.

In Figure 1, highlighted in green is the area corresponding to the case study of the Manuel de J. Calle System. Furthermore, the main irrigation canal, which water supply comes from the Bulubulu and Cañar rivers, is shown with a red line and does not have irrigation reservoirs [60]. The expected MJCS flow is 14 m^3/s. However, the main channel flow decreases during the summer season to 7 m^3/s. During this time, irrigation shifts are limited to once per month for each farm [47].

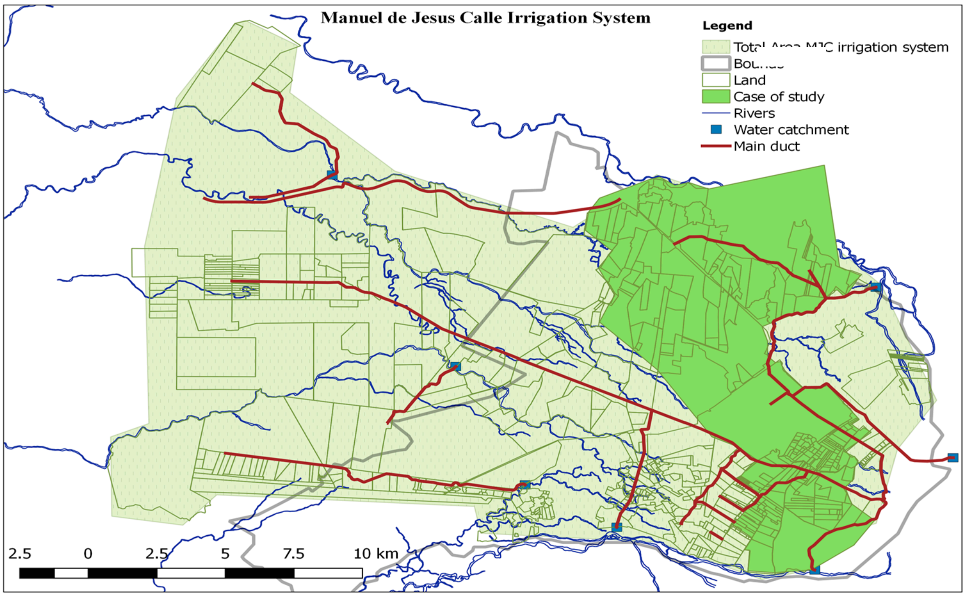

Figure 1. Manuel de Jesus Calle System Study Area (Source: ISUB; Register, 2014).

In Ecuador, monocultures such as rice, sugar cane, and bananas are typical of the coastal region. The yield of these products is of great economic importance and contributes to the food security of the population [62]. Thus, to guarantee production farmers receive benefits from the State such as minimum prices and agricultural subsidies. The production of rice and sugar cane supplies most of the national demand, while bananas and cacao are exported almost entirely to international markets.

The dry season (summer) begins in June and lasts until December, while the rainy season (winter) begins in January and lasts until May. Annual precipitation reaches its highest peak at 1300 mm, while in the dry season it falls to 57 mm [63,64]. In winter, irrigation is optional for many crops, so it is aimed at supplying the need of rice fields. However, during the dry season irrigation is necessary to cover the requirements of all crops. The lack of rainfall leads to reduced productivity and even financial losses; however, these are often subsidized by the State [65].

Figure 2 presents the water requirements for each water demand occurring between the months of April and August. It is important to note that there are no seasonal crops in MJCS, apart from rice, the phenotypic characteristics of which establish a cycle between sowing and harvest of approximately five and a half months, thus allowing two crops per year.

Data for water requirements were calculated using the CROPWAT v8.0 software designed by the Food and Agriculture Organization of the United Nations (FAO). Climatic variables were obtained from the "San Carlos-INGEN" weather station, using CLIMWAT 2.0 software, and were compared with the National Institute of Meteorology and Hydrology (NIMH) database. The Kc and the crop evapotranspiration (*Eto*) obtained by CROPWAT were used to calculate the water requirements; the results were compared with the information from the National Institute of Agricultural Research (*NIAR*) in 2014. The soil was classified as fine-grained.

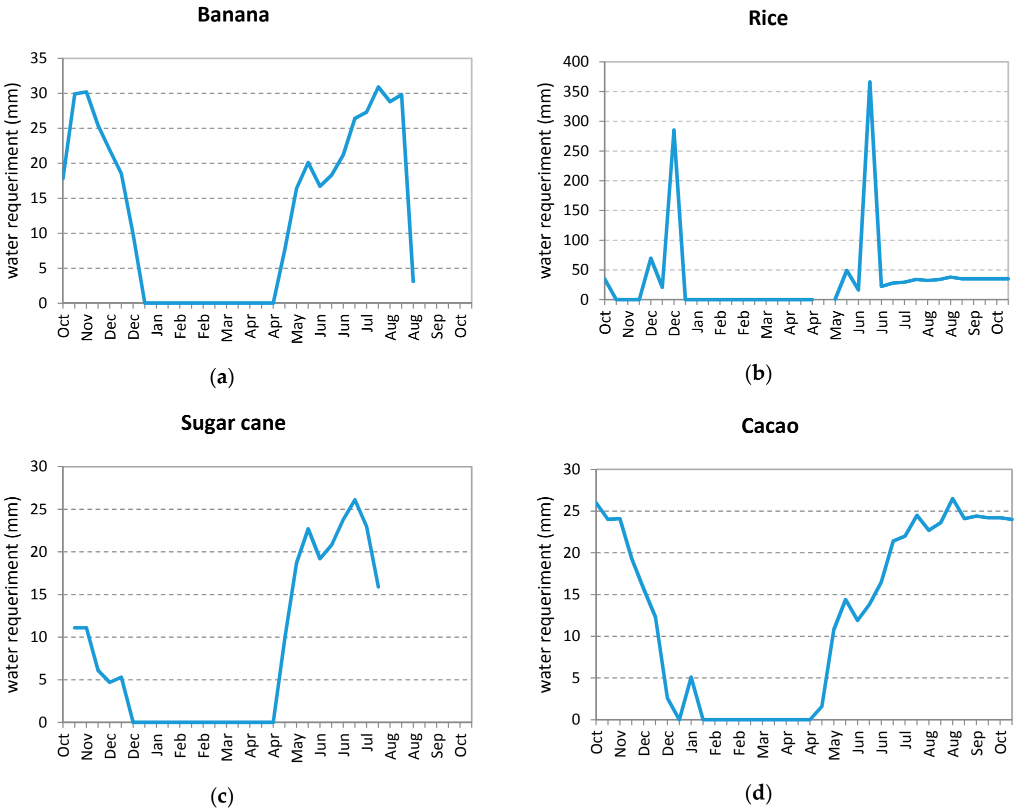

Figure 2. Requirements of irrigation water of crops (mm/month), through CROPWAT calculation: (**a**) bananas per year; (**b**) rice, two cycles per year; (**c**) sugar cane per year; and (**d**) cacao per year.

3. Materials and Methods

The objective of this paper is to simulate the application of pricing policies and to analyze their impact on the proceeds of farmers in the largest public irrigation system in Ecuador, Manuel de Jesus Calle (MJCS). These farms are monocultures of banana, cacao, sugar cane, and rice. Because of this, this research observes the variation of farmers' incomes and the change in production due to the increase in water prices. To reach this objective, the study was based on data gathered through surveys performed at MJCS. The survey gathered information on income, costs, and agricultural production resources using open and closed questions based on Sumpsi et al. (1998) [66] (Table 1). During 2014, in total 25 surveys were made to farmers, in addition to interviews held with representatives of the Ministry of Agriculture, MJCS, and the Secretariat for Water. Furthermore, additional data were obtained from the ISUB register (2014) [67]. The sample was selected to represent the production model of MJCS farms.

Table 1. Net annual profit per farm and irrigation system, compiled through a survey carried out in 2014.

Crop	Irrigation	Income (USD/ha/Year)	Costs (USD/ha/Year)	Irrigation Cost (USD/ha/Year)	Net Profit (USD/ha/Year)
Banana	Gravity	10,125.78	5682.00	260.78	4183.00
	Sprinkler	10,658.71	5544.00	274.50	4840.21
	Rainfed	6928.16	5700.00	166.00	1062.16
Cacao	Gravity	2204.98	1634.00	226.51	344.48
	Sprinkler	2477.51	1499.00	254.50	724.01
	Rainfed	1734.26	1560.00	134.00	40.26
Rice	Gravity	3964.56	2536.00	254.35	1174.22
	Rainfed	2962.53	2500.00	140.00	322.53
Sugar cane	Gravity	1989.68	1100.00	148.00	741.68
	Rainfed	1447.04	1257.00	101.96	88.08

Once the database was classified and filtered according to the type of farm, the base scenario was modeled by mathematical programming. The Agro-Food System Analysis Model (AFSAM) was calibrated with the Positive Mathematical Programming (PMP) [68], modeled with the General Algebraic Modeling System (GAMS), and solved with the CONOPT3 Numeric Solver.

3.1. The AFSAM

AFSAM simulates scenarios in which price instruments are applied in order to promote the reduction of irrigation water consumption [69]. AFSAM maximizes the income of farmers subject to the restriction of existing resources to produce bananas, sugar cane, rice, and cacao. The AFSAM baseline scenario has a linear and a non-linear development that correspond to the PMP method [68,70] in order to obtain the dual values as calibration parameters, according to the surface observed in the base year [71]. This baseline model represents the actual scenario based on the information gathered in the field.

AFSAM considers a set of variables comprised by crops (c), irrigation technology (i), and states of nature (t), which refers to the stages that occur during the production cycle such as dry and rainy seasons. Equation (1) represents the objective function with which the income of each farm is maximized. The income expressed in dollars per year comes from the product between the yield ($Yield_{c,i}$) and the price ($Price_c$), plus all state subsidies in dollars per year ($Subs$). The cost function is determined by the total cost of production in USD per year ($CostV_{c,i}$) and irrigation costs in USD per year ($CostV_{c,i}$). The coefficient of risk aversion (ϕ) [72] was included into this model based on the work of Woedem [37], assuming a value close to $0 < \phi < 1$ [73], which represents uncertainty in a production cycle.

$$Maximise\ Z = \sum_c \sum_i [(Price_c * Yield_{c,i} + Subs - CostV_{c,i}) * X_{c,i} - Costirr_{c,i}] - \sigma\phi \quad (1)$$

Subject to:

$$\sum_i X_{c,i} \le LandA_c \quad (2)$$

$$\sum_i WaterR_{c,i,t} * X_{c,i} \le WaterA_{c,t} \quad (3)$$

$$\sum_i LaborR_{c,i} * X_{c,i} \le LaborA_c \quad (4)$$

$$X_{c,iri1} + X_{c,iri2} \le Landirr_c \quad (5)$$

$$X_{c,i} \le X^0_{c,i} * 1 + \varepsilon[\lambda] \quad (6)$$

$$x \ge 0$$

variables:

$X_{c,i}$ = Crop area under irrigation in hectares
$WaterR_{c,i,t}$ = Water requirement in m^3 per year
$LaborR_{c,i}$ = Work requirement in wages per production cycle
$iri1,\ iri2$ = Types of irrigation systems (gravity and sprinkling, respectively), and dry land for production without irrigation
$LandA_c$, $WaterA_{c,t}$ and $LaborA_c$ = Availability of resources on the land (water, and labor respectively)
$Landirr_c$ = Ground surface under irrigation
$X^0_{c,i}$ = Observable surface
ε = Disturbance factor
σ = Standard deviation of income. It is assumed that the attitude toward risks is analyzed through the mean and variance income framework

In the second part, the nonlinear function is solved through Equation (7), to obtain the dual values (PMP) and to gauge the cost function included in the objective function. The parameters $\alpha_{c,i}$ and $\beta_{c,i}$ are calculated from the marginal values of the linear model and $X'_{c,i}$ is the area under irrigation.

$$MaximiseZ = \sum_c \sum_i \left[\left[Price_c * Yield_{c,i} + Subs - (\alpha_{c,i} + 0.5 * \beta_{c,i} * X'_{c,i}) \right] * X'_{c,i} - Costirr_{c,i} \right] - \sigma\phi \quad (7)$$

3.2. Water Cost Scenarios

The AFSAM proposes an initial cost of irrigation water usage (t) in USD/m^3/s under initial water allocation (q) in m^3/s, until total water consumption (Q) is obtained. In addition, the irrigated area (s) is established in hectares. Subscript n was used to identify the change in each step.

The baseline scenario correctly reproduced the observed situations considering the implicit costs [62]. For the simulation, the three water policy instruments detailed in Table 2 were presented.

- The first proposal is the increase of a fixed price related to the value of t° USD/hectare. There, S° represents the irrigated crop by hectare. This first scenario involves an increase in the rate of irrigation per hectare. The optimization model analyzes five different stages, when $t^\circ = 22$ USD/ha.
- The second proposal simulates a volumetric pricing policy, where $t^\circ < t_n$, and an increase in water value USD/m^3 when q in the water demand (m^3) was observed, where $t^\circ = 0.003$ USD/m^3.
- The third proposal is a water block application. The value of t increases in each block (Q_n). Each block has a different price, where q_1 has the lowest cost and q_4 the highest. In q_1 the water cost is $t_1 = 0.0005$ USD/m^3; in the second water block, q_2, $t_2 = 0.001$ USD/m^3; in the third block, $t_3 = 0.01$ USD/m^3; and, in the fourth block, $t_4 = 0.1$ USD/m^3.

Table 2. Calculation of irrigation water usage according to type of water pricing policy project.

Model	Policy	Cost Irrigation Equation
Baseline		$S^\circ * t^\circ$
With Policy	Fixed Increase	$S^\circ * t_n$
	Volumetric	$q * t_n$
	Blocks	$Q_n * t_n$

The AFSAM allows changes in accordance with each policy type for each scenario. In this sense, the system assisted in gathering information on both the behavior of the farmer, as well as the variation of water demands.

$$Costirr_{c,i} = \left[\left(Qvol * X'_{c,i} \right) * t_n \right] \quad (8)$$

The volumetric scenario is represented in Equation (8), and is calculated through the product between $Qvol$, which is the flow rate consumed in m^3, with $X'_{c,i}$ and the price of water t_n USD/m^3. In this equation, the value of t_n varies in each simulated scenario. In the baseline scenario, $Costirr_{c,i}$, the cost of irrigation, is represented by $[(S_{c,i} * t_n)]$, where $S_{c,i}$ represents the irrigated area in hectares.

4. Results

4.1. Survey Results

The survey results produced during the fieldwork in 2014 are presented in this section. The questions posed had the intent of identifying the opinions of farmers regarding a hypothetical increase of the current water cost. The survey revealed that nearly 60% of farmers required more water. In addition, it was revealed that the main channel needed extensive repairs. Moreover, 52% of the farmers interviewed indicated that they consume groundwater through well drilling and pump extraction, which is an unauthorized practice. In this case, the cost of groundwater usage is equal to that of energy used during extraction. Thus, the cost of irrigation is increased due to the additional cost of energy. Figures 3 and 4 show the readiness of the farmers to pay for water (Figure 3), and their perception regarding the increase in cost (Figure 4). The x-axis of each figure indicates the difference of the hypothetical increase in dollars, depending on the scenario presented to each farmer. In this same axis, the answers are presented by increment value, disregarding the answers "do not know, do not answer".

The results in Figure 3 demonstrate the predisposition to pay for an increase in water costs. In this figure, the values on the x-axis represent an increase ranging from $1 to $7 from the current cost per hectare. However, for a theoretical increase of $5 a hypothetical "improvements in the irrigation system" condition was created. In this case, 55% of those interviewed demonstrated a greater disposition to pay the increase. Those who did not accept this increase commented that they did not have confidence in the ISUB administration and considered it to be a "weak institution". Farmers with low water availability showed a greater readiness to increase in payment than that of farmers with easier access to irrigation.

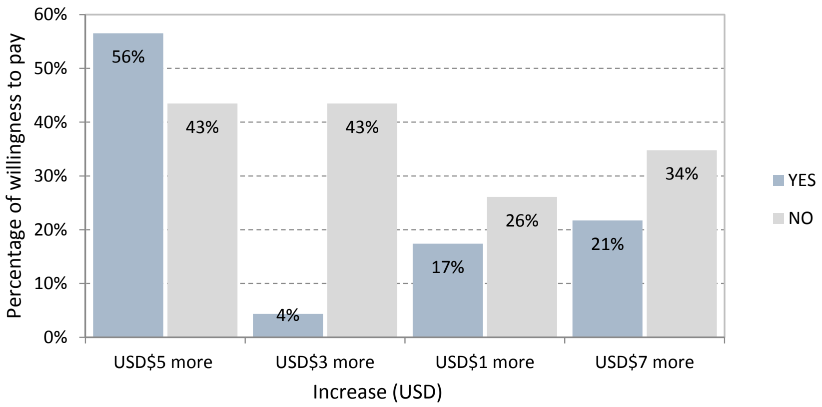

Figure 3. Results of the survey showing the willingness of farmers to pay increased irrigation costs.

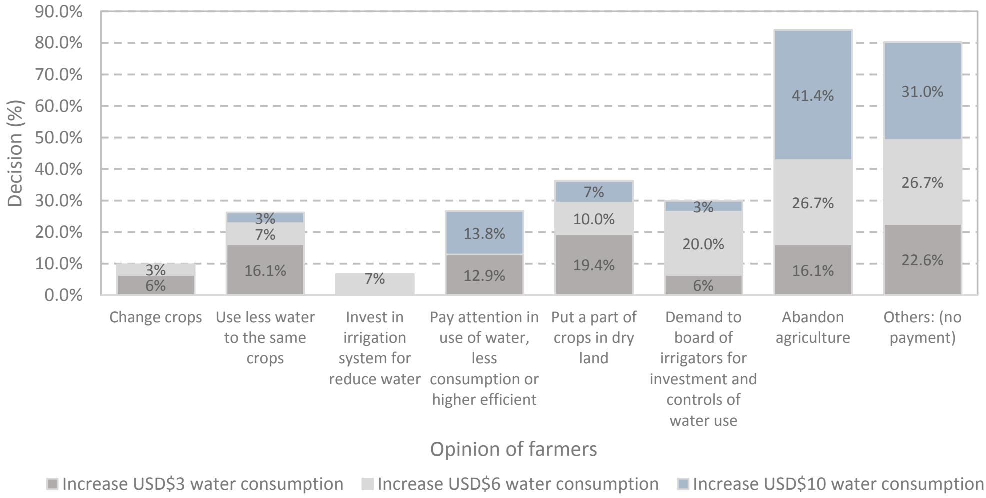

Figure 4. Farmers' attitude towards increases in the cost of irrigation water.

Regarding the second round of questions, the disposition of the farmers to pay an increase in the price was negative, even if the stated increase was only $1 per hectare.

Figure 4 shows the opinions of farmers, represented on axis x, when water takes values between $3 and $10 per hectare. The results indicated a higher percentage of three possibilities: (A) reduce water consumption; (B) abandon agriculture; and (C) other decisions (not pay the cost of a new water irrigation system, but continue to use the current irrigation system).

Furthermore, the survey demonstrated that some farmers considered the possibility of changing the type of crop to rainfed water systems to reduce the consumption of irrigation. These results are presented in relation to the scenarios proposed in AFSAM to evaluate the farmers' reaction to the proposed increases. In fact, the survey demonstrated the relation between the higher water price assumed in each simulated scenario, and the actual amount that farmers were willing to pay.

4.2. Economic Impacts

The AFSAM uses the information seen in Table 1 to maximize the objective function as well as the water requirement data for each crop (Figure 2) as part of the set resource constraints. First, by optimizing the objective function, the willingness of farmers regarding the initial production plan changed due to the increase in irrigation costs. In fact, it was noted that a water block policy reduced both farmers' profits and water consumption. Second, fixed charges did not influence a change in current water demand, thus farmers' incomes would experience a smaller impact. Third, a volumetric pricing policy reduced the demand for water for each crop and irrigation technique in proportion to the increased cost of irrigation water (Figures 5–7 and Figure 10).

Figure 5 displays the trend of the farmers' income curve for each proposed project in contrast to the baseline scenario. In this stated scenario, the total benefit of the farmers was $122,000 per year. In addition, it was seen that the trend of the income curve had a more pronounced decline due to the application of a water block instrument. In fact, between the first and second block, profits were reduced by 40%, i.e., $73,000 per year. In the fourth and final block, the benefit was reduced to $43,000 per year, which represents a reduction of more than 60%.

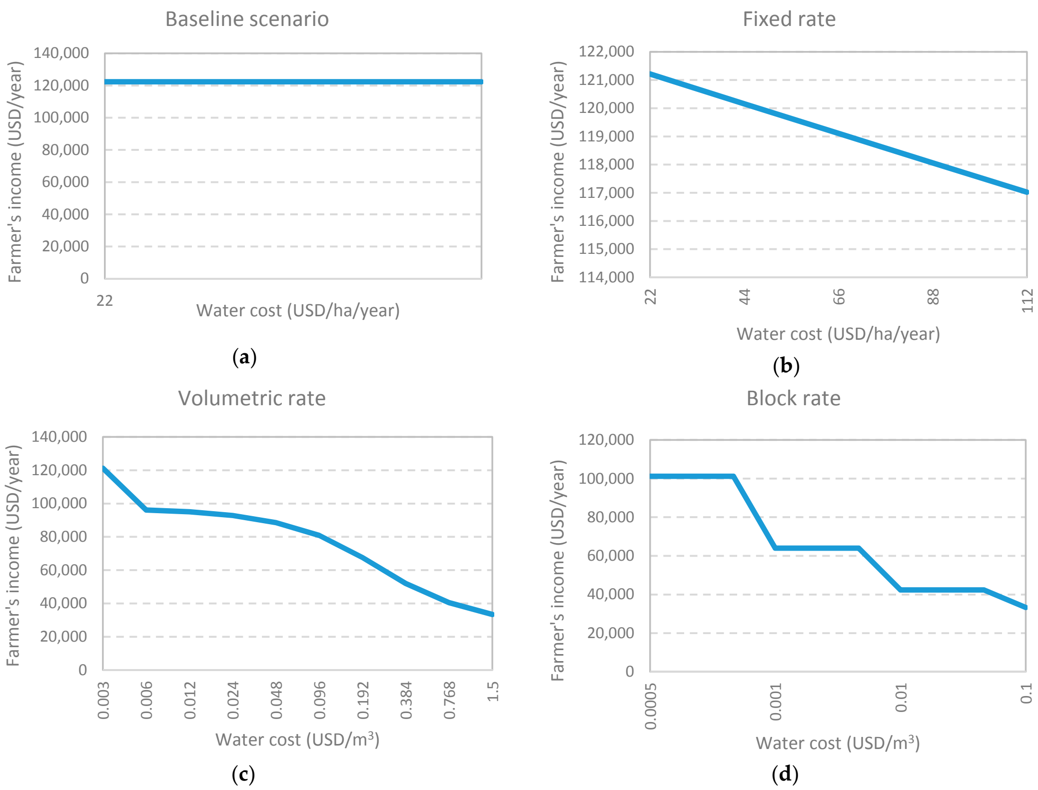

Figure 5. Evolution of the farmers' income curve trend through the simulation of three pricing policies compared to the baseline scenario: (**a**) income curve in the base scenario with the current rate ($22 USD/ha); (**b**) income trend by an increase in the fixed rate; (**c**) trend of farmers' income by a volumetric rate; and (**d**) reduction of revenues through the application of a block rate.

Figure 5 illustrates that the fixed cost proposal showed a variation of less than 5% with regards to baseline revenues; in other words, there was a reduction of $6100 per year compared to a fixed cost value of t = $132/year per hectare. Finally, volumetric costs led to a reduction of approximately 20% between t = 0.003 and t = 0.006, and the decline in revenues remained at 30% between t = 0.048 and t = 0.096, which meant a decrease of up to $80,000 per year. Comparatively, the volumetric policy had a relatively smaller impact than that generated by the application of water blocks, with a difference of about 10%.

As the cost of using irrigation water increases, variable production costs increase as well. The cost/revenue ratio for each scenario determines the effect on farmers' net income. According to the data in Table 3, fixed rates have a higher cost/revenue ratio than other simulated policies, resulting in lower income reduction. Therefore, it can be observed that the application of a block tariff represents a greater effect on the incomes of farmers. Moreover, a volumetric rate, depending on the value of the water allocated, can influence the reduction of water consumption and thus reduce the negative effects on farmers' incomes. In summary, the application of pricing policies determines a difference between the initial incomes, whereas the farmers' income represents the partial value of recovery of the irrigation system's O&M costs. In other words, the State institutions and the ISUB, in this case, would obtain economic resources directly from the farmers.

Table 3. Cost/revenue rate for each price policy application scenario.

	Fixed Increase	**Block Rate**	**Volumetric Rate**
Standard deviation	0.011	0.131	0.068
Average	1.447	1.344	1.374
Median	1.447	1.296	1.383

4.3. Implementation of a Fixed Cost Policy

Figure 6 shows the tendency of a water demand curve versus a fixed cost policy. In the base model, the price of irrigation water is t = 22 USD/ha per year. The project proposed in this scenario indicates the increase of t where $t < t_n$, which multiplies the area under irrigation ($S_{c,i} * t_n$).

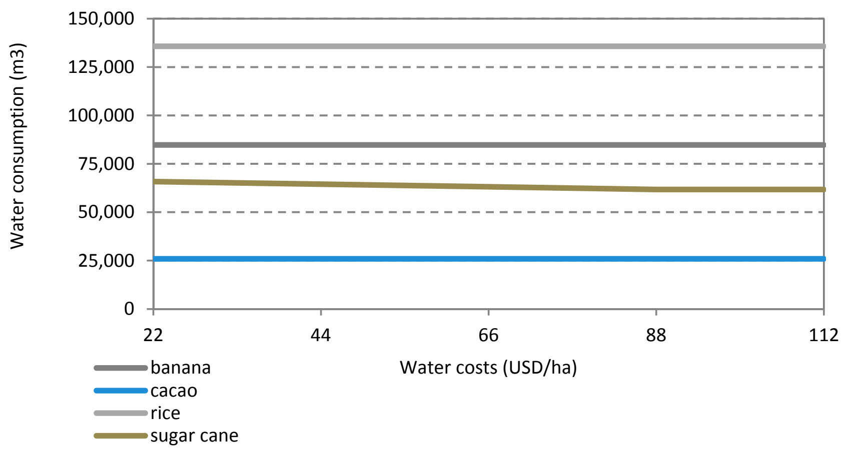

Figure 6. Project of fixed costs for the usage of irrigation water in MJCS. Water-Usage tendency curve for rice, banana, cacao, and sugar cane crops.

Figure 6 shows that the application of a fixed cost policy does not significantly influence the reduction of water demand. In this sense, the demand is inelastic because the applied cost does not affect the farmers' work behavior. Thus, it was observed that the water consumption of crops such as sugar cane fluctuated only in 8% of the total; that is, approximately 5200 m^3 per year. Furthermore, it should be noted that an unspecified simulation was established in the graph to observe the value that influences the change in water consumption. This means that when a rate of $1000/ha per year was reached, there was a change in water consumption. Therefore, the values proposed in the survey and in the fixed cost proposal did not have the necessary impact, as the value of the water was too low to cause a change in consumption.

4.4. Implementation of the Volumetric Price Policy

The AFSAM volumetric policy model for the project resolved the gradual increase of the values of t. In this sense, the simulation of water costs took the current value established by the Water Law (t) to maintain a proportional increase of $0.003/m^3 to $1/m^3. In this way, the cost of irrigation water (USD/m^3) for each monoculture can be observed on X-axis. The crop with the highest water consumption was banana, followed by rice.

The results of the simulation indicated in Figure 7 demonstrate that the water demand at MJCS is flexible for crops after a price of t = 0.48 USD/m^3. In fact, banana production maintained its normal water consumption of 61,000 m^3, up to t = 0.048 USD/m^3. However, when the value of t exceeded this value, it was observed that consumption decreased by 10%. Because of an increase in water cost, t = 0.096 USD/m^3, the reduction is 60%, and, when t = 0.192 USD/m^3 occurred, water consumption for banana crops decreased by 38,000 m^3.

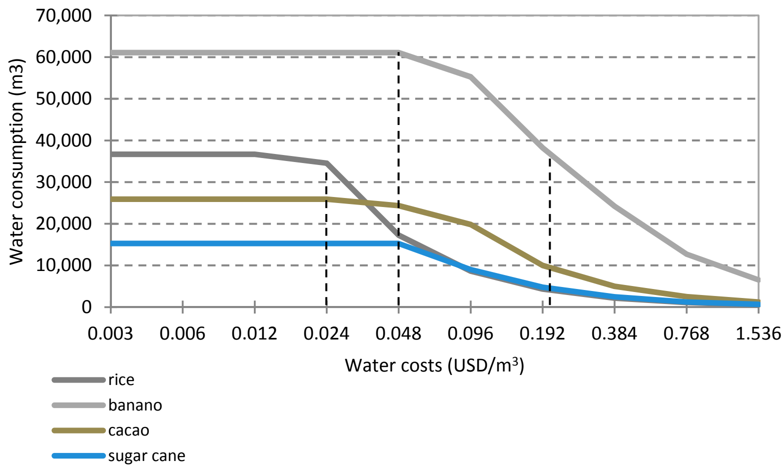

Figure 7. Volumetric prices for water consumption in MJCS. Water demand curve tendencies for rice, banana, cacao, and sugar cane crops.

Moreover, the scenario shows that water consumption for rice crops remained without any significant change until the price of irrigation water reached t = 0.024 USD/m^3, maintaining a volume of 34,000 m^3. However, when values greater than t = 0.024 occurred, water consumption was reduced by 50%. In the case of cacao and sugar cane production, the curve tendency demonstrated that, when values of t = 0.048 USD/m^3 occurred, the slope decreased from 24,000 m^3 to 19,000 m^3.

Overall, 50% of the irrigation water consumption used by crops decreased when the cost of irrigation water was t = 0.20 USD/m^3. When t takes values greater than $0.20, this becomes more notable, as can be seen in the downward curve of each crop.

Figures 8 and 9 show the effects of the results on the cultivated surface. The curve tendency, which represents the surfaces with irrigation and without irrigation, maintain an inverse relation as the value of the irrigation water increases. In Figure 8, the curve that represents the banana crop is above the rest of the crops. Thus, the tendency of the cultivated area of banana under sprinkler irrigation was greater than the surface under surface irrigation. This comparison occurred in all curves representing the cultivated area. This fluctuation occurred when the model showed a differentiated rate by irrigation technique.

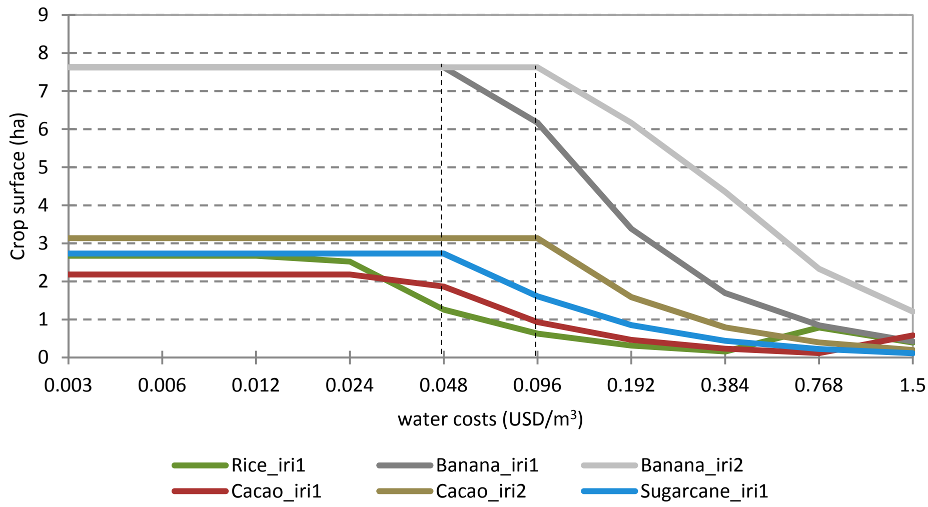

Figure 8. Variation of cultivation area with irrigation water.

The results show that the cultivated area decreased for almost all crops when t = 0.024 USD/m^3 and 0.096 USD/m^3, i.e., the area under irrigation was reduced by 50%. In the case of smaller farms such as cacao crops, there is less sensitivity to this variation. According to Figure 9, the tendency of rain-fed crops maintains an increase when t reaches the same price range of irrigation water. Therefore, in this scenario, farmers assumed an increase in irrigation costs. Later, banana cultivation changed from six to more than 16 hectares and rice from 14 to 16 hectares under rain-fed irrigation. As for cacao and sugar cane farms, the results show that the curve tendency did not undergo significant changes as other crops demanded more resources, limiting their development.

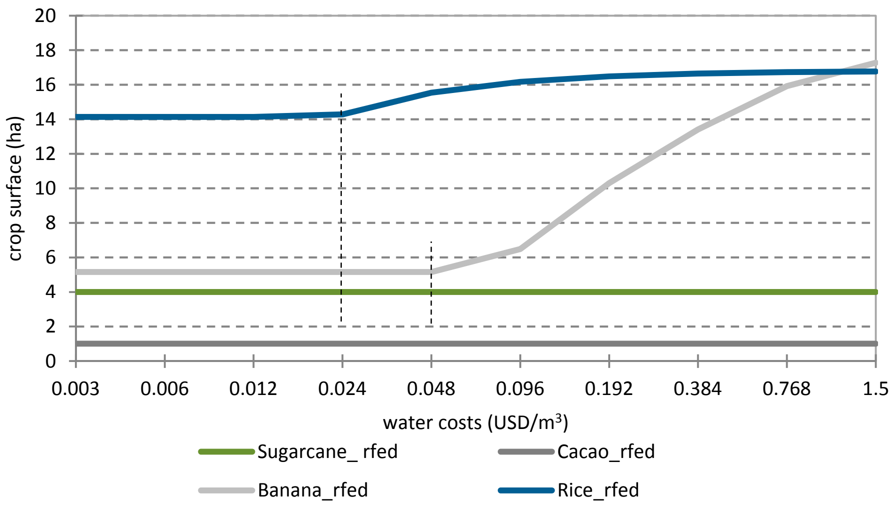

Figure 9. Variation of cultivation area devoid of irrigation water.

Based on the methodology applied by Amir and Fisher [74], an elastic behavior (−0.1 to −1) for prices above 0.048 USD/m^3 can be observed. However, in the case of rice, a totally inelastic attitude (−1) is observed at 0.024 USD/m^3 (Table 4). The same can be stated with regards to sugar cane and cacao cultivation when the water value is 0.192 USD/m^3, as the curve takes a totally inelastic trend (−1). Exceptionally, banana cultivation has a lower inelasticity (−0.2 to −0.9) compared to the other crops analyzed in the same water price. In this way, there exists sensitivity to the increase in the price of irrigation water in all crops of the Manuel de Jesus Calle system, especially when water takes a value of 0.048 USD/m^3.

Table 4. Determination of the elasticity of water demand when applying a volumetric rate

Price (USD/m^3)	Volumetric Pricing			
	Rice	Banana	Cacao	Sugar Cane
0.003	0.0	0.0	0.0	0.0
0.012	−0.1	0.0	0.0	0.0
0.024	−1.0	0.0	−0.1	0.0
0.048	−1.0	−0.2	−0.3	−0.8
0.096	−1.0	−0.5	−1.0	−0.9
0.192	−1.0	−0.7	−1.0	−1.0
0.384	−1.0	−0.9	−1.0	−1.0
0.768	−1.0	−1.0	−1.0	−1.0

4.5. Increasing Block Rate

The formulation of a cost scenario by water blocks through the application of the AFSAM allowed differentiating the consumption of water according to the capacity of each type of farm. However, it was not possible to control the availability of well water because the volume of consumption is unknown since this is an uncommon practice.

Figure 10 shows the results of the block water consumption formulated by AFSAM. It can also be seen that the trend of water consumption has pronounced variations in each consumption block. In fact, each stage of the cost of irrigation shows that there are significant water savings. In the case of banana, the volume of water consumed was reduced from 84,000 m^3 to 58,000 m^3 during the first consumption block; in other words, there was a reduction of approximately 30%. Meanwhile, for the second block, the reduction was almost 70%. In the case of rice, the reduction reached approximately 70% in the first stage (from 70,000 m^3 to 20,000 m^3). In the case of sugar cane and cacao, the volume of consumption fell from 23,000 m^3 to 9500 m^3 (60% less); and from 25,000 m^3 to 16,000 m^3 (30% less), respectively. In this way, the slope tendency of each crop behaved similarly. The decrease in the demand for water between the second and third blocks reached an additional 30% to that in the first block, i.e., there was a direct relationship between the cost of water and the reduction in demand.

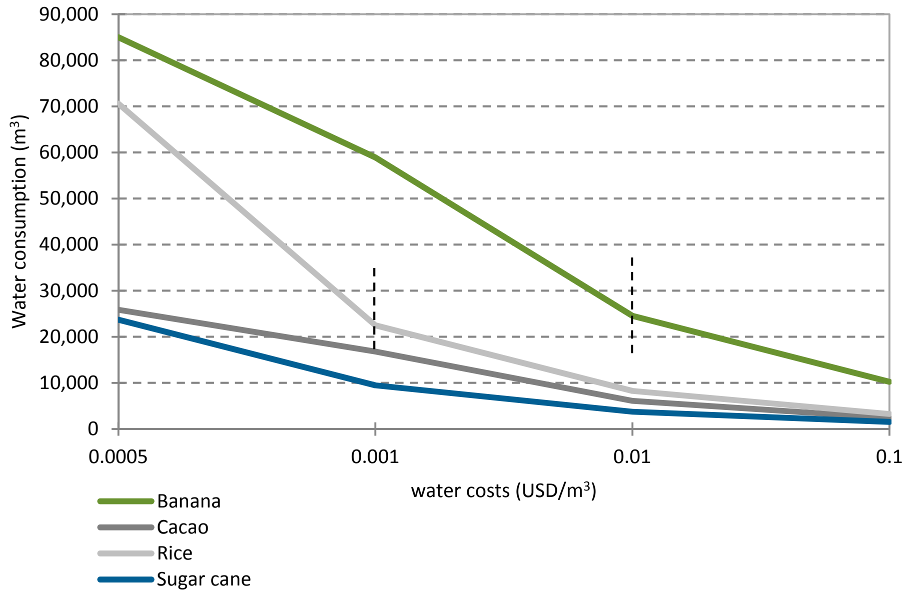

Figure 10. Scheme of costs by water blocks. Rice, banana, cacao, and sugar cane water consumption tendencies.

5. Discussion and Conclusions

This paper analyzes the effects of water pricing policies in a group of monocultures of the agro-food sector in Ecuador. Its objective was to evaluate the impact of price instruments on the income of farmers and the reduction of water consumption. Principally, the focus was directed to volumetric pricing as the most appropriate instrument to influence farmers' behavior. In this sense, very few studies have previously been performed to analyze the pricing policy in Ecuador. Therefore, this document is proposed as an initial tool to evaluate the regulation of water resources in a resource-rich environment, and a regulatory framework in the reform process. One limitation presented in the preparation of this study related to the gathering of data from MJCS, due to the mistrust of farmers when delivering the information for the research. In addition, for this paper, flooding type irrigation was considered, as it is the most widely used system of irrigation.

This research also considers the possibility of prohibiting the establishment of water markets by the current Water Law, since it is seen as a form of privatization of water resources. This fact undoubtedly limits the partaking of the private sector in the management of irrigation water. As a result, public institutions have focused their attention on improving both farmers' skills and irrigation infrastructure as a way of strengthening water resource regulation and, therefore, reducing poor water-use practices.

The baseline scenario proves that it maintains certain production characteristics such as the predominance of monocultures and a low specialization of the irrigation technique, together with low irrigation costs. In fact, the conditions mentioned in this article represent the main challenge for applying a pricing policy at MJCS. The presence of traditional crops, such as banana and sugar cane, as well as the implementation of policies to encourage agriculture, present a limitation for applying changes to go from current irrigation systems to more efficient ones.

The refinement method used in this research has been widely used in the evaluation of water pricing policies. As would be expected, the current water price of $22/hectare per year only allows for a partial recovery of some of the O&M costs, without presenting a reduction in water demand. Therefore, it can be established that the current cost does not consider the difference between crop yields or agricultural incomes. Therefore, the current cost does not reflect the price of real water, nor does it establish differentiation for industrial or food production purposes. In fact, the current water cost does not allow for a change to the use of irrigation techniques, considering that 95% of the land is under surface irrigation. On the other hand, the results obtained by simulation showed that, when the model has a cost of $1,000 per hectare, the production plan changes due to the high simulated cost. On the other hand, there is no control over the groundwater consumption of wells, which means that it is not possible to limit the use of water that each farm consumes in total.

In effect, the results of the survey indicate that the view of farmers about a hypothetical increase in the price of irrigation water was negative, and could translate into a reduction of cultivated area. This means that the farmers' decision was guided more toward either abandoning agriculture altogether or making a change to more rainfed-friendly crops. This has a direct effect on employment reduction and on income. This perspective suggests the need to improve the irrigation network to increase water availability, together with strengthening the trust in the ability of the ISUB to resolve conflicts, which, according to the results obtained, was viewed as a significant factor to improve water availability, together with the collection and application of increased irrigation tariffs.

On the other hand, the results of the volumetric policy simulation shown in Figure 5 demonstrated a direct relationship between the gradual reduction of water demand and the income of farmers. In this respect, the response to the increase was to substitute irrigation water with rain-fed crops. In specific cases, sugar cane and rice fields showed a degree of change due to pricing policies. However, the results indicate that volumetric expenditures are the most efficient method for they have the capacity to reduce water consumption with a lower impact on the proceeds of farmers.

The tendency of the current water-demand curve showed a slow response from farmers to low pricing rates. In fact, farmers' responses were only evident at rates above \$0.20USD/m^3, when a volumetric tariff was applied. This price represents the point of reference between a partial and a drastic reduction of water demand. In addition, an approximate 50% loss of income for farmers can be observed. It was also noted that rice and sugar cane farms are more sensitive to the application of volumetric prices, as profits from these are lower than those generated by banana or cacao farms.

In areas such as La Troncal, agriculture is the main source of income for most families. A reduction in cultivated areas due to pricing policies could signify a complete change from an agricultural labor force to wage labor. Moreover, it must be considered that a reduction of the cultivated area will affect the supply of raw material destined to the agro-industries located in the area, many of which depend on local production. This scenario implies that the consequences of applying a water pricing policy in Ecuador should be analyzed. However, this study has the advantage of evaluating a current problem and discussing some criteria on policy instruments in an area as sensitive as the Ecuadorian agriculture. However, volumetric consumption measurement is required, and the additional costs required for the implementation of measurement equipment may incur transaction costs additional to those assessed in this research.

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Abbreviation

AFSAM	Agro-Food System Analysis Model
Eto	Food and Agriculture Organization
FAO	Food and Agriculture Organization
GAMS	General Algebraic Modeling System
ISUB	Irrigation System Users Board
IWRM	Integrated Water Resources Management
MJCS	Manuel de Jesus Calle Irrigation System
NIAR	National Institute of Agricultural Research
NIMH	National Institute of Meteorology and Hydrology
O&M	Operation and maintenance
PMP	Positive Mathematical Programming
PWC	Water Public Enterprise
SENESCYT (acronym in its Spanish)	Secretariat of Higher Education, Science, Technology and Innovation of Ecuador
WRCA	Water Regulation and Control Agency

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